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PRODUCT DESIGN IMPROVEMENT OF A MULTIFUNCTIONAL WHEELBARROW

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ABSTRACT

This study was conducted to redesign a wheelbarrow commonly used in workshop environments, focusing on improving efficiency, safety, and ergonomic handling during the transportation of heavy loads. The original design was found to have several limitations, including low stability, difficulty in manoeuvring within confined spaces, and discomfort due to poor handle placement and unbalanced weight distribution. The main objective of this study was to address these issues by developing a more user-friendly and practical design that suits real workshop conditions. The methodology involved analysing the existing design, developing a new model, and conducting performance testing in an actual workshop environment. Performance was assessed through physical observation, measurement of load transfer time, and user satisfaction surveys. The results showed significant improvements in handling, load stability, and user fatigue reduction. The new design also contributed to reduce task completion time and smoother movement across workshop areas. In conclusion, the study demonstrates that redesigning basic equipment like the wheelbarrow can significantly improve work effectiveness, enhance safety, and provide greater user comfort in daily workshop operations.

1.0 Introduction

The wheelbarrow is a simple yet essential tool that has been in use since ancient times. Its earliest documented use dates back to 2nd-century China, where it served military logistics and agricultural purposes. The wheelbarrow later appeared in Europe during the Middle Ages, where it was primarily employed on farms and construction sites for transporting soil, crops, and building materials. The traditional structure of the wheelbarrow consists of a single front wheel, a supporting frame, and two handles. It has remained largely unchanged due to its simplicity and effectiveness.

However, as work processes became more specialized and industrialized, the wheelbarrow evolved to serve a wider range of applications. Today, it is extensively used in construction, landscaping, agriculture, and workshop environments to facilitate the efficient transportation of heavy loads, equipment, and materials (Emmanuel et al., 2022). Despite their widespread use, conventional wheelbarrows often encounter issues such as instability, uneven weight distribution, and difficulty in maneuvering through confined spaces. These challenges have driven continuous improvements and modern redesigns aimed at enhancing functionality, safety, and ergonomic performance (Kaur et al., 2023; Hafsa et al., 2023).

The modern wheelbarrow developed by Noor et al. (2024a) represents a significant leap in ergonomic and mechanical design for manual material handling. The use of a lightweight aluminium alloy frame not only enhances durability and corrosion resistance but also reduces the overall weight of the wheelbarrow, making it easier to push and maneuver, especially on uneven terrain. The inclusion of a pneumatic front wheel and rear caster wheels further improves mobility and stability, allowing users to transport materials smoothly with minimal effort.

A key innovation lies in the mechanical design, which incorporates a 2:1 spur gear system and fixed pulley mechanism. This configuration allows the wheelbarrow to tilt up to 70°, significantly reducing the lifting force required by up to 50%**.** As a result, users can unload materials faster and more efficiently, leading to a 53.8% increase in transport speed compared to traditional wheelbarrows (Noor et al., 2024a). This not only translates to significant time savings**,** especially in repetitive tasks like loading and unloading sand, cement, or debris, but also helps maintain productivity in high-demand construction or agricultural environments.

Furthermore, the design features ergonomic handles and a four-wheel support structure, which are intentionally engineered to minimize musculoskeletal strain. These elements encourage a natural hand and wrist position, reducing fatigue during prolonged use. The four-wheel configuration distributes the load more evenly, improving balance and reducing the physical burden on the operator. This modern wheelbarrow design provides a comfortable, efficient, and user-friendly solution, particularly for users performing frequent or heavy-duty transport tasks.

In a separate innovation, Mazlee et al. (2023) developed an adjustable wheelbarrow that integrates a hydraulic/manual scissor lift mechanism, offering a more versatile and ergonomic solution for manual load handling. The key feature of this design is the ability to raise and lower the load platform using a hydraulic lift, which drastically reduces the need for the user to bend down or apply excessive lifting force. This is particularly beneficial when handling heavy or repetitive loads, as it helps to maintain a proper posture and minimize the risk of back strain or injury.

