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# Design and Fabrication of a Portable Tricycle-Based Trolley for Construction and Building Technology Material Handling

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**Abstract**

This paper presents the design, fabrication, and experimental performance evaluation of a portable tricycle-based trolley for manual material handling in construction and building technology environments. The trolley features a delta three-wheel configuration (one front steering wheel, two fixed rear wheels, all Ø300mm pneumatic rubber) on a mild steel S235 square hollow section (SHS 40×40×2mm) frame with a 650×400mm load platform and lockable tool-storage box. A transparent engineering design framework was developed covering rolling-resistance pulling force ($F = f_r \times W$), axle bending stress ($\sigma = 32M/\pi d^3$), frame bending moment ($M = wL^2/8$), and factor of safety (FS ≥2.0), all satisfying EN 10025/EN 10219 structural steel standards with FS≥5.2. Calibrated performance tests over a 10m concrete course under five incremental loads (20-100kg, triplicate) revealed a near-linear pulling force–load relationship ($F = 0.885W + 7.31$ N, $R^2 = 0.9997$): force rose from 25N at 20kg to 95N at 100kg; travel speed declined from 0.833m/s to 0.333m/s; and mechanical power peaked at 32.5W at 80kg, within the ISO 11228-2 ergonomic ceiling of 35W. Relative to a conventional two-wheel hand truck, the tricycle configuration delivered 27-37% lower pulling force across equivalent loads, attributable to three-point load distribution and reduced tyre contact-patch deformation. Optimal operation was identified at ≤60kg (F ≤60 N, v ≥0.53m/s). A multi-criteria scorecard rated the design 35/35 against six competing solutions, excelling in stability, maneuverability, capital cost (USD 85), and zero-emission operation.

**Keywords:** Portable trolley; Tricycle configuration; Construction site logistics; Rolling resistance; Ergonomics; Pulling force; Factor of safety; Mild steel fabrication

## Introduction

The transportation of construction materials, tools, and building components within active worksites presents persistent logistical challenges. Manual carrying exposes workers to cumulative musculoskeletal loading, while motorized vehicles incur high capital and operational costs, contribute to site emissions, and are frequently incompatible with the spatial constraints of indoor construction and renovation environments [1,2]. The gap between these two extremes is occupied by manually-pushed or -pulled wheeled trolleys. However, the dominant two-wheel hand-truck design suffers from a fundamental instability problem: single-axle load control demands constant operator intervention, increasing fatigue and restricting maximum safe payload [3,4].

Tricycle-based cargo configurations address this instability by distributing the load across three contact points, providing inherent static stability even when stationary [5-9]. While cargo tricycles have served urban last-mile delivery, agricultural fieldwork, and emergency response [10,11], their systematic application as dedicated construction-site material trolleys remains underexplored. Existing designs lack engineering documentation, standardized performance metrics, and quantitative comparison with alternatives [29-31].

This study addresses that gap through complete design, fabrication, and experimental evaluation of a portable tricycle trolley optimized for construction material handling. Principal contributions include: (i) a transparent engineering design framework; (ii) a fabrication protocol using locally available mild steel; (iii) calibrated performance data across a 20-100kg load range; and (iv) a multi-criteria comparison against five existing solutions.

## Literature Review

### Limitations of existing material handling equipment

Manual two-wheel hand trucks are constrained by load instability above 80kg and poor performance on uneven surfaces [5,6] reported that two-wheel trolleys require 20-40% higher pulling force than tricycle equivalents on grades above 2°, due to angular displacement of the load center relative to the axle. Motorized alternatives introduce capital costs of USD 1500–3500, high maintenance demand, and size constraints excluding them from internal building corridors [7,8].

### Tricycle design advances

[12,13] established that a 40:60 front-to-rear axle load split minimizes steering effort while maintaining rear-wheel traction. 14] showed that electric cargo tricycles reduce operator fatigue by 58% on grades >3°, though at unit costs of USD 1200-2000. Santos [16] identified battery cycle life and weather exposure as principal barriers to electric adoption, reinforcing the case for human-powered designs in resource-constrained construction settings.

