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Anthropometric-Based Ergonomic Design of a Portable Mini Ladder Hoist for Loading and Unloading Operations at Medium-Scale Ports

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Abstract

Loading and unloading activities at small- and medium-scale ports are often performed manually, exposing workers to excessive physical loads, awkward postures, and an increased risk of work-related musculoskeletal disorders (WMSDs). This study aimed to develop an anthropometric-based ergonomic portable mini ladder hoist to improve the safety and efficiency of loading and unloading operations. The study employed a Research and Development (R&D) approach involving anthropometric measurements of 20 stevedores using 16 standing-posture dimensions. The collected data were analyzed using Minitab 19 to determine the mean, standard deviation, and 5th and 95th percentile values, which were used as the basis for ergonomic design. Morphological analysis and a weighted decision matrix were applied to generate and select the optimum design concept. The selected concept was modeled in SolidWorks and evaluated through engineering calculations, including structural strength, wire-rope selection, pulley sizing, and motor power requirements. The final design consisted of a portable wheel-mounted frame fabricated from S235 steel and powered by a 1 HP electric hoist. The ladder hoist was designed to safely support a total lifting load of 320 kg with a lifting height of 3 m. Ergonomic evaluation using the Rapid Entire Body Assessment (REBA) method indicated a reduction in risk level from high-risk manual handling to a medium-risk category after implementation of the proposed design. The novelty of this study lies in the integration of local port-worker anthropometric data, morphological design methods, and mechanical design considerations into the development of a portable ladder hoist. The proposed design provides a practical and cost-effective lifting solution for loading and unloading operations at medium-scale ports and similar material-handling environments.

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1. Introduction

Loading and unloading activities at small- and medium-scale ports are still predominantly performed using manual material handling methods with limited mechanical assistance. In medium-scale ports in Indonesia, such as Lorens Say Port, Maumere, workers frequently handle heavy loads under conditions involving height differences between docks, transport vehicles, and cargo areas. These activities require repetitive lifting, carrying, climbing, and trunk bending, which expose workers to awkward postures, excessive physical exertion, and a high risk of work-related musculoskeletal disorders (WMSDs). Previous studies have reported that manual material handling is closely associated with biomechanical overload, fatigue, and musculoskeletal complaints, particularly when lifting activities are performed repetitively or under non-ergonomic working conditions [1], [2], [3], [4], [5], [6], [7]. In addition, the absence of ergonomically designed lifting aids can reduce operational efficiency and increase the potential for occupational accidents during loading and unloading operations [8], [9], [10].

Research in ergonomic material handling has shifted from merely identifying physical workload toward developing engineering interventions that reduce direct manual handling. Recent studies have applied biomechanical assessment, REBA, RULA, NIOSH-based evaluation, wearable sensors, and online ergonomic assessment systems to evaluate manual

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material handling risks and support ergonomic improvement [1], [2], [3], [11]. These approaches are useful for identifying hazardous postures and quantifying ergonomic risk; however, many studies remain focused on assessment rather than the development of practical lifting equipment. Other studies on material handling system design have emphasized that equipment selection should consider productivity, human factors, cost, mobility, and operational constraints rather than only load transfer capability [12], [13]. Therefore, the design of a lifting aid for port operations should integrate both mechanical performance and ergonomic compatibility.

Anthropometric data play an important role in ergonomic product design because they ensure that equipment dimensions correspond to the physical characteristics of the intended users. In work-equipment design, anthropometry is commonly used to determine working height, reach distance, handle position, clearance, access dimensions, and operating posture [14], [15]. However, many commercially available hoist systems and lifting devices are designed using generic dimensional assumptions and do not consider the anthropometric characteristics of local workers. As a result, important ergonomic parameters such as handle height, reach distance, frame clearance, and control position may not match the users' body dimensions, leading to discomfort, unsafe postures, reduced usability, and inefficient operation.

