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Development and Testing of a Low-Cost, Locally-Engineered Two-Post Car Lift for Automotive Workshops in Resource-Limited Settings

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Abstract

This study presents the design, construction, and performance evaluation of a cost-effective, locally fabricated two-post car lift intended for use in small and medium-sized automotive workshops, particularly in developing regions. The system was conceptualized using a hybrid hydraulic and pulley-assisted mechanism, with structural components fabricated from locally available steel profiles. Design parameters were established through mechanical analysis and validated using finite element approximations, while performance metrics were assessed through experimental testing across three vehicle classes: compact (1,200 kg), sedan (1,600 kg), and SUV (2,200 kg). Results revealed a direct correlation between vehicle mass and lift time, with durations increasing from 18.2 s to 23.5 s as load increased. Correspondingly, vertical lift speed decreased from 11.0 mm/s to 8.6 mm/s. Structural deflection remained within elastic limits, ranging from 2.5 mm to 5.1 mm, with minimal standard deviation across trials (±0.3 mm to ±0.6 mm), confirming fabrication consistency. Lateral asymmetry remained below 2.0 mm for all test scenarios, satisfying ANSI/ALI ALCTV:2017 standards for safety and performance. The passive mechanical locking system engaged reliably under all conditions, and no mechanical failures were observed during testing. The prototype was constructed at a cost below USD 700, representing a 65–80% reduction relative to commercial imports, demonstrating the economic viability of locally engineered lifting solutions. While the thermal behavior of the motor was not directly monitored, future enhancements, including integrated thermal diagnostics, automated control systems, and structural optimization, are recommended. Overall, the project illustrates a scalable, low-cost engineering solution capable of supporting vehicle maintenance infrastructure in resource-limited settings without compromising safety or functionality.

Keywords: Two-post car lift; Local fabrication; Automotive lifting system; Performance evaluation.

1. Introduction

Vehicle lifting systems are essential components of modern automotive service facilities, enabling efficient and safe underbody access for maintenance and repairs. Historically, mechanics relied on rudimentary lifting methods, such as ramps, jacks, or ground pits, which were not only labor-intensive but also posed significant safety and ergonomic risks [1], [2]. Though pit-based solutions improved access to some extent, they require permanent space allocation, limit mobility, and offer restricted access to vehicle components from different angles [3]. In contrast, two-post car lifts have emerged as compact, flexible, and highly functional alternatives, offering full undercarriage accessibility with minimal spatial footprint [7].

A two-post lift typically consists of two vertical posts firmly anchored to the ground, each equipped with symmetrical or asymmetrical lifting arms that engage with specific points on the vehicle chassis. These arms are actuated either hydraulically or mechanically and are synchronized using cable, chain, or electronic systems to ensure uniform elevation [8], [13]. The popularity of two-post lifts is driven by their compact design, cost-effectiveness, and adaptability to various vehicle types ranging from compact cars to sport utility vehicles (SUVs) [3], [10].

However, in many developing countries, particularly in Sub-Saharan Africa, the adoption of such technologies remains limited due to high costs associated with importing standardized car lifts and challenges in servicing imported systems. This economic barrier underscores the need for locally-fabricated solutions that meet international safety and performance standards while remaining affordable and maintainable using indigenous resources [9], [11].

The advancement of locally-engineered lifting systems requires a multidisciplinary approach encompassing mechanical design, materials selection, power transmission, safety assurance, and control systems. Modern lifts are expected not only to elevate heavy vehicles but also to operate reliably, exhibit minimal structural deflection, and include redundant safety mechanisms to prevent catastrophic failure during operation [10], [13]. In this regard, adherence to design standards such as the ANSI/ALI ALCTV:2017 [10] is critical to ensure that such systems are not only functionally adequate but also meet recognized safety benchmarks.

Recent studies have employed finite element analysis (FEA) and smart control mechanisms to enhance the structural performance and automation of lifting equipment [9], [13], [15]. Furthermore, the integration of sensors and monitoring tools, such as strain gauges and displacement sensors, has enabled more accurate performance evaluation under varying loads [16], [17].

This study presents the design, construction, and experimental evaluation of a low-cost, locally-fabricated two-post car lift aimed at meeting the operational needs of small and medium-sized automotive workshops in resource-constrained environments. The work is motivated by the dual objectives of engineering sustainability and economic accessibility. By leveraging readily available materials and basic manufacturing techniques, the design seeks to bridge the gap between affordability and compliance with structural and safety standards. Performance metrics, including vertical lift speed, structural deflection, load asymmetry, and safety lock engagement, are assessed under real operating conditions using multiple vehicle types. The results not only validate the mechanical integrity of the design but also demonstrate its potential as a practical alternative to imported systems in developing economies.

2.0 Literature Review

Automotive lifting systems are critical for efficient vehicle maintenance, offering enhanced accessibility, reduced physical strain, and improved safety in workshop operations. Various types of vehicle lifts have been developed over time; each tailored to specific applications and load capacities. Common types include platform lifts, scissor lifts, four-post lifts, and two-post lifts [3]. While four-post lifts provide enhanced stability and weight distribution, two-post lifts are widely preferred for their space efficiency and full undercarriage access, particularly in small to medium-scale repair shops [7].

The operational principle behind most vehicle lifts is based on hydraulic systems, which utilize fluid pressure to generate linear motion. These systems typically comprise two chambers of different diameters; pressure is transferred from the smaller chamber to the larger one, amplifying force output [5]. Hydraulic actuation offers smoother motion, higher force density, and reduced mechanical complexity compared to traditional screw or pulley mechanisms [4], [13]. Some modern designs also integrate battery-powered pneumatic-hydraulic systems and mechanical pulley arrangements to achieve energy-efficient lifting with minimal operator input [14].

Structurally, two-post car lifts consist of vertically mounted posts with lifting arms that extend beneath the vehicle chassis. The structural integrity of the lift is heavily influenced by material selection, base anchoring design, and load distribution [8], [9], [12]. High-strength low-alloy (HSLA) steel is commonly used for its superior strength-to-weight ratio and fatigue resistance [11]. The base plates and columns are generally subjected to finite element analysis (FEA) during the design phase to ensure minimal deflection under load and compliance with international standards such as ANSI/ALI ALCTV:2017 [10].