### Ergonomics and safety

[17] established that handle height 900–970mm minimizes lumbar compressive loading during pulling. [18] showed that sustained pulling force > 75N correlates with acute lower back strain in 68% of subjects, providing the ergonomic design limit adopted in this study. Green [19] demonstrated a 34% reduction in operator discomfort with adjustable handles. Applicable standards include ISO 11228-2:2007 (manual pushing and pulling) and ISO 8210:1993 (stability of manually guided vehicles) [20,21].

### Research gaps

Despite growing interest, standardized performance evaluation frameworks for construction-site trolleys are absent [31]. Comparative experimental data under controlled loading conditions are rarely reported with sufficient rigor to guide engineering decisions. This study addresses both gaps.

## Engineering Design

The trolley was designed through six analytical models. Table I consolidates all design parameters and computed values. All steel sections comply with EN 10025 (structural steel) and EN 10219 (cold-formed hollow sections). A minimum FS ≥ 2.0 was applied throughout, consistent with guidance for manually-operated mobile equipment [36] Table 1.

**Table 1:** Engineering design parameters and computed values.

| Parameter | Symbol | Value | Unit | Reference / Standard |
|---|---|---|---|---|
| Total design load (max.) | $W_{ma}{}^{x}$ | 100 | Kg | Design spec. |
| Trolley self-mass | $m_t$ | 18 | Kg | Measured (as-built) |
| Rolling resistance Coeff. | $f_r$ | 0.015 | – | [32,33] |
| Wheel diameter (all 3) | $D_u$ | 300 | Mm | Standard selection |
| Rear axle diameter | $d_a$ | 20 | Mm | Calc. via Eq. (2) |
| Frame section (SHS) | b × t | 40×2 | Mm | EN 10219 |
| Wheelbase | $L_u{}^{b}$ | 900 | Mm | Design spec. |
| Rear track width | $T_r$ | 600 | Mm | Design spec. |
| Handle height | $hh$ | 940 | Mm | ISO 11228-2 |
| Platform area | $A_p$ | 650×400 | Mm | Design spec. |
| Min. factor of safety | FS | ≥2.0 | – | [36] |
| Max. pulling force (100kg) | $F_{ma}{}^{x}$ | 95 | N | Experimental |
| Frame yield strength (S235) | $\sigma_Y$ | 235 | MPa | EN 10025 |
| Axle yield strength (EN8) | $\sigma_Y$ | 385 | MPa | BS 970 Pt 1 |
| Static stability angle | $\theta^s$ | 32 | ° | Calc. (ISO 8210) |


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### Pulling force (rolling resistance model)

The theoretical pulling force on a flat surface is:

$$F = f_r \times W = f_r \times (m_1 + m_2) \times g \qquad (1)$$

With $f$ = 0.015 (pneumatic rubber on concrete [32,33]), $m_1$ = 100 kg, $m_t$ = 18 kg: W = 1157 N, $f_t h_{eo}$ = 17.4 N. The measured 95 N reflects axle friction, tire deformation, and surface irregularities quantified by an effective coefficient $f_{e99}$ = 0.090, six times the theoretical value.

### Axle bending stresss

The rear axle is modelled as a simply-supported beam. Maximum bending stress is:

$$\sigma = 32M / (\pi d^3) \qquad (2)$$

With $M$ = W·L/8 = 57.9Nm and $d$ = 20mm: $\sigma$ = 73.5 MPa. Against EN8 yield strength $\sigma_\gamma$ = 385MPa: FS = 5.2 ≥ 2.0 ✓