From a mechanical engineering perspective, the development of a portable ladder hoist for port operations must satisfy multiple design requirements simultaneously, including load-carrying capacity, lifting height, structural strength, stability, portability, ease of operation, manufacturing cost, corrosion resistance, and compliance with applicable safety standards. Previous lifting-equipment studies have demonstrated that the design of hoist systems requires careful consideration of lifting mechanisms, wire ropes, pulleys, load capacity, and structural integrity to ensure safe and reliable operation while preventing component failure [16] In addition, systematic concept development methods such as morphological analysis and computer-aided design (CAD) have been successfully applied in engineering design to generate, evaluate, and optimize alternative product configurations [17]. Material selection also plays a critical role in ensuring equipment durability and service life, particularly in humid and corrosive environments, where inadequate material properties or insufficient structural dimensions may lead to premature failure and increased maintenance requirements [18]. In Indonesia, lifting equipment must comply with the safety requirements stipulated in Permenaker No. 8 of 2020, while lifting components such as wire ropes and hoisting systems should conform to internationally recognized standards, including ASME B30.9. Integrating these mechanical, ergonomic, economic, and regulatory requirements into a single design presents a significant engineering challenge, particularly for portable lifting equipment intended for medium-scale ports with limited operational space and infrastructure.

Although previous studies have discussed manual material handling risks, ergonomic assessment methods, material handling equipment selection, and anthropometric design principles, limited research has systematically integrated standing-posture anthropometric data of port workers into the engineering design of a portable mini ladder hoist for medium-scale port loading and unloading activities. Existing studies generally focus on risk assessment or general lifting equipment design, while the translation of local worker anthropometry into specific hoist-ladder design parameters remains insufficiently addressed. Therefore, a research gap exists in developing a portable hoist ladder that combines anthropometric-based ergonomic dimensioning, morphological concept selection, structural design calculation, and lifting-equipment safety considerations in one integrated design process.

Based on this gap, this study aims to develop an anthropometric-based ergonomic portable mini ladder hoist for loading and unloading operations at medium-scale ports. Specifically, the objectives of this study are: (1) to identify the anthropometric characteristics of stevedoring workers using standing-posture measurements; (2) to translate the 5th and 95th percentile anthropometric values into relevant ergonomic design dimensions; (3) to generate and select the optimum ladder-hoist concept using morphological analysis and a weighted decision matrix; (4) to develop the selected concept into a detailed design using SolidWorks; and (5) to evaluate the final design based on load capacity, frame strength, wire-rope selection, pulley diameter, motor power, and ergonomic risk reduction. The expected outcome of this study is a portable mini ladder hoist design with a safe working capacity of 320 kg, a lifting height of 3 m, and ergonomic dimensions suitable for the majority of port workers. The proposed design is expected to provide a practical engineering solution for

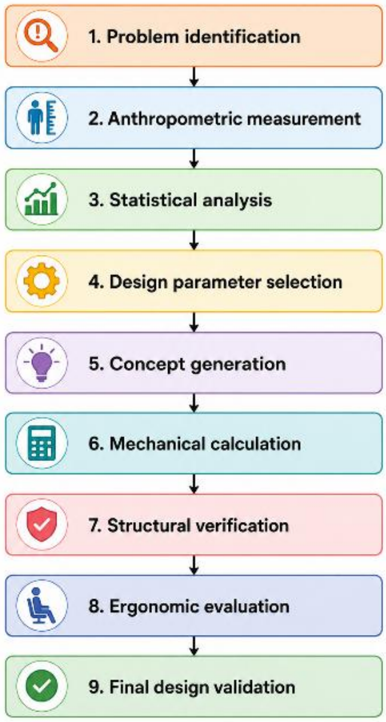

Figure 1. Design process flow

reducing manual handling risk and improving loading and unloading operations in small- and medium-scale port environments.

2. Methods

The portable mini ladder hoist was designed using a morphological analysis approach within a Research and Development (R&D) framework. The design process consisted of identifying operational requirements and design constraints, generating alternative concepts, constructing a morphological chart, synthesizing design concepts, and selecting the optimum concept using a weighted decision matrix. The design alternatives considered variations in the drive system, frame material, structural configuration, mobility system, lifting mechanism, power transmission, safety system, and corrosion protection.