The scissor lift system allows the wheelbarrow bed to be elevated to a height that is comfortable for loading and unloading, enhancing efficiency and saving time, especially in tasks that involve frequent material transfers. Rather than manually tilting or lifting the load, the user can activate the hydraulic mechanism with minimal effort, thus reducing physical fatigue. This feature is especially valuable in industrial or agricultural settings where multiple trips and heavy materials are involved.

To ensure structural integrity and safety, the design was validated through 3D modeling and finite element analysis (FEA), which confirmed that the wheelbarrow could safely handle a load of up to 686 N. The use of mild and stainless-steel components not only ensures strength and durability but also provides resistance to environmental factors such as corrosion. These material choices contribute to a longer lifespan of the tool with minimal maintenance (Mazlee et al., 2023). This adjustable wheelbarrow combines engineering precision and user-centric design, delivering a solution that enhances productivity**,** reduces physical burden, and promotes comfort and safety in daily operations.

A subsequent redesign by Noor et al. (2024b) explored two ergonomic concepts aimed at improving user comfort and operational efficiency. Concept: An integrated system into a manual hydraulic jack system, allowing users to lift and unload materials with minimal physical exertion. This design was specifically engineered to reduce the need for excessive bending or lifting, which are common sources of musculoskeletal strain in conventional wheelbarrow use. The hydraulic mechanism could be activated with controlled force, giving users greater command overload manipulation, particularly when handling heavy construction materials.

The handle position and lifting motion in Concept A were aligned with ergonomic standards, promoting a more upright posture and reducing lower back stress. In contrast, Concept B**,** which involved a four-stroke engine and pneumatic unloading system, offered mechanical assistance but was deemed less practical for small-scale or remote operations due to its added weight, complexity, and maintenance needs. Ultimately, Concept A was preferred for its simplicity, ease of use, and superior postural support, making it more suitable for daily use by workers in varying environments and physical conditions (Noor et al., 2024b).

The development of a motorized wheelbarrow powered by a 33cc two-stroke engine coupled with a chain-sprocket drive mechanism represents a significant advancement in material transport efficiency at construction sites. The design was capable of reducing brick transport time by up to 90% over a 50-meter distance, highlighting its effectiveness in high-repetition tasks. The self-propelling function eliminated the need for continuous manual pushing, thus reducing operator fatigue and improving overall productivity (Azman et al. 2024). The compact yet powerful engine, combined with a reinforced chassis, made it suitable for maneuvering through narrow or uneven terrain without compromising speed or stability, providing a more comfortable and time-saving solution compared to conventional wheelbarrows.

Building upon this foundation of mechanized material handling, Abdulrahman et al. (2024) adopted a context-specific design approach tailored to the unique challenges of Nigerian construction environments. Their improved motorized wheelbarrow utilized ASTM A36 structural steel for structural integrity while maintaining portability. Unlike Azman's combustion-driven model, Abdulrahman’s wheelbarrow was powered by a 0.5 hp electric motor and equipped with pneumatic tires, enhancing adaptability on unpaved or rugged terrain. With a load capacity of 136 kg, it supported high-volume material movement with minimal physical strain. The design underwent rigorous validation using SolidWorks simulations, confirming its mechanical reliability and operational safety**.**

While both innovations address the same fundamental need to reduce physical workload and improve transport efficiency. His model also aligned with the United Nations Sustainable Development Goals (SDGs) 3, 8, and 9, emphasizing health and well-being (SDG 3)**,** decent work and economic growth (SDG 8)**,** and industry innovation and infrastructure (SDG 9**)**. This highlights the broader impact of the design not only in improving user experience but also in promoting sustainable and inclusive technological solutions in the construction sector **(**Abdulrahman et al. 2024)**.**

Leng et al. (2024) introduced a Multipurpose Wheelbarrow designed to enhance versatility in handling a variety of load types. One of its key innovations is foldable side plates to enable the effective transport of elongated materials such as steel rods or rebar, which are often incompatible with standard wheelbarrow designs. Furthermore, a 360° rotatable base significantly improved maneuverability within confined or cluttered workspaces, while integrated rear brakes and a front puller enhanced control and safety when navigating inclines or uneven terrain. The inclusion of ergonomic handles supported natural hand posture, thereby reducing wrist strain and contributing to user comfort during prolonged use. Evaluations of this design revealed not only improved safety features but also economic advantages, making it a cost-effective and ergonomically optimized solution for both construction and agricultural applications (Leng et al. 2024).