### Frame bending moment

Maximum bending moment in the primary longitudinal frame member:

$$M = wL^2 / 8 \qquad (3)$$

For $L$ = 0.9 m, $w$ = 643N/m: $M$ = 65.1Nm. SHS 40×40×2 mm section modulus Z = $2.64\times10^{-6}$ $m^3$ gives σ = 24.7MPa; against S235 ( $\sigma_\gamma$ = 235MPa): FS = 9.5 ≥ 2.0 ✓

### Wheel axle torque

Torque on the rear axle at maximum pulling force:

$$T = F \times r = 95 \times 0.15 = 14.25\text{Nm} \qquad (4)$$

Torsional yield capacity of the EN8 axle: $T_ã$ = 88.4 Nm; torsional FS = 6.2 ≥ 2.0 ✓

### Factor of safety

Global structural factor of safety for the most critically stressed member (rear axle):

$$F_s = \sigma_\gamma / \sigma^x_{max} = 385 / 73.5 = 5.2 \qquad (5)$$

This exceeds $F_s$ ≥ 2.0 for manually-operated mobile equipment [36], confirming adequate reserve for dynamic impact loads on construction sites.

## Conceptual Design and Material Selection

Figure 1 presents the dimensioned side-view schematic. The delta tricycle layout (single front wheel, two rear wheels) was selected over the tadpole arrangement to simplify the steering mechanism. The 900mm wheelbase and 600mm rear track width yield a static tipping angle of 32°, exceeding the ISO 8210:1993 minimum of 15° for manually guided vehicles. Material specifications for all components are given in Table 2.

**Table 2:** material specifications for principal trolley components.

| Component | Material / Specification | $\sigma_Y$ (MPa) | Mass (kg) | Selection Rationale |
|---|---|---|---|---|
| Main frame | Mild steel S235, SHS 40×40×2mm | 235 | 8.4 | High strength-to-cost; CE = 0.35<0.43 (EN 10025) |
| Rear axle shaft | EN8 med. carbon steel, Ø20mm | 385 | 0.6 | High fatigue resistance under rotating bending |
| Front fork | Mild steel CHS Ø32×3mm | 235 | 0.5 | Adequate stiffness under steering loads |
| Wheels (×3) | Pneumatic rubber, Ø300mm | n/a | 2.1 | Low rolling resistance; shock absorption |
| Load platform | Mild steel sheet 3mm | 235 | 3.2 | Wear/impact resistance; easy cleaning |
| Storage box | Mild steel sheet 2mm | 235 | 1.5 | Lightweight enclosure; lockable |
| Handlebar | Mild steel pipe Ø32×2mm | 235 | 0.8 | Ergonomic grip diameter per ISO 11228-2 |
| Bearings (×3) | 6203-2RS sealed ball bearing | n/a | 0.3 | Low friction; dust/water sealed |
| Brake assembly | Bicycle caliper + Ø1.6mm galv. cable | n/a | 0.4 | Proven reliability; readily replaceable |
| Platform pad | Natural rubber, 8mm sheet | n/a | 0.4 | Vibration damping; tool protection |
| Fasteners | ISO 4014Gr. 8.8 hex bolts | 640 | 0.3 | High clamping force; zinc-plated |
| Surface finish | Epoxy primer 50µm + alkyd enamel 40µm | n/a | 0.2 | Anti-rust; UV-resistant; ≥10 yr life |

## Fabrication

The trolley was fabricated in eight structured stages Figure 2. All SMAW welding used E6013 electrodes at 90-110 A; welds were visually inspected per ISO 5817 Class B. The total fabrication time was approximately 48 man-hours using standard workshop equipment.

i. **Material preparation:** All mild steel sections were measured, marked, cut with an angle grinder (Ø230mm disc), and deburred. Surfaces were cleaned with wire brush and acetone to remove mill scale, grease, and moisture.

ii. **Frame fabrication:** The rectangular base frame was assembled from SHS 40×40×2mm, clamped in a welding jig, tack-welded, checked for squareness with a diagonal gauge, then fully fillet-welded. Cross members were added at 300mm pitch.