Anthropometric data were collected from 20 stevedores at Lorens Say Port, Maumere, following the measurement procedures of Pheasant and Haslegrave. The data were analyzed using Minitab 19 to determine the mean, standard deviation, and the 5th and 95th percentile values, which were used to establish ergonomic design dimensions. The selected concept was subsequently modeled in SolidWorks and evaluated through engineering calculations, including load capacity, structural strength, wire-rope selection, pulley sizing, and motor power requirements. The design evaluation was performed with reference to Permenaker No. 8 of 2020 and ASME B30.9 to ensure compliance with applicable lifting-equipment safety requirements.

2.1. Design needs and requirements

The design of the portable mini lifting crane hoist emphasizes safety, portability, structural strength, ease of operation, cost efficiency, corrosion resistance, and sufficient loading capacity (250 kg). Safety during lifting operations is considered the primary requirement to minimize the risk of load failure, instability, and operator injury. The crane must also be portable and mobile so that it can be easily moved and positioned in limited working areas, particularly in port or warehouse environments. Structural strength is required to ensure that the frame and lifting components can withstand the target load with an appropriate safety factor. In addition, the design should be simple to operate, economical to manufacture, and resistant to corrosion in marine environments. Therefore, the selected design must combine reliable lifting performance, ergonomic operation, durable material selection, and practical fabrication feasibility.

Table 1. Design alternatives brainstorming.

Design Element	Variant 1	Variant 2	Variant 3	Variant 4
Drive System	Manual (+) Low cost; simple mechanism; no electrical dependency; easy maintenance; suitable for low-capacity operation. (-) High operator fatigue; low lifting speed; limited lifting capacity; inconsistent operation.	Electric hoist (+) High efficiency; stable lifting speed; easy automation; low operator effort; suitable for continuous operation. (-) Requires power supply; higher initial cost; electrical hazards in wet environments.	Hydraulic (+) Very high lifting force; smooth motion; suitable for heavy loads; good motion control. (-) Hydraulic leakage risk; high maintenance; expensive components; sensitive to contamination.	Pneumatic (+) Safe in explosive environments; fast actuation; lightweight system. (-) Unstable pressure; noisy operation; requires compressor; lower lifting precision.
Frame Material	Hollow Steel (+) High strength-to-cost ratio; easy fabrication; widely available; good structural rigidity. (-) Susceptible to corrosion; relatively heavy.	Channel Steel (+) High bending resistance; strong structural support; economical. (-) Higher weight; less aesthetic; difficult portability.		
Structural Configuration	Fixed frame (+) High stability; simple structure; low maintenance. (-) Not portable; limited operational flexibility.	Movable boom (+) Easy relocation; flexible operation; suitable for multiple locations. (-) Lower rigidity; potential stability issues.	Telescopic boom (+) Adjustable height; compact storage; adaptable operation. (-) Complex mechanism; higher manufacturing cost; maintenance required.	Suspended boom (+) Space-saving; easy transportation; compact storage. (-) Reduced structural stiffness; hinge wear risk.
Mobility System	Stationary (+) Maximum stability; simple design; low maintenance. (-) No mobility; limited operational area.	Wheel-mounted (+) Easy movement; flexible positioning; improved operational efficiency. (-) Wheel locking required; reduced stability during lifting.	Rail-mounted (+) Smooth guided movement; stable transportation path; suitable for repetitive loading. (-) Requires rail installation; higher infrastructure cost.	
Safety System	Lock Pin (+) Simple mechanism; low cost; reliable passive safety. (-) Manual engagement required; limited automation.	Emergency Brake (+) Rapid stopping capability; improved operational safety. (-) Higher system complexity; additional maintenance.	Overload Sensor (+) Prevents excessive loading; improves safety monitoring; automatic protection. (-) Requires electrical integration; higher cost.	
Corrosion Protection	Galvanized Coating (+) Good corrosion resistance; economical; durable outdoor protection. (-) Surface damage may reduce protection effectiveness.	Marine Paint (+) Easy application; low cost; customizable coating (-) Requires periodic repainting; limited durability.		