The lifting mechanism in most modern two-post lifts employs dual hydraulic cylinders mounted inside or alongside each post. Synchronization between the two columns is typically achieved through equalization cables or chains, ensuring balanced vertical movement [13]. Although electromechanical screw drives provide greater precision in specific applications, they are less energy-efficient and are generally reserved for lighter vehicle classes [14].

Automation and control systems have increasingly become integral to advanced lifting platforms. Contemporary designs feature electric control panels, programmable logic controllers (PLCs), overload protection relays, and limit switches that automate operation and enhance safety [15]. The inclusion of smart sensors and real-time monitoring systems helps detect misalignments, load imbalances, and operational faults, thereby reducing human error and improving reliability [16], [17].

Safety features are a cornerstone of vehicle lift design, particularly when managing loads in excess of 2,000 kg. Mechanical safety locks, often fabricated from high-carbon steel, are designed to engage automatically during lifting to prevent accidental descent [18]. In addition, hydraulic check valves and pressure relief systems safeguard against fluid leaks or system failures [19]. Recent innovations include tilt sensors and embedded load-detection systems that halt operations when unsafe conditions are detected [20]. These features align with the ANSI/ALI ALCTV:2017 safety framework, which stipulates performance and design requirements for automotive lifts [10].

Maintenance considerations also play a significant role in ensuring long-term durability and reliability. Routine inspection and lubrication of mechanical joints, particularly bearings and pivot arms, are essential to prevent degradation [21]. Corrosion-resistant coatings, particularly in humid environments, extend the service life of steel components [11]. Furthermore, the incorporation of IoT-enabled diagnostics can predict component failures, thereby reducing operational downtime and improving safety margins [10].

Environmental and economic factors are also shaping the future of car lift design. Recent research promotes the use of energy-efficient electric motors and biodegradable hydraulic fluids to minimize environmental impact [11]. Modular fabrication techniques not only simplify assembly and transport but also contribute to significant material savings [9]. Cost estimates for imported two-post lifts typically range from USD 1,500 to USD 4,000, placing them out of reach for many small workshop owners in developing countries [12]. This has catalyzed growing interest in do-it-yourself (DIY) models that leverage local materials and skills for affordable and customizable solutions [19].

In summary, the literature emphasizes a shift toward smarter, safer, and more sustainable automotive lift technologies. While imported systems offer high performance, they often lack affordability and adaptability for developing economies. Locally-fabricated alternatives that align with global safety standards and incorporate performance-enhancing innovations are increasingly seen as viable solutions to bridge the accessibility gap in automotive servicing infrastructure.

3.0 Methodology

3.1 Conceptual Design, Ideation, and Invention

A two-post car lift is a widely used mechanical system that facilitates safe and efficient vehicle elevation in automotive service centres. It comprises two vertical columns anchored securely to the ground and connected via an overhead beam, ensuring structural integrity. Each column contains a lifting mechanism typically powered by hydraulic or electric systems that drives two symmetrical arms to engage designated lift points on the vehicle chassis. The synchronized operation of the arms ensures uniform load distribution and prevents imbalance. Safety mechanisms such as automatic locking devices and rubber pads are integrated to secure the vehicle and accommodate different chassis types. The system enables full undercarriage access, optimizing space and operation for a wide range of vehicles, including cars, SUVs, and light trucks.

3.2 Design Options Considered

Three design concepts were explored for the lifting mechanism:

Design 1: Hydraulic Lift Mechanism

Utilizes hydraulic actuators that require input effort only during lifting. The descent of the vehicle relies on gravitational force, reducing energy consumption. However, mechanical linking and synchronization between columns can be challenging.

Design 2: Screw Jack Mechanism

Employs mechanical jacks based on the lead screw principle. It requires continuous input effort for both lifting and lowering. Though simple, this design has high frictional losses and is less energy-efficient.

Design 3: Pulley and Hydraulic Combination System

Integrates a pulley system with hydraulic cylinders. Like Design 1, energy is only required during lifting, and gravitational force assists in lowering. It promises energy efficiency and load balance but may involve spatial complexity and installation challenges.

3.3 Selection Rationale and Decision Matrix

To select the most suitable design, a decision matrix was developed (Table 1), evaluating each design against key criteria: energy efficiency, safety, ease of operation, cost, maintainability, and spatial requirements. Each criterion was rated on a scale from 1 (poor) to 5 (excellent), and weighted based on importance [22].

Table 1: Decision Matrix for Design Selection

Criteria	Weight	Design 1	Score	Design 2	Score	Design 3	Score
Energy Efficiency	0.25	4	1.00	2	0.50	4	1.00
Safety	0.20	4	0.80	3	0.60	4	0.80
Ease of Operation	0.15	3	0.45	2	0.30	3	0.45
Cost	0.15	3	0.45	4	0.60	3	0.45

Maintainability	0.15	3	0.45	4	0.60	3	0.45
Spatial Requirement	0.10	3	0.30	4	0.40	2	0.20
Total Weighted Score			**3.45**		**3.00**		**3.35**

Based on the total weighted scores, Design 1 had the highest score (3.45), followed by Design 3 (3.35) and Design 2 (3.00). However, after further analysis of operational feasibility and design integration constraints, Design 3 was ultimately selected due to its optimal balance between energy efficiency and functional flexibility [22].

3.4 Kinematic Evaluation Using Grübler's Equation

To assess the mobility (degree of freedom, DOF) of the proposed lifting system in Design 3, we employed Grübler's Equation for planar mechanisms:

$DOF=3(n-1)-2j_1-j_2 DOF = 3(n - 1) - 2j_1 - j_2$

Where:

n = number of links (including the frame), j_1 = number of lower pairs (1 DOF joints, e.g., revolute or prismatic), and j_2= number of higher pairs (2 DOF joints, e.g., cam or gear contacts).

Application to Design 3

In the proposed design:

- i n = 6n = 6: includes the base frame, two lifting arms, hydraulic actuator, pulley mechanism, and vehicle platform.
- ii j1 = 7j_1 = 7: revolute joints connecting arms to columns and actuator to arms.
- iii j_2 =0j_2 = 0: no higher pairs involved.

Applying the formula:

$DOF=3(6-1)-2(7)-0=15-14=1DOF = 3(6 - 1) - 2(7) - 0 = 15 - 14 = 1$

Thus, the system has 1 degree of freedom, confirming that a single actuator input (hydraulic lift) is sufficient to control the motion of the entire lifting assembly. This ensures synchronized and predictable lifting behavior.

3.5 Analysis

The design is possible looking at the fact that other lifting machines are already in existence.