Similar to Abdulrahman et al. (2024), who emphasized terrain adaptability and user-centered design in motorized wheelbarrow development, Leng et al.'s innovation also prioritizes usability, operator comfort, and safety, but through structural adaptability and multifunctionality. This reflects a shared design philosophy aimed at enhancing user experience and efficiency in diverse working conditions.

To enhance the versatility and resilience of manual load-handling tools, Gowda et al. (2021) introduced a multi-utility wheelbarrow that addresses both routine operational needs and emergency preparedness, particularly in flood-prone environments. The design incorporates dual front wheels to improve balance and reduce the risk of tipping, along with low-pressure pneumatic tires that enhance shock absorption during transportation over uneven terrain. Furthermore, ergonomic adjustability is built into the structural components to accommodate users of diverse heights and reduce the risk of musculoskeletal disorders during prolonged use (Gowda et al. 2021).

A defining innovation of this model is its flotation capability, which allows the wheelbarrow to be repurposed as a rescue device during flood emergencies. This feature reflects a forward-thinking approach to integrating disaster response functions into conventional manual equipment. The frame, made from lightweight but durable materials such as plastic or aluminum alloy, strikes a balance between strength and maneuverability.

Performance testing validated the design's dual-purpose functionality, confirming its effectiveness in both standard industrial applications and emergency scenarios. The study also emphasized the importance of cost-efficiency, achieved through careful material selection and design-for-manufacture considerations. This innovation sets a precedent for the development of context-responsive, multifunctional tools in both industrial and humanitarian contexts, particularly for use in developing regions with limited access to specialized equipment.

2.0 Methodology

This research employs a systematic engineering design methodology to redesign a multifunctional wheelbarrow that addresses the limitations of the conventional model in terms of efficiency, ergonomics, and suitability for real-world workshop applications. The design process was structured into sequential phases, beginning with the identification of user needs, followed by an evaluation of the existing design, conceptual development of new features, and culminating in performance testing under actual working conditions.

Each stage of the methodology was carefully designed to ensure that the improvements made were supported by empirical findings and grounded in real user requirements. This structured approach not only facilitates the resolution of technical deficiencies in the original design but also contributes to enhanced user safety, comfort, and operational effectiveness.

The methodology adopted in this study follows a structured process as illustrated in Figure 1. The process begins with the identification of research objectives which define the purpose and scope of the multifunctional wheelbarrow design. This is followed by the conceptual sketching stage where the initial design ideas are translated into freehand sketches to explore form, functionality, and ergonomics. At this stage, a preliminary hand sketch was produced to illustrate the initial concept of the multifunctional wheelbarrow. The sketch provided a visual representation of the proposed design, enabling an early assessment of its overall form, structural configuration and intended functionality. It also served as a medium for exploring alternative design options, particularly with respect to ergonomics, user comfort, and load distribution. Through this stage the potential design limitations and areas for improvement were identified before advancing to the computer-aided design (CAD) modeling phase. The preliminary hand sketch therefore functioned as a critical intermediate step, bridging the transition from conceptual ideation to detailed digital modeling as shown in Figure 2.

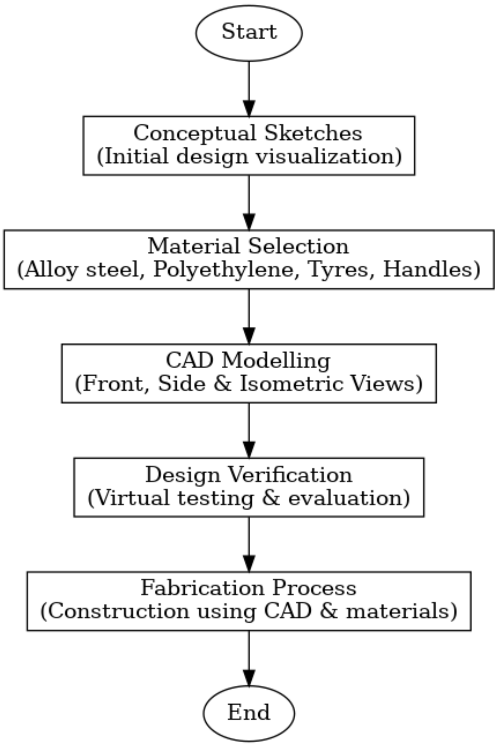

Figure 1. Flowchart of design improvement for the multifunction wheelbarrow.