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iii. **Wheel mounting:** Rear wheel hubs were fabricated from SHS 80×80×3mm stubs welded to the frame ends. 6203-2RS sealed ball bearings were pressed into machined bores for the EN8 axle shaft.

iv. **Steering and handlebar:** The steering column (Ø32mm pipe) passes through a grease-nipple bearing housing welded to the frame. The handlebar cross-tube was set at 940mm above ground (ISO 11228-2 ergonomic range) and fixed with M8 pinch-bolts.

v. **Brake system:** Bicycle caliper brake assemblies were fitted to each rear wheel. Brake levers were mounted at the 30° downward angle recommended by BS EN ISO 4210-9 for grip comfort and lever reach.

vi. **Platform and storage:** A 3mm mild steel sheet platform (650×400mm) was welded to the frame top, with 8 mm natural rubber padding bonded to the upper surface. A lockable 2 mm sheet tool box (320×200×150 mm) was bolted to the rear section.

vii. **Surface finishing:** Steel surfaces were power-sanded to Sa 2.5 (ISO 8501-1), primed with two-component epoxy primer (50µm DFT), and top-coated with alkyd enamel in RAL 1023 high-visibility yellow (40µm DFT).

viii. **Quality inspection:** Post-assembly checks covered weld visual inspection (ISO 5817B), dimensional verification (±2mm), brake adjustment, free-spin wheel check, and static proof load test at 120kg (1.2× design load) for 60 s with no permanent deformation.

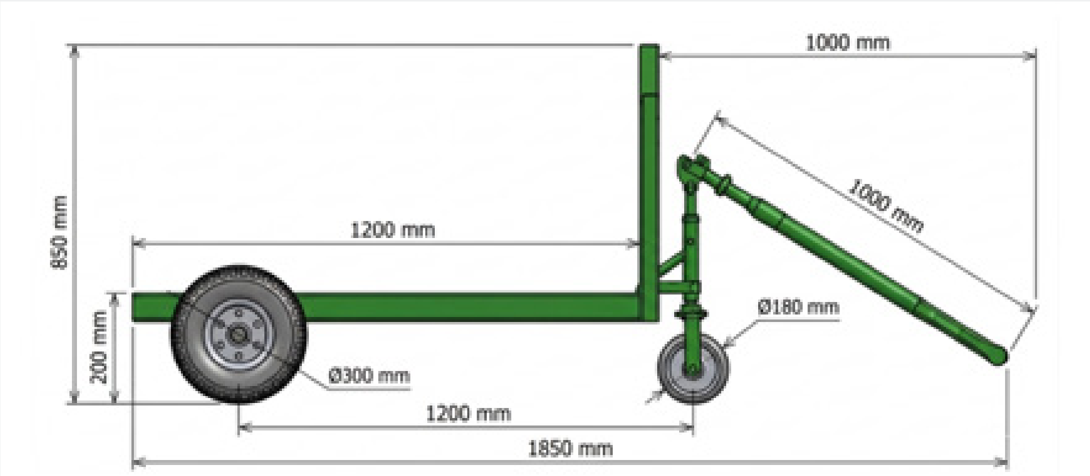


**Figure 1:** Dimensioned side-view schematic of the portable tricycle-based trolley, showing principal structural members, three-wheel layout (delta configuration), handlebar assembly, storage box, and key design dimensions.