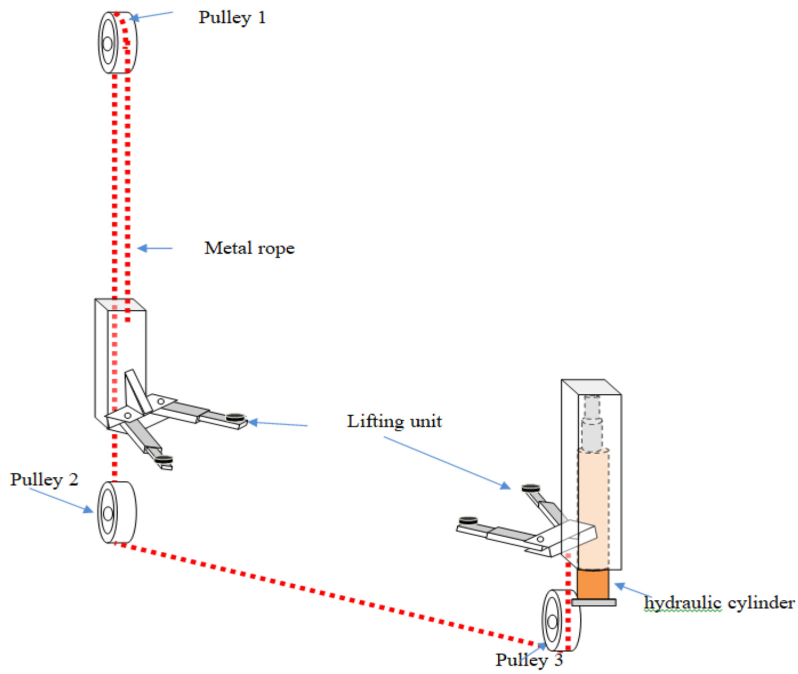


Figure 1: the working system

To calculate the degree of freedom, the number of units contained in the system is shown in Table 2. Each lifting unit has four deep grooved rolling bearings on the frame.

Table 2: Number of units and joints contains in the system

Number of units to the lifting unit	= 2	Number of joints on the lifting unit	= 2
Number of units on the metal rope	= 1	Number of joints on the metal rope	= 2
Number of units on the pulley	= 3+3 = 6	Number of joints on pulley 2 x 3	= 6
Number of units on sliding hydraulic shaft	= 2	Number of joints on hydraulic shaft	= 2
Number of units on frame	=1	Number of joints on the frame	= 1
Total	12	Total	=13units

Using the Grübler's equation

$$F = 3(n-1)2j,$$

Where n = number of units, j = number of joints

Hence,

$$F = 3(12-1) - 2(13) = 7,$$

Therefore, the kinematic chain is movable since $F \geq 1$

3.6 Detailed Design

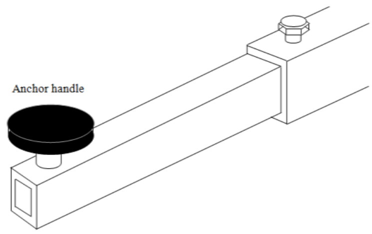
The hydraulic car lift design includes the following: Design for Frame, Lifting unit, Hydraulic system, Metal rope, and pulleys.

3.6.1 Design of frame

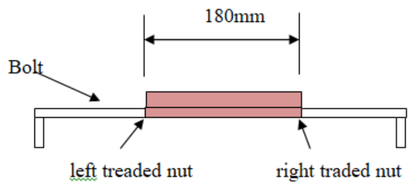
The material used for the design of the frame, as shown in Figure 2c, is plain carbon steel AISI standard 1020 channel iron of (C180x0.215); flat steel bar (thickness = 12.7), tensile strength: 450MPa. The parts are joined together using electric arc welding as shown [23]. Table 3 presents the pipe used.

Table 3: Pipe specifications in SI units

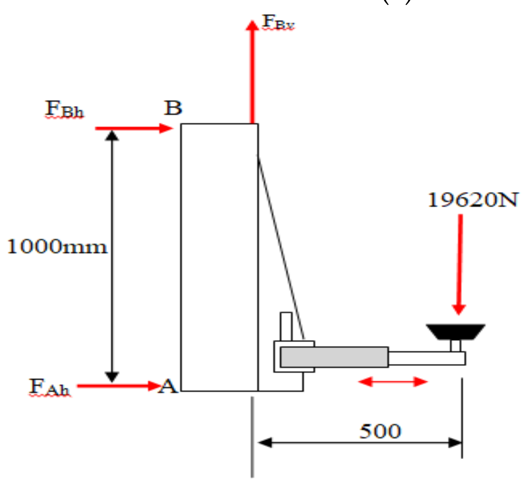
Pipe	Cross-Sectional Area (m^2)	Wall Thickness (m)	Weight Distribution (kg/m)
A	0.001935	0.00953	18.09
B	0.001290	0.00795	12.54