Figure 2. Preliminary hand sketch of design improvement for multifunctional wheelbarrow.

Following conceptual development, the multifunctional wheelbarrow was designed with particular emphasis on material selection to ensure structural strength, durability, and user comfort. The primary frame and supporting structure were specified in alloy steel, selected for its high strength-to-weight ratio, resistance to deformation under heavy loads, and long-term durability in outdoor applications. The tray was designed using polyethylene plastic, which offers a lightweight yet robust container that is resistant to corrosion, chemical exposure, and environmental degradation. For mobility, four rotatable tyres were incorporated into the design to facilitate smooth maneuverability and enhance stability across varying terrains. Furthermore, the handlebars were fitted with ergonomically designed grips manufactured from soft yet durable material to improve comfort, reduce hand fatigue, and ensure safe handling during extended operation.

The design was further developed into a three-dimensional (3D) model using Autodesk Inventor. This stage enabled precise dimensional control, accurate representation of structural components, and verification of assembly feasibility. The CAD model also provided a platform for evaluating component integration, load distribution, and ergonomic considerations within the overall system. In addition, the digital environment facilitated the simulation of design scenarios, enabling the identification of potential weaknesses and areas requiring refinement prior to fabrication. The design was finally subjected to an evaluation and refinement phase, where its structural integrity, functionality, and user-oriented features were critically reviewed. This ensured that the multifunctional wheelbarrow design not only met the defined objectives but also demonstrated practical applicability and potential for real-world implementation, as illustrated in Figure 3.

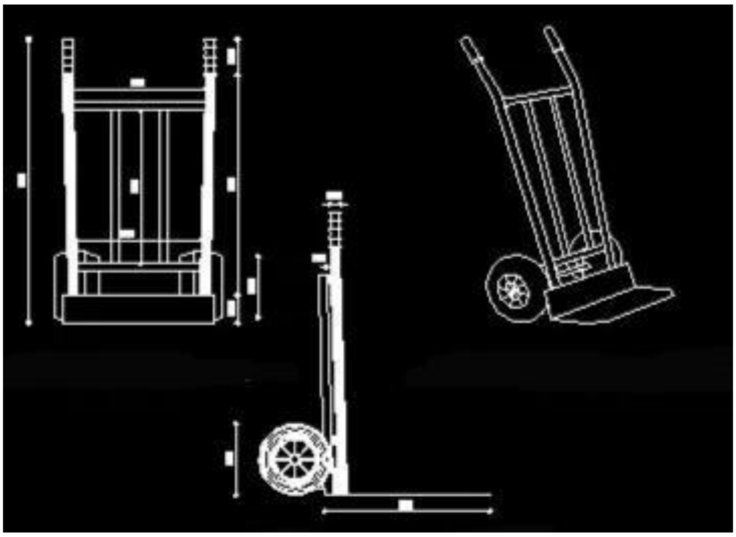

Figure 3. CAD drawing of design improvement for multifunctional wheelbarrow.

3.0 Result

This section presents the outcomes of the design improvement for the multifunction wheelbarrow process, comprising three key phases: analysis of the original design, development of the new design, and performance evaluation. The initial analysis identified several critical limitations in the existing model, including poor load stability, limited manoeuvrability, and inadequate ergonomic features.

Based on these findings, a new design was developed with improved structural elements and user-focused enhancements. The product was then tested in a real workshop environment to evaluate its functional capability and effectiveness under practical working conditions.