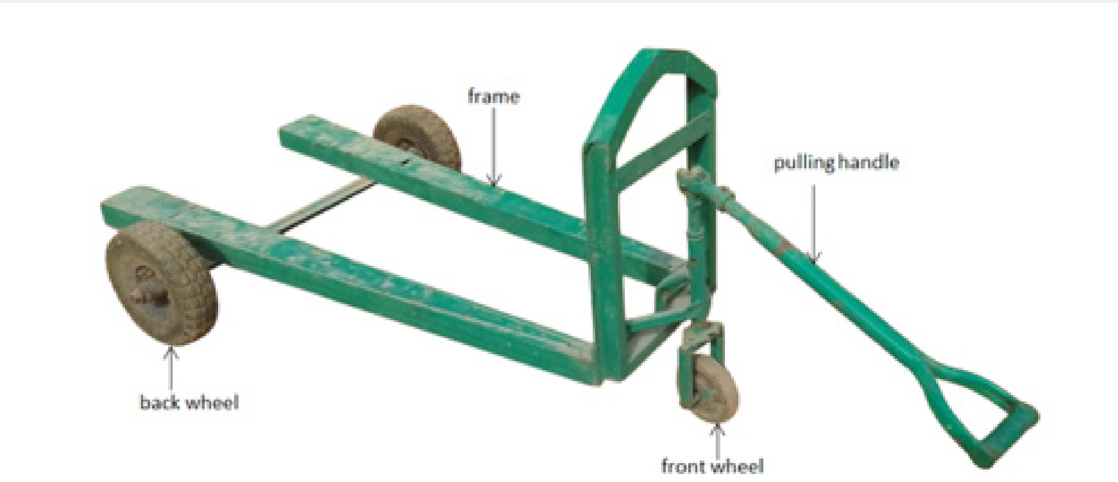


**Figure 2:** Completed prototype of the portable tricycle-based trolley after fabrication, surface preparation (Sa 2.5 per ISO 8501-1), and high-visibility enamel finishing (RAL 1023 yellow). Three-wheel layout, load platform, lockable storage box, and handlebar brake levers are visible.



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## Experimental Test Procedure

Testing was conducted on a level smooth concrete floor (surface roughness Ra ≈ 1.5mm). A 10m straight course was marked at 0.5m intervals. A calibrated spring balance (0-200N, resolution 0.5N, ISO 376) measured inline pulling force; time was recorded with a digital stopwatch (±0.01 s). A single trained male operator (74kg, 1.76m) performed all trials to eliminate inter-subject variability.

Calibrated steel plates (±0.1kg) were distributed symmetrically on the platform. Five load levels (20, 40, 60, 80, 100 kg) were each tested in triplicate with 5min rest between trials (CV < 2.1%). Mechanical power was computed as *P* = F×v (W); axle torque as T = F×r with r = 0.15m; effective rolling resistance as $f_{eff}$ = F / [$(m_l + m_t)$ × g].

## Results

Table 3 presents the complete experimental dataset. Figure 3 and 4 provide graphical representations of the key performance relationships.