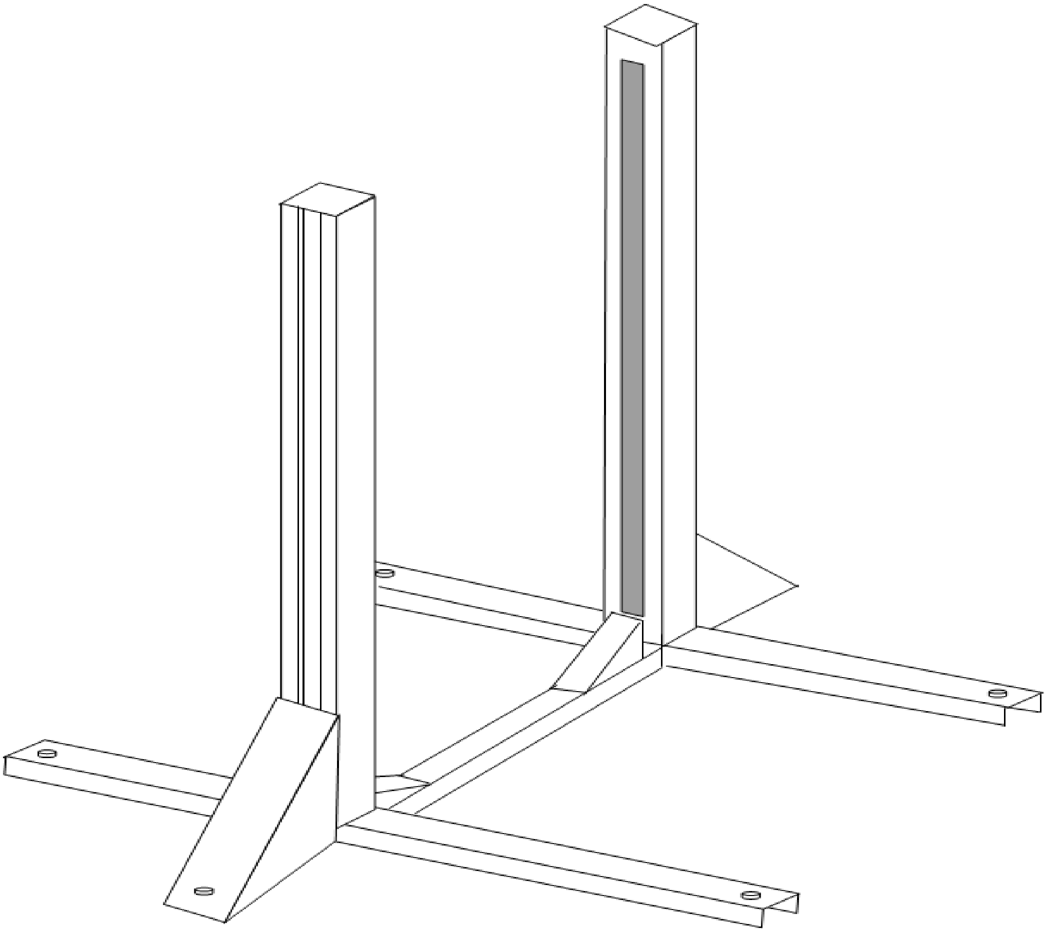
(a)



(b)



(c)



(d)