Figure 4 presents the newly proposed design features a multifunctional structure that can be reconfigured from a conventional wheelbarrow into a trolley and also a tipping bin. Its key features include a front wheel system with additional support for enhanced stability, a hinged mechanism to enable tipping functionality, and the use of durable materials such as lightweight steel and polymer plastics to ensure strength and longevity under operational loads.

Figure 4. New design Wheelbarrow.

Table 1 summarises the key features integrated into the new design of the multifunctional wheelbarrow, highlighting its operational versatility, structural enhancements and user-centric improvements. Each feature presented in the table corresponds to a specific functional or ergonomic upgrade aimed at addressing the limitations of the conventional wheelbarrow.

Table 1: Features of the new design Multifunctional Wheelbarrow

No.	Design Feature	Functional Description
1	Multifunctional Capability (3 in 1 Design)	Operates in three modes: *wheelbarrow*, *trolley*, and *tipping bin*. - *Wheelbarrow*: Transports bulk materials such as soil, sand, and cement efficiently. - *Trolley*: Adjusted to carry boxed goods or light machinery. - *Tipping Bin*: Integrated hinged system enables safe and controlled unloading, reducing operator strain.
2	Lightweight yet Robust Frame Structure	- Constructed using lightweight steel for high structural integrity without adding excess weight. - The main container is made of durable polymer plastic, offering impact resistance and weatherproof characteristics for indoor and outdoor use.
3	Front Wheel System with Additional Support	- A pneumatic front wheel allows smooth movement and effective shock absorption under heavy loads. - Two rear swivel caster wheels act as stabilisers, particularly useful during tipping or mode transitions, improving balance and directional control.
4	Ergonomic Design for Single-Operator Use	- Dual-position handle design supports ergonomic operation in both wheelbarrow and trolley modes. - The entire unit is operable by a single user, reducing manpower requirements and increasing operational efficiency, which is critical in labour-limited settings.

A total of six application modes have been systematically developed to demonstrate the functional versatility of the redesigned multifunction wheelbarrow. These modes were formulated based on practical load-handling scenarios commonly encountered in workshop and light industrial environments, taking into account factors such as load weight, dimensional height, and the necessity of unloading. The adaptability of the structure, including its modular frame and ergonomic features, enables the wheelbarrow to transition between various configurations depending on task requirements. The detailed operational modes are illustrated in Figures 5 to 10.

In Figure 5, the wheelbarrow operates in its most basic form to facilitate the transport of lightweight loads (<10 kg). This mode is optimal for the movement of small tools, components, or lightweight materials within short distances. Its compactness and manoeuvrability support high-frequency transport cycles, particularly in constrained indoor spaces.

Figure 6 depicts the configuration used for moderately heavy loads (<50 kg) that require unloading. The incorporation of a hinged tipping system ensures safe and controlled discharge of materials such as construction debris or granular substances, while simultaneously minimizing physical strain on the user.

Figure 7 addresses the scenario of transporting tall and heavy items (<50 kg; height <2.5 m). This mode accommodates vertically stacked or oversized loads by maintaining structural balance and allowing for ergonomic unloading, even with a raised center of gravity.

The configuration shown in Figure 8 is designed for carrying very heavy loads (<100 kg) within a secure container. Structural reinforcements in the frame and the use of durable materials ensure safe operation across uneven or semi-rough surfaces, offering improved load integrity and transport reliability.

As illustrated in Figure 9, the wheelbarrow may also be used to transport long and heavy items (<100 kg; height <2.5 m), such as metal rods or construction beams. The open-frame layout provides lateral stability and weight distribution, facilitating the safe movement of elongated materials without compromising balance or control.

Lastly, Figure 10 presents the mode for handling tall but lightweight materials (<20 kg; height <2.5 m). This configuration is suitable for transporting volumetric but low-density items, such as foam packaging, plastic bins, or lightweight fabricated parts, while ensuring vertical clearance and load stability.

Collectively, these application modes illustrate the multifunction wheelbarrow's operational flexibility, its ergonomic and structural responsiveness to varying task demands, and its potential to optimize material handling in real-world technical environments.

Figure 5. Operational Mode 1.

Figure 6. Operational Mode 2.

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Figure 7. Operational Mode 3.