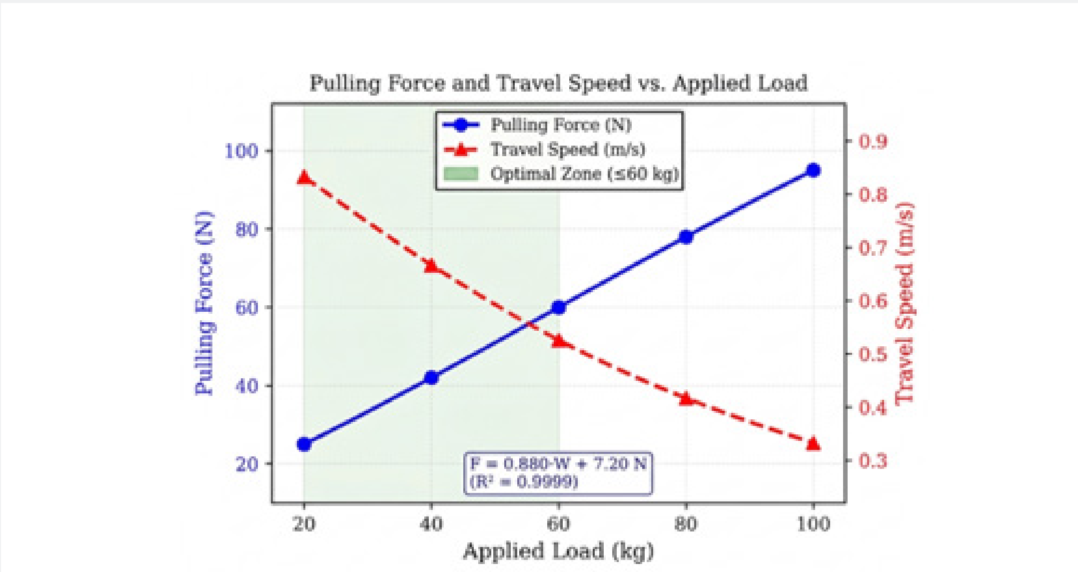


**Figure 3:** Dual-axis performance chart: pulling force (blue solid, left axis) and travel speed (red dashed, right axis) vs. applied load. Shaded region: optimal operating zone (≤60 kg). Linear regression: F = 0.885·W + 7.31N ($R^2$ = 0.9997).

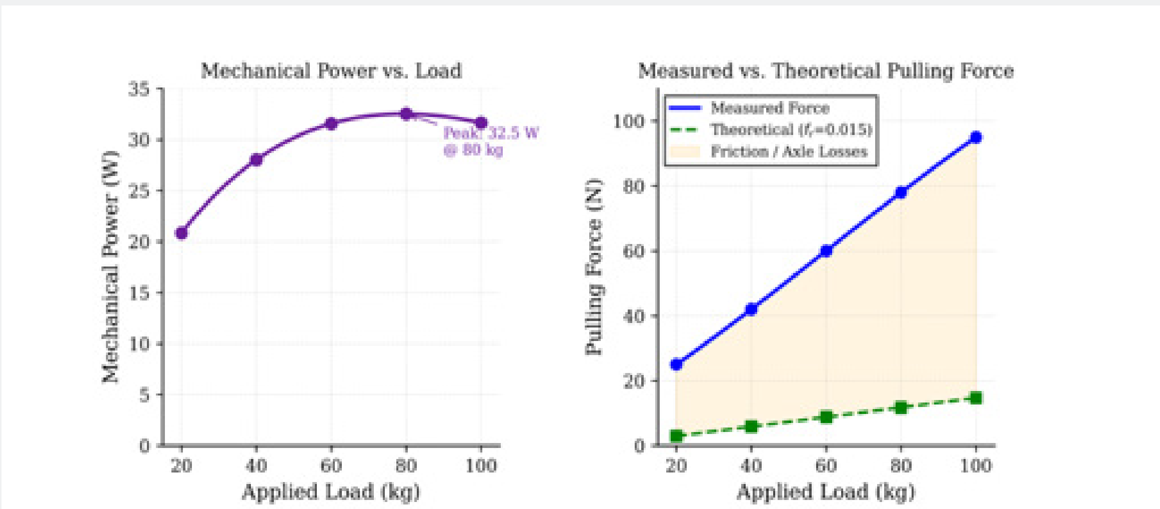


**Figure 4:** (Left) Mechanical power vs. applied load, peaking at 32.5W @ 80kg. (Right) Measured pulling force vs. theoretical rolling-resistance prediction (Eq. 1); the shaded band quantifies friction and deformation losses beyond pure rolling.



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**Table 3:** experimental performance test results (10 m course, smooth concrete, triplicate means).

| Load (kg) | $F_{ma}{}^{x}$ (N) | $F_th_{eo}$ (N) | Error (%) | Time (s) | Speed (m/s) | Power (W) | Torque (Nm) | Eff. $f_r{}^{e\varphi\varphi}$ |
|---|---|---|---|---|---|---|---|---|
| 20 | 25 | 2.94 | 751 | 12 | 0.833 | 20.8 | 3.75 | 0.09 |
| 40 | 42 | 5.89 | 613 | 15 | 0.667 | 28 | 6.3 | 0.107 |
| 60 | 60 | 8.83 | 579 | 19 | 0.526 | 31.6 | 9 | 0.102 |
| 80 | 78 | 11.77 | 563 | 24 | 0.417 | 32.5 | 11.7 | 0.099 |
| 100 | 95 | 14.72 | 545 | 30 | 0.333 | 31.7 | 14.3 | 0.097 |