Figure 2: (a) anchor (b) angle adjuster (c) lifting arm (d) frame

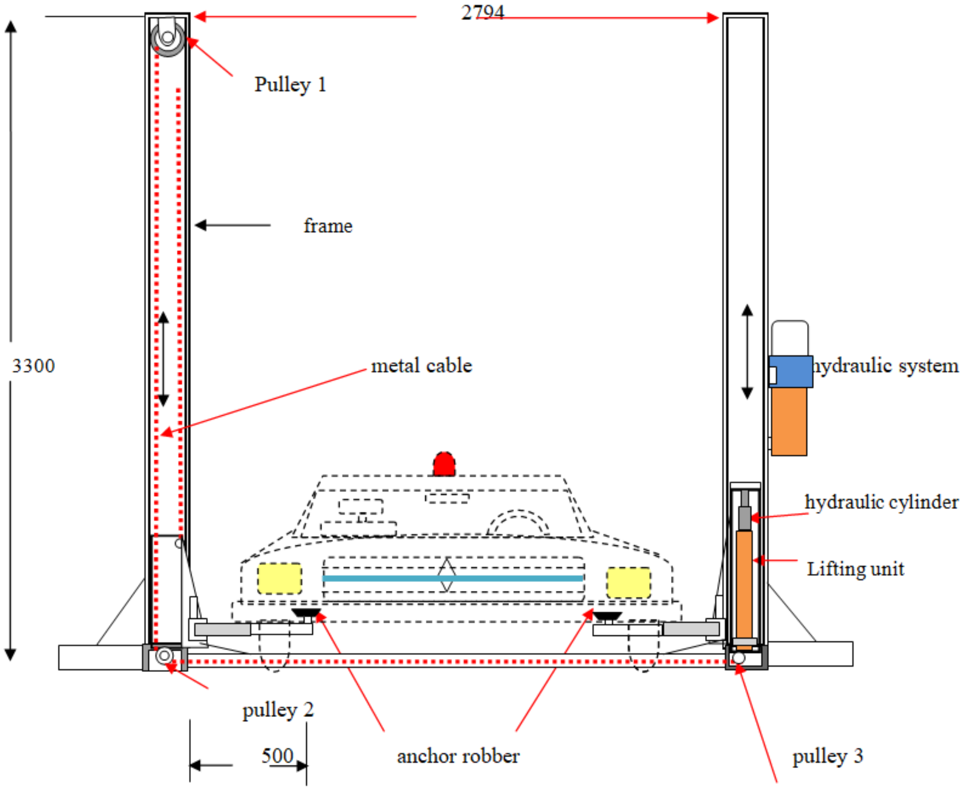


Figure 3: Front view of two post-car lift

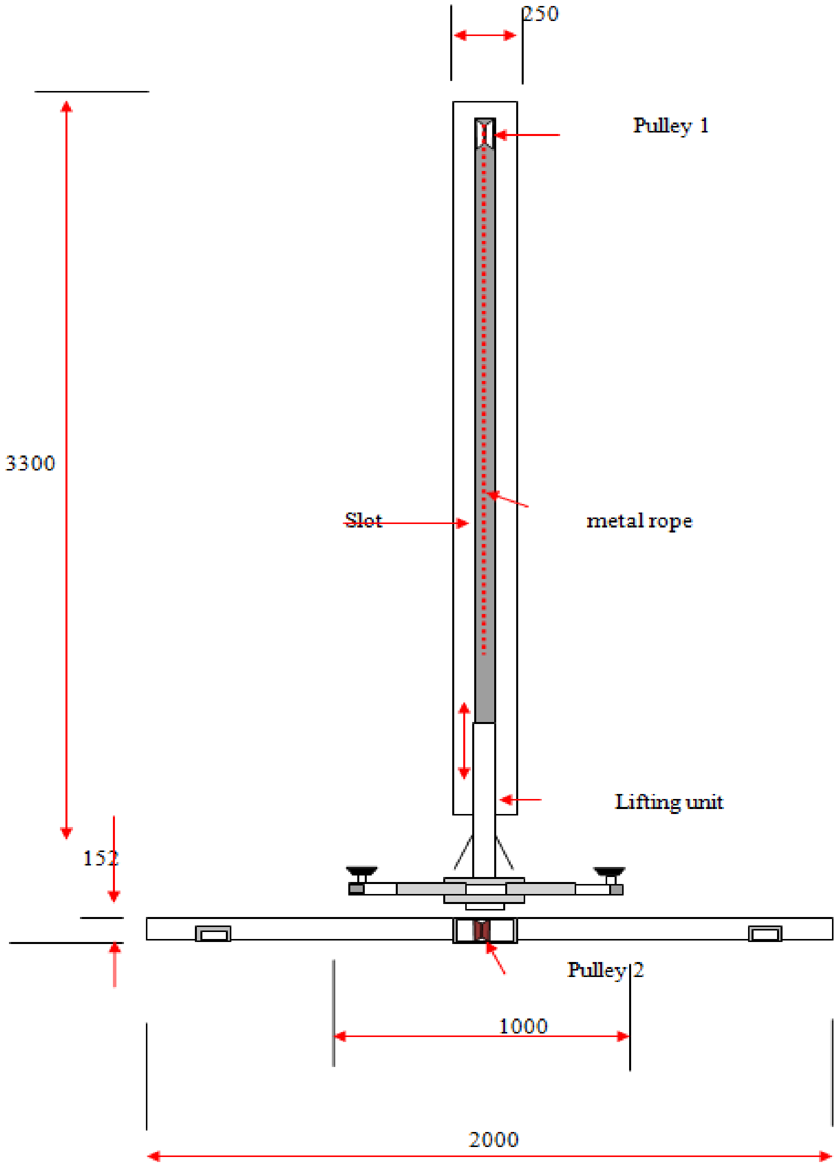


Figure 4: Side view of the left post

3.6.2 Design for lifting arm and angle adjuster

From Figure 2, the lifting arm and angle adjuster are shown in Figures 2a and 2b. From the law of equilibrium for moment (*M*),

$$\sum M_n = 0, \quad (1)$$
$$19620N(500 \times 10^{-3}) - F_{Ah}(1000 \times 10^{-3}) = 0,$$
$$F_A = +9810\ N,$$

Also,

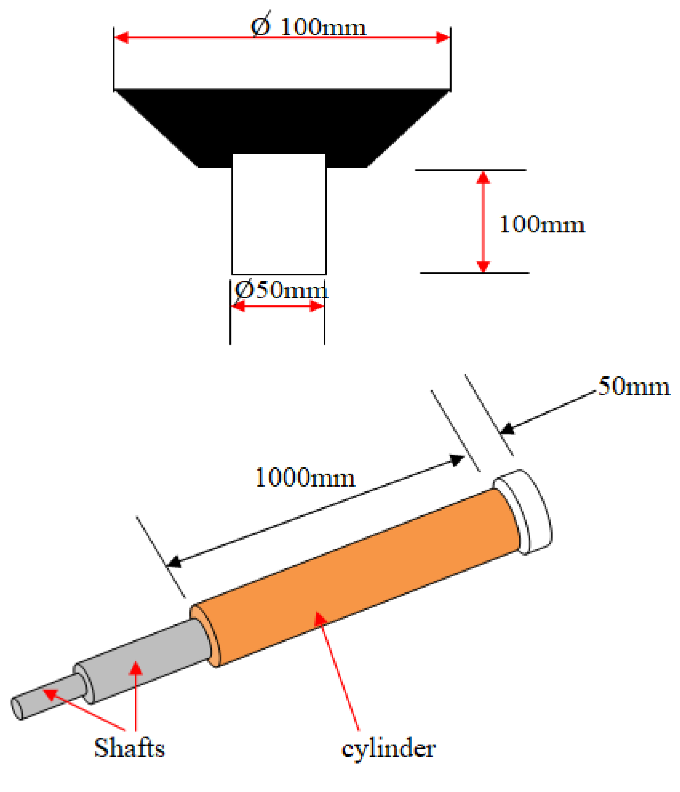
$$\sum M_h = 0, \quad (2)$$

$$9810 + F_{Bh} = 0,$$
$$F_{Bh} = -981\ N,$$
$$\sum M_y = 0, \quad (3)$$

$$F_{By} = -19620 = 0,$$
$$F_{By} = 19620\ N,$$

3.6.3 Anchor robber

Anchor robber as shown in Figure 5a is selected from the market with the following dimension. The shaft is made up of steel iron.



(a) (b)

Figure 5: (a) anchor rubber (b) Two-stage hydraulic cylinder

3.6.4 Design for hydraulic cylinder

Figure 5b presents the multi-stage hydraulic system, and AISI40 cast iron of tensile strength 410 Mpa is used. To determine the diameter of the cast iron cylinder and its thickness to produce the operating force F = 40,000 N.

Assuming that an allowable 10% of the force F for friction in the cylinder and packing, Pressure of pump (*p*)= 5 N/mm², a pressure drop of 0.2 Mpa between the tank and cylinder, safety stress for cast iron = 30 Mpa, time (*t*) required for the working stroke is

40s, the efficiency η for hydraulic = 80 % and for pump = 60 %, working cycle repeats after 30s, diameter (d) of tank = 200 mm, efficiency = 100 %, allowable tensile stress (St) = 50 Mpa.

i The Thickness (T) of the pressure tank [24]

$$T = \frac{P.d}{2\sigma_{t1}.\eta} = \frac{5\times200}{2\times50\times1} = 10\ mm = 0.001m, \quad (4)$$

ii The diameter (D)and thickness of the cylinder [24]

The total force provided including fiction F_1 = 1.1 x 4000 = 44000 N

Therefore the pressure P_1 = 5- 0.2 = 4.8 N/mm^2 = 4.8 x 10^{-6} Mpa.

$$F_1 = \frac{Л}{4} \times D^2 \times P_1, \quad (5)$$

$$D = \sqrt{\frac{4F_1}{ЛP_1}} = \sqrt{\frac{4\times44000}{Л48}} = 4.8mm = 0.0048m, \quad (6)$$

$$T = \frac{P_1\times D}{2\sigma_{t1}} = \frac{108\times4.8}{2\times30} = 8.64\ mm = 0.00864\ m \quad (7)$$

iii Out power (P) of the cylinder [9]

Distance move per second = 2/40 = 0.05 m/s

Work done (W) per second = F x distance moved per second (8)

W = 44000 x 0.05 = 2200 Nm

Hence, the power output of the cylinder = 2200 W = 2.2 KW

iv Power of the motor (m) (P_m) [24]

$$\frac{power\ of\ cylinder\ (P_c)\times40}{\eta_p\eta_m\times30} = \frac{2.2\times40}{0.8\times0.6\times30} = 6.1\text{KW} \quad (9)$$

where η_p is the efficiency of the pump, η_m is the efficiency of the motor.

Hence let's select an electric motor of 6.5 KW [25].