Figure 8. Operational Mode 4.

Figure 9. Operational Mode 5.

Figure 10. Operational Mode 6.

Performance evaluation focused on four main indicators load transfer time, handling efficiency**,** load stability, and reduction of user fatigue. The results demonstrated significant improvements across all aspects, confirming that the redesigned wheelbarrow effectively addresses the limitations of the original model and enhances operational performance in workshop tasks.

To evaluate the effectiveness of the redesigned multifunction wheelbarrow, a user-based assessment was conducted involving 30 respondents (26 male, 4 female). Participants were asked to rate both the original and redesigned models based on four key usability criteria using a 5-point Likert scale. The criteria included stability and practicality, ease of handling, handle comfort, and reduction in physical fatigue. The result is shown in Table 2.

Table 2: Mean scores and percentage improvement between the original wheelbarrow and the redesigned multifunctional wheelbarrow.

No.	Evaluation Criteria	Mean Score (Original)	Mean Score (Redesign)	% Improvement
1	Stability and Practicality/User-friendly	2.8	4.5	60.7%
2	Ease of Handling	3.0	4.6	53.3%
3	Handle Comfort	2.7	4.4	62.9%
4	Reduction in Physical Fatigue	2.5	4.3	72.0%

Table 2 presents a comparative summary of user evaluation scores for both the original and redesigned multifunction wheelbarrow. The analysis indicates substantial improvements across all four assessed criteria, highlighting the effectiveness of the redesign in addressing key operational and ergonomic limitations of the original model.

The most significant enhancement was recorded under the criterion reduction in physical fatigue, which showed a 72.0% increase in mean score. This improvement is attributed to the ergonomic optimization of handle placement, improved weight distribution, and the integration of a front support system, all of which reduce muscular strain during prolonged or repetitive use.

Likewise, the criterion Handle Comfort demonstrated a 62.9% improvement, indicating that the revised dual-position grip design provided better adaptability to user preferences, contributing to overall ease of use and comfort during operation. The Stability and Practicality criterion increased by 60.7%, reflecting the structural reinforcements and multifunctional adaptability introduced in the redesign factors that enhance safety and task versatility in workshop environments.

Ease of handling recorded a 53.3% increase, suggesting that improvements in the wheel system, overall balance, and convertibility between functional modes contributed to better manoeuvrability and control. These findings collectively validate the redesigned product’s performance advantages, as perceived by end users, and reinforce the importance of user-centered engineering design practices in improving manual material handling tools.

Overall, the results underscore that the multifunction wheelbarrow redesign not only met the intended ergonomic and operational objectives but also delivered measurable enhancements in user satisfaction, safety and efficiency.

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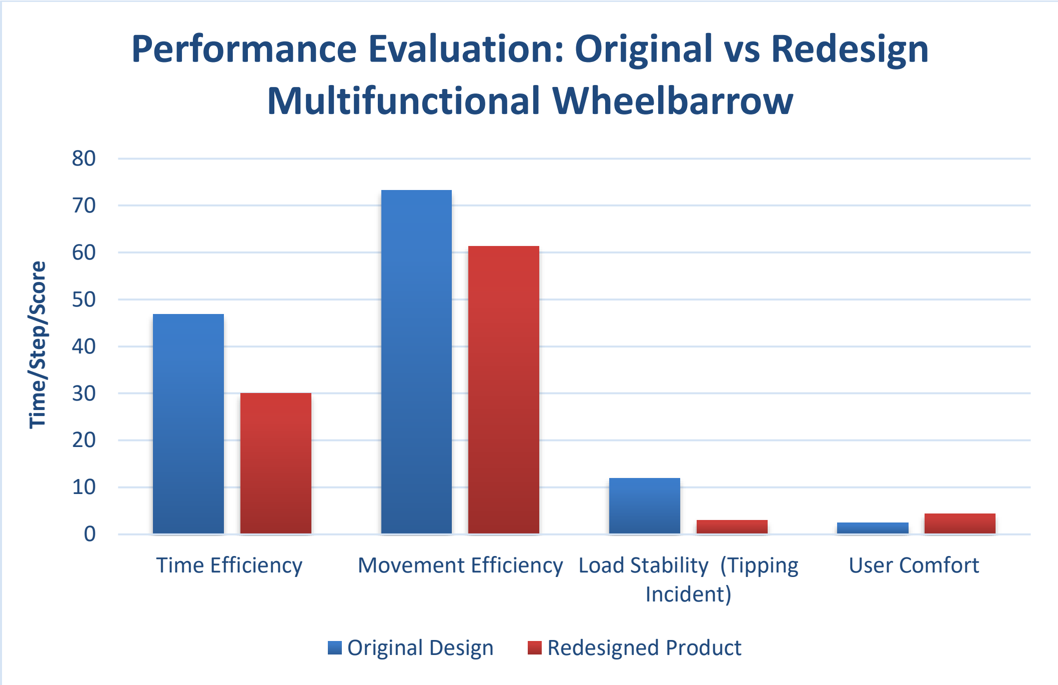