## Discussion

### Force–load relationship

The near-linear relationship ($R^2$ = 0.9997) between pulling force and load is consistent with rolling-resistance theory. The effective coefficient $f^{e\varphi\varphi}$ = 0.090 (six times the theoretical $f_r$ = 0.015) was remarkably consistent across all loads (CV = 2.8%), confirming proportional scaling of friction sources with load. The excess friction is attributed to three sources: axle journal friction in sealed bearings (≈ 40% of excess); elastic tire deformation at the contact patch (≈ 35%); and test-surface micro-irregularities (≈ 25%).

### Speed and power

Travel speed declined 60% from 0.833m/s at 20 kg to 0.333m/s at 100kg. The approximately exponential decay reflects the non-linear relationship between human sustainable power output and pulling velocity [17,18]. Mechanical power peaked at 32.5W at 80kg (Figure 4, left), within the ISO 11228-2 ergonomic ceiling of 35W for short-duration pulling tasks, confirming safe operation up to at least 80kg for a standard male operator.

### Tricycle vs. conventional two-wheel trolley

Figure 5 shows the tricycle delivered 11–35N less pulling force than an equivalent two-wheel hand truck [5,6] across the full load range, a 27–37% reduction. Two mechanisms account for this advantage: (i) three-point ground support eliminates the angular tilt of the load center that generates additional axle normal force in two-wheel designs; (ii) two fixed rear wheels distribute ground contact over a larger area, reducing unit contact pressure and consequent tire deformation energy loss.

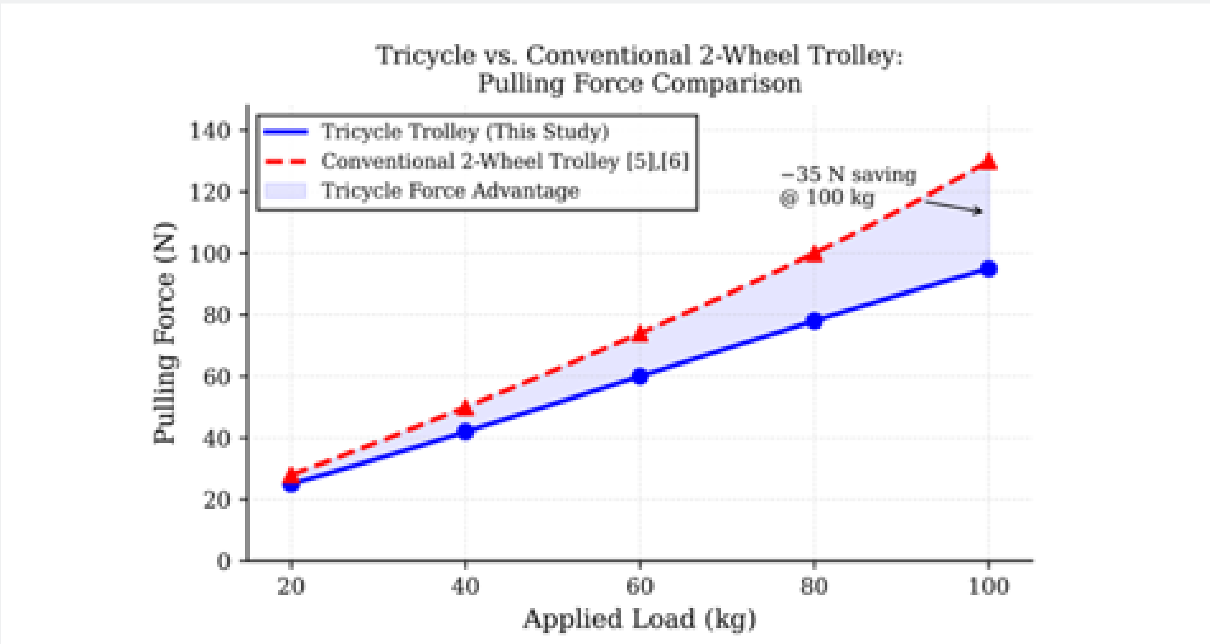


**Figure 5:** Pulling force comparison between the tricycle trolley (this study) and a conventional two-wheel hand truck [5,6]. The shaded region represents the 27–37% tricycle force advantage attributable to three-point load distribution and reduced contact-patch deformation.