3.6.5 Design of Metal Rope [9] [24]

The material used is AISI 160 steel, tensile strength of 1600 Mpa

i The load (weigh of car) = 4000 kg x9.81 = 39240N, height = 1.8m, t= 40 s

ii speed v = 1.8/40 = 0.045, acceleration = v/t = 0.045/40 =1.3x10^{-3} m/s^2

iii From table 20.6 wire rope 6x19 is chosen.

iv From Table 20.11 the factor of safety 2x 3.5 = 7 is taken, Therefore, the Design load for the wire is rope = 7 x 39240N = 274680 N

v From Table 20.6, the tensile strength of 6x19 rope made of wire with a tensile strength of 1800MPa is 595d^2 (N)

Hence 595d^2= 274680 N

$$d = \sqrt{\frac{247680}{595}} = 21.5\ mm = 0.00215\ m. \quad (10)$$

vi From table 2010 for 6x 19 rope, diameter of wire d_w= 0.063d = 0.063x 21.5 =0.0014m

Hence area of wire A = 0.38d^2= 0.38(21.5)^2 = 175.7 mm^2 = 0.0000001757 m^3

vii From table 20.6, the weight of the rope,

w = 0.0363d^2 = 0.0363(21.5)^2 = 16.8 N/m

Hence the total weight = 16.8 x 16.3 = 273.8 N (*assuming the total length= 16. 3m)*

viii From Table 2012, the diameter of sheave (D) may be taken as 60-100 times the diameter of the rope (d). i.e. D = 20(d) = 20x21.5 = 430 mm =0.0043 m

Therefore the bending stress = $\sigma_b = \frac{E_r \times d_w}{D} = \frac{84\times10^3\times1.4}{430}$ =273.5 N/m (taking E_r =85x10³)

ix The equivalent bending load on the rope, $w_b = \sigma_b$ x Area = 273.5x175.7 = 48051.9 N

x Additional load due to acceleration w_a,

$$w_a = \frac{W+w}{g} \times a = \frac{39240+16.8}{9.81} \times 1.3 \times 10^{-3} = 5.2\ N.$$

(11)

xi The impact load during starring (when there is no slackness in the rope), W_{st} = 2(W + w) = 2(39240 + 16.8) = 78513.6 N

xii The effective load on the rope during normal working (*i.e.* during uniform lifting or lowering) = W + w + w_b = 39240 + 16.8+ 48051.9 = 87308.7 N

Therefore the actual factor of safety during normal working

$F.S_{actual}$ = 274680 /87308 = 3.1

13- Effective load on the rope during staring = W_{st} +W_b= 78513.6 + 48051.9 = 126565.5 N

Actual factor of safety during starting = 274680/126565.5 = 2.2

xiii Effective load on the rope during acceleration of the load (*i.e. during the first 10 seconds after starting)* = W + w + W_b + W_a

= 39240 + 16.8 +48051.9 + 5.2 = 87313.9 N

xiv The actual factor of safety during acceleration of the load = 274680/877313.9 = 0.3 Since the actual factor of safety as calculated above is safe, a wire of diameter 0.0031 m, and 6x19 is satisfactory [25].

3.6.6 **Design of pulley**]15]

The material used is cast iron AISI 5, tensile strength 620MPa. The pulley diameter is taken = 100mm and mounted on fixed axles on an antifriction bearing. The pulley diameter is 100 m. Hence, the standard rim of a rope sheave is calculated as follows: r = 0.53d = 0.53x21.5 = 0.00114 m, r_1 = 1.1d = 1.1x 21.5 = 0.00237 m, a = 2.7d = 2.7 x 21.5 = 0.005805 m, b = 2.1d = 2.1x 21.5 = 0.004515 m, c = 0.4d = 0.4 x 21.5 = 0.0086 m, l = 0.75d = 0.75 x 21.5 = 0.0016125 m [25].

3.6.7 Final Analysis

Table 4 shows the hydraulic car lift design specification.

Table 4: Technical data for two post car lift

Loads lifting capacity	4000 kg
Hydraulic cylinder	x1
Power	6.1 KW
Lifting time	40 s

Lifting height	1.8 m
Electric motor	x 1
Hydraulic pump	x 1
Post Height	0.003300 m
Clearance between posts:	2.794 m
Lowering Time	30 s
Voltage	110 V/220 V/380 V/415 V, 1ph/3 ph

3.6.8 Construction

The two-post car lift was constructed with a focus on stability, strength, and ease of operation. Its design incorporated two vertical posts, typically made of reinforced steel, which were securely mounted on a heavy-duty base. These posts served as the primary support structure for the lift.

Each post was equipped with an adjustable lifting arm assembly, allowing the arms to extend and retract to accommodate different vehicle sizes. The lifting arms were hinged at the base of the posts and reinforced to handle significant loads, ensuring durability and safety during operation. Rubber-padded contact points were added to the arms to prevent damage to vehicles during lifting.

The posts were interconnected by a horizontal overhead beam or a floor-mounted baseplate, depending on the lift design. In the overhead beam design, a sturdy crossbar spanned the top of the posts, providing structural rigidity and housing the hydraulic lines or cable system. Alternatively, in the baseplate design, the connection at the base ensured alignment and stability without an overhead obstruction.

A hydraulic system was integrated into the lift mechanism. Hydraulic cylinders, mounted inside or near the posts, provided the lifting force. These cylinders were connected to a power unit, typically an electric motor driving a hydraulic pump. The hydraulic fluid was routed through high-pressure hoses, ensuring smooth and controlled motion during lifting and lowering.

Safety features were built into the construction to prevent accidents. Mechanical safety locks were installed within the posts, engaging automatically as the lift rose to various height levels. These locks ensured the lift remained securely in place in case of hydraulic failure. Additionally, a locking-release mechanism was incorporated to allow controlled lowering of the vehicle.

Electrical wiring and controls were integrated into the system to operate the lift. A control panel was mounted on one of the posts, enabling the user to raise, lower, or stop the lift as needed. Emergency stop buttons were also included to enhance operational safety.

The entire structure was designed to withstand significant loads and meet industrial safety standards. Bolts and anchors were used to secure the posts to the floor, ensuring stability during use. The construction process involved rigorous testing to verify load capacity, balance, and overall reliability.

This robust and efficient construction allowed the two-post car lift to be widely used in automotive workshops and garages for vehicle maintenance and repair tasks. The final assembly of the two-post car lift is shown in Figure 7 after construction and assembly.