Figure 11. Performance between original wheelbarrow and redesign multifunctional wheelbarrow.

Figure 11 presents the average results from 30 respondents comparing the original and redesigned multifunction wheelbarrow of physical testing to transport a 30kg load over a 50meter distance using a wheelbarrow. Four key criteria were evaluated: time efficiency, movement efficiency, load stability, and user comfort. The overall averages indicate notable improvements across all parameters, validating the ergonomic and functional advantages of the redesigned model.

The comparative analysis between the original and redesigned multifunction wheelbarrow, based on responses from 30 participants, reveals significant ergonomic and functional improvements. Time efficiency increased markedly, with the average load transfer time reduced from 46.86 seconds to 30.06 seconds, representing a 35.85% improvement. Similarly, movement efficiency improved with the step count decreasing from 73.2 to 61.4 steps. A 16.12% reduction indicates smoother handling and reduced physical effort.

Load stability was significantly improved, as evidenced by a 75% reduction in incidents of tipping or imbalance during transport. Furthermore, user comfort scores increased substantially, rising from an average of 2.4 to 4.4 (on a 5-point scale), reflecting better handle design, balance distribution and ease of control. These results collectively demonstrate the success of the redesigned wheelbarrow in addressing the limitations of the original model, particularly in improving operator efficiency, safety and physical comfort in real-world workshop applications.

4.0 Conclusion

This study successfully demonstrated that the redesigned multifunction wheelbarrow offers substantial ergonomic and operational enhancements over the conventional model. The redesign wheelbarrow, developed through a structured engineering design methodology, successfully mitigated the primary limitation of the original model, including inadequate load stability, suboptimal handling efficiency and poor ergonomic performance.

Quantitative analysis of physical performance revealed a 35.85% reduction in task completion time, a 16.12% improvement in movement efficiency (measured via step count), a 75% reduction in tipping incidents, and an 83.33% increase in comfort score. These results validate the effectiveness of the redesigned product in real workshop environments, especially under conditions involving heavy or bulky loads.

In addition to physical testing, user evaluation involving 30 participants (26 male, 4 female) further confirmed the design's user-centric advantages. The redesigned wheelbarrow achieved a 60.7% improvement in perceived stability and practicality, 53.3% improvement in ease of handling, 62.9% increase in handle comfort, and a 72.0% reduction in reported physical fatigue. These improvements indicate not only better technical functionality but also enhanced user satisfaction and operational sustainability.

Overall, the study underscores the importance of combining ergonomic design principles with empirical testing in the development of manual transport equipment. The findings suggest that even traditional tools like wheelbarrows can benefit greatly from design innovation. Future work may explore the integration of smart features (e.g., load sensors, tipping indicators), use of lightweight composite materials, or modular configurations to extend applicability across diverse industrial and construction settings.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the author(s) used OpenAI's ChatGPT to assist in improving the readability and language of the text. All content generated by ChatGPT was subject to thorough review, editing, and revision by the author(s) to ensure its accuracy, completeness, and alignment with the research objectives. The author(s) take full responsibility for the integrity and content of the published work. This declaration complies with ICGESD 2025 guidelines on the use of generative AI in scientific writing.

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