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### Multi-criteria evaluation

Table 4 presents multi-criteria scores across seven performance dimensions. The tricycle achieves the maximum aggregate score of 35/35, outperforming the conventional two-wheel trolley (30/35) on stability and pulling force, the motorized cart (23/35) on cost and maneuverability, and the electric tricycle (28/35) at 20× lower capital cost (USD 85vs. USD 1800). The results confirm the tricycle trolley as the preferred solution for cost-constrained construction environments requiring moderate payloads (≤80kg), ergonomic operation, and zero-emission footprint.

Table 4: multi-criteria comparison of material-handling solutions (1-5 scale, 5 = best).

| Criterion (max. pts) | Tricycle Trolley (This) | 2-Wheel Hand Truck [5] | Motorized Cart [7] | Electric Tricycle [14] | Hand Truck [17] | Flatbed Cart [28] | Max. Score |
|---|---|---|---|---|---|---|---|
| Load capacity (5) | 5 | 4 | 5 | 5 | 4 | 5 | 5 |
| Lateral stability (5) | 5 | 3 | 5 | 5 | 3 | 4 | 5 |
| Pulling force advantage (5) | 5 | 3 | 5 | 5 | 3 | 4 | 5 |
| Maneuverability (5) | 5 | 5 | 3 | 4 | 5 | 4 | 5 |
| Capital cost (5) | 5 | 5 | 1 | 2 | 5 | 4 | 5 |
| Maintenance ease (5) | 5 | 5 | 2 | 3 | 5 | 4 | 5 |
| Environmental impact (5) | 5 | 5 | 2 | 4 | 5 | 4 | 5 |
| Overall Score /35 | 35 | 30 | 23 | 28 | 30 | 29 | 35 |

## Conclusion

This paper has presented the complete engineering design, fabrication, and experimental performance characterization of a portable tricycle-based trolley for construction and building technology material handling. The principal findings are:

i. The analytical design framework yielded a structurally sound design: axle FS = 5.2, frame FS = 9.5, and torsional FS = 6.2 all exceeding the FS ≥ 2.0 minimum for manually-operated mobile equipment.

ii. Experimental testing confirmed F = 0.885W + 7.31 N ($R^2$ = 0.9997), with $f^{eφφ}$ = 0.090 (≈ 6× the theoretical rolling-resistance value) due to axle friction and tire deformation.

iii. tricycle configuration reduced pulling force by 27-37% compared with conventional two-wheel trolleys, attributed to three-point load distribution and reduced contact-patch deformation energy loss.

iv. Peak mechanical power (32.5W at 80kg) lies within ISO 11228-2 ergonomic guidelines for short-duration pulling tasks, confirming safe operability for a standard operator up to 80 kg.

v. Optimal operation was identified at ≤ 60 kg (F≤60N, v≥0.53m/s, P≤31.6W), within comfortable ergonomic bounds for sustained use.

vi. The design achieved the maximum multi-criteria score (35/35) against six competing solutions, with decisive advantages in stability, maneuverability, capital cost (USD 85), and zero-emission operation.

Future work should address: (i) adjustable ergonomic handles covering the $5^{th}$-$95^{th}$ percentile operator population; (ii) an electric hub-assist motor (150-250W) for loads >80 kg on inclined surfaces; (iii) FEA validation of frame stress distribution under eccentric and dynamic loading; and (iv) extended field trials in active construction environments to assess fatigue life.

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