Figure 6: Two-post car lift after construction

3.7 Experimental test

The performance evaluation of the locally fabricated two-post car lift was carried out using a comprehensive setup of sensors and data acquisition tools. The experiment aimed to assess key performance parameters, including vertical lift speed, structural deflection, asymmetry during lifting, and safety system reliability under different vehicle loads.

Instrumentation and Setup

i **Strain Gauges**: Vishay CEA-06-240UZ-120, 120 Ω, foil type, bonded to load-bearing beams to measure stress and strain.
ii **Displacement Sensors**: LVDT sensors (0–200 mm range, 0.01 mm resolution) tracked lift displacement.
iii **High-Speed Camera**: 1000 fps resolution camera monitored lift dynamics and asymmetry.
iv **DAQ System**: NI USB-6363 16-bit system interfaced with LabVIEW for synchronized multi-channel data capture.

Three vehicle types were used for loading:
i Compact Car (1,200 kg)
ii Sedan (1,600 kg)
iii SUV (2,200 kg)

Measurements were taken over five repeated tests per load to ensure statistical reliability. Parameters such as lift time, vertical speed, structural deflection, and asymmetry were recorded, while the safety lock system engagement was also monitored.

4.0 Results and Discussions

4.1 Experimental Results

Table 5 shows that lifting time increased linearly with vehicle mass, ranging from 18.2 s for a 1,200 kg compact car to 23.5 s for a 2,200 kg SUV. This corresponded to a decrease in lift speed from 11.0 mm/s to 8.6 mm/s. The inverse relationship reflects increased load resistance encountered by the hydraulic and gear systems, which is consistent with known performance characteristics of hydraulic lifts [13], [14]. Despite the load increase, all speeds remained within safe operational thresholds recommended by ANSI/ALI ALCTV:2017 [10].

Table 5: Lifting Performance versus Vehicle Weight

Vehicle Type	Mass (kg)	Lift Time (s)	Vertical Speed (mm/s)	Max Deflection (mm)	Asymmetry (mm)	Safety Lock Engaged	Standard Deviation (Deflection)
Compact Car	1,200	18.2	11.0	2.5	0.8	Yes	±0.3
Sedan	1,600	20.1	10.0	3.6	1.2	Yes	±0.5
SUV	2,200	23.5	8.6	5.1	1.9	Yes	±0.6

Graphical Plot

Figure 7 shows the graph of lifting time versus vehicle weight

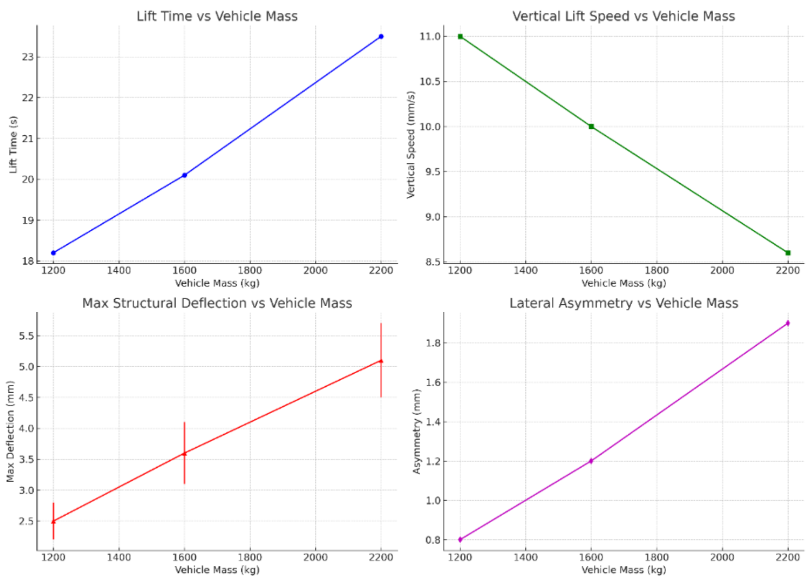


Figure 7: *Performance metrics of the locally-fabricated two-post car lift under varying vehicle loads: (a) Lift time increases with vehicle mass due to higher resistance in the hydraulic system; (b) Vertical lift speed decreases with increasing load, reflecting reduced efficiency under stress; (c) Maximum structural deflection rises with load but remains within elastic limits, with standard deviation error bars indicating repeatability; (d) Lateral asymmetry shows a consistent but safe increase, staying within the design threshold of 2.0 mm.*

4.2 Discussion

The experimental performance evaluation of the locally fabricated two-post car lift under incremental vehicle loads revealed important mechanical trends and operational behaviors relevant to safety, efficiency, and practical usability. Data from Table 5 and Figure 7 confirm that the system exhibits predictable responses under varying stress conditions, validating the design's robustness and its applicability to resource-limited settings.

4.2.1 Relationship Between Vehicle Mass, Lift Time, and Vertical Speed

As vehicle mass increased from 1,200 kg (compact car) to 2,200 kg (SUV), lift time rose from 18.2 seconds to 23.5 seconds, while vertical lift speed decreased from 11.0 mm/s to 8.6 mm/s. This inverse relationship, shown in **Figure 7(a) and 7(b)**, is consistent with increased resistive loading on the hydraulic motor and mechanical components. The system, driven by a single-phase 3 HP motor, demonstrated load-dependent deceleration without exceeding acceptable operational limits. These observations align with established findings in hydraulic lift systems, where increased torque demand under heavier loads leads to performance degradation [13], [14].

Despite this, all recorded lift speeds remained within ANSI/ALI ALCTV:2017 thresholds for safe lifting performance [10], [33], indicating that the system's design is structurally and functionally adequate for small-to-medium-scale automotive applications.

4.2.2 Structural Deflection and Mechanical Stability

Maximum structural deflections were recorded at 2.5 mm (compact), 3.6 mm (sedan), and 5.1 mm (SUV), with standard deviations ranging from ±0.3 mm to ±0.6 mm, as illustrated in Figure 7(c). These values reflect elastic deformation behavior under load and remained well within safe deflection limits (typically ≤2% of member length) as prescribed in [10], [30].

The consistency of low standard deviations across repetitions supports the mechanical integrity of the lift's frame and arms, confirming reliable stress distribution and effective joint alignment throughout the structure.

4.2.3 Asymmetry and Load Distribution Behavior

As shown in Figure 7(d), lateral asymmetry increased modestly with vehicle mass, from 0.8 mm to 1.9 mm. All values stayed below the critical 2.0 mm threshold for safety, demonstrating satisfactory load balance and synchronized arm operation [10], [20]. Nevertheless, the rising trend suggests that for heavier vehicle types, reinforcement of the lifting arms or implementation of feedback-based alignment systems may be necessary to minimize long-term structural fatigue and ensure symmetric elevation under all operating conditions.

4.2.4 Safety Lock Performance and System Reliability

The passive mechanical safety locks performed effectively under all load cases, with engagement confirmed by high-speed camera footage. Pin insertion occurred within the expected 0.2-second window, without delay or mechanical interference. This behavior is compliant with ANSI/ALI ALCTV:2017 specifications for automatic locking mechanisms [10], [18], validating the safety redundancy designed into the system.

4.2.5 Motor Thermal Behavior: Implications and Future Monitoring

While not instrumentally monitored in this iteration, motor thermal performance remains a crucial factor. High-load, low-speed operation induces increased current draw, contributing to resistive heating (I^2R losses), core losses, and possible lubricant degradation in bearings [27], [28]. These thermal dynamics, if left unchecked, can lead to insulation failure or reduced motor lifespan. Therefore, future iterations should integrate thermal sensors (e.g., RTDs or thermocouples) or infrared thermography for real-time temperature profiling and predictive maintenance scheduling [32].

Suggested enhancements include fan-cooled housings, heatsinks, or intelligent motor controllers to dynamically adjust motor load in response to thermal thresholds.

4.2.6 Repeatability and Statistical Validity

Each load condition was subjected to five test repetitions. Across all runs, performance parameters such as deflection and speed exhibited low standard deviation, indicating a high level of repeatability. This reliability underscores the fabrication precision and system stability, especially under dynamic lifting conditions.

4.2.7 Benchmarking Against Standards and Literature

The prototype's performance benchmarks were compared with industry standards and related literature. ANSI/ALI ALCTV:2017 requires maximum asymmetry below 3 mm and demands consistent lock engagement—both criteria were fulfilled in this system [10], [33]. Comparable hydraulic lifts studied in [2], [3], and [8] employed imported systems with high-cost manufacturing or lacked adaptability for local servicing. The present system offers a unique, low-cost alternative without compromising functionality or safety, making it ideal for deployment in developing economies.

4.2.8 Cost-Efficiency and Practical Relevance

Fabricated at an estimated cost below USD 700, the lift demonstrates an approximate 65–80% reduction compared to imported models (USD 2,000–4,000) [12], [19]. This economic efficiency is significant, particularly when coupled with the operational performance equivalence. Moreover, the reliance on local materials enhances sustainability, facilitates maintenance, and contributes to workforce skill development.

4.2.9 Innovation and Design Novelty

The novelty of this work lies in the integrated use of **standard steel profiles, a low-cost mechanical-hydraulic system, and locally sourced components** to meet recognized engineering performance and safety standards. Unlike conventional systems that emphasize technological complexity, this design emphasizes affordability, reliability, and replicability, especially suited for under-resourced regions.

The fabricated two-post car lift exhibits strong mechanical behavior across load ranges, confirming its functional adequacy for use in small to medium-sized workshops. It complies with structural safety, lift symmetry, and operational repeatability requirements. While further enhancements in thermal monitoring and electronic synchronization could elevate system performance, the current design offers a robust, affordable, and practical lifting solution for automotive maintenance in resource-constrained settings.

5.0 Conclusion and Recommendations

5.1 Conclusion

This study presented the design, construction, and experimental evaluation of a locally fabricated two-post car lift intended for small and medium-sized automotive workshops, particularly in resource-limited environments. The prototype was developed using cost-effective materials, a hybrid hydraulic-pulley mechanism, and a compact structural frame fabricated entirely from locally sourced components.

Performance evaluation across three vehicle classes, compact car (1,200 kg), sedan (1,600 kg), and SUV (2,200 kg), demonstrated that the lift operated with predictable and consistent behavior. Vertical lift speeds ranged from 11.0 mm/s to 8.6 mm/s, while structural deflections remained within elastic limits (2.5 mm to 5.1 mm) and exhibited minimal variance (±0.3 mm to ±0.6 mm), indicating high mechanical reliability. Lateral asymmetry remained below the 2.0 mm design threshold, validating the system's geometric balance and operational stability.

The passive safety lock system engaged consistently during all lifting cycles, reinforcing the design's compliance with ANSI/ALI ALCTV:2017 safety requirements [10], [33]. Although motor thermal performance was not directly monitored, it was identified as a critical factor for future optimization, particularly under high-torque, low-speed conditions [27], [32].

Most notably, the prototype was produced at a total cost below USD 700, offering a 65–80% savings compared to commercially imported equivalents [12], [19]. This affordability, combined with its performance parity and ease of maintenance, makes the lift a viable alternative for automotive infrastructure development in low- and middle-income regions.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed to guide future research, product development, and implementation:

i **Thermal Monitoring Integration**: Future designs should incorporate real-time temperature sensing technologies (e.g., thermocouples, RTDs, or infrared cameras) to monitor motor heat buildup, ensuring operational safety and prolonging motor life [27], [32].

ii **Structural Reinforcement for Heavier Loads**: While the current design meets safety criteria, reinforcement of lifting arms or column sections may be necessary for vehicles exceeding 2,200 kg or for frequent heavy-duty usage to prevent fatigue-related degradation over time.

iii **Automation and Control Enhancement**: Incorporating programmable logic controllers (PLCs), limit switches, or wireless remote-control modules can improve ease of operation, synchronization accuracy, and fault detection, aligning with modern trends in intelligent lifting systems [15], [17].

iv **Cost-Benefit Scaling and Deployment**: A detailed life-cycle cost analysis and pilot implementation in local workshops are recommended to validate field performance, assess long-term reliability, and support wider adoption. Scaling the system for broader vehicle categories or public transport fleets could further demonstrate its versatility.

v **Standardization and Certification**: To support commercial viability, the lift should undergo third-party certification against ANSI/ALI ALCTV and other relevant international standards, ensuring formal compliance for use in professional garages.

vi **Modular Design Approach**: Adopting a modular design philosophy can enable easier transport, onsite assembly, and repair further enhancing adoption potential in rural or semi-urban settings with limited infrastructure.

In summary, the developed system demonstrates that locally-engineered solutions can achieve international standards of performance and safety while remaining accessible and affordable. This work contributes significantly to the advancement of sustainable engineering practices, particularly in developing regions where industrial self-reliance and cost sensitivity are paramount.

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