2.2. Design limitations and constraints

After identifying the design requirements, a conceptual design of the equipment was carried out. The design concept was created by considering ergonomics, stability, and reliability of the equipment in lifting loads. The Hoist Ladder design was based on Ministerial Regulation No. 8 of 2020 concerning lifting and transport equipment, as follows:

1. Load Capacity (Article 17 paragraphs 1 and 2)
2. Tool Stability (Article 17 Paragraph 3)
3. Lifting Mechanism
4. Operational Safety (article 18)
5. Equipment Eligibility (Article 24)
6. Use of Environmentally Friendly Materials (Article 5 paragraph 1)
7. Operator Protection Article 19 paragraphs 1 and 2)
8. Marking and information (Article 21)
9. Operation in special environments (Article 16 paragraph 3)

The design of the portable mini lifting crane hoist was developed under several limitations and constraints. The crane is restricted to a specified maximum load capacity and must not be operated beyond its rated lifting capacity. The lifting height must be sufficient

Table 2. Anthropometric data and explanation.

No.	Anthropometric Data	Explanation
D1	Height	The vertical distance from the stepping surface to the very top of the head
D2	Standing eye height	The vertical distance from the floor to the outer corner of the right eye.
D3	Standing shoulder height	The vertical distance from the floor to the protruding shoulder blade when the subject is standing upright.
D4	Standing elbow height	The vertical distance from the floor to the lowest point on the right elbow. The subject stands upright with both arms hanging naturally.
D5a	Standing hip height	The vertical distance from the floor to the right hip when the subject is standing upright.
D5b	Standing waist height	The vertical distance from the floor to the waist.
D6	Height of vertebra	The vertical distance from the floor to the right hand's knuckles *(metacarpals).*
D7	Fingertip height	The vertical distance from the floor to the tip of the middle finger of the right hand *(dactylion)*
D8	Knee/kneecap height	The vertical distance from the floor to the right kneecap.
D9	Height of hand grip upwards in standing position	The subject's right hand was placed upwards with the wrist gripping the cylinder shaft. The height of the hand grip was measured vertically from the floor to the axis of the cylinder shaft.
D10	Forward arm span	The horizontal distance from the shoulder to the tip of the middle finger of the right hand.
D11	Shoulder-hand grip length forward	The hand is positioned straight horizontally forward and gripping the cylinder shaft. This dimension is measured from the shoulder (acromion) to the tip of the right middle finger.
D12	Length of hand grip forward	The hand is positioned straight horizontally forward, gripping the cylinder shaft This dimension is measured from the back of the shoulder (shoulder blade) to the center of the cylinder shaft.
D13	Length of arm span to the side	The length dimension of the arm span to the side is measured from the maximum distance from the tip of the middle finger of the right hand to the tip of the middle finger of the left hand.
D14	Elbow span length	The upper arms and elbows of both hands are folded/bent tightly and then stretched out to the sides with the upper and lower arms forming a perpendicular axis to the body. This dimension is measured from the tip of the right elbow to the tip of the left elbow.
D15	Weight	The subject's body weight was measured using a weight scale.

for loading and unloading activities while maintaining structural stability and safe load movement. Since the equipment is intended for use in limited working areas such as ports, docks, warehouses, or loading zones, the design must be compact, portable, and easy to reposition. Material selection is limited to locally available and affordable materials that provide adequate strength, durability, and corrosion resistance in humid or marine environments. The manufacturing cost must remain low by using simple structural profiles, standard components, and common fabrication methods such as welding and bolting. In addition, the design must consider relevant safety requirements for lifting equipment, including structural safety factors, load stability, operator protection, and the use of reliable lifting components. These constraints ensure that the final design is practical, safe, economical, and suitable for real operational conditions.

2.3. Brainstorming of design alternatives

The portable mini ladder hoist was developed using a morphological analysis approach. Design alternatives were generated based on the functional requirements, operational needs, and design constraints identified during the preliminary design stage. The analysis considered the main subsystems of the equipment, including the drive system, frame material, structural configuration, mobility system, lifting mechanism, power transmission, safety system, and corrosion protection. The resulting design concepts were evaluated against criteria related to safety, portability, structural strength, ease of operation, manufacturing cost, corrosion resistance, and load-carrying capability. The design alternatives generated through the morphological analysis are summarized in Table 1.

2.4. Anthropometric measurements

Anthropometric data were collected from 20 stevedores using standing posture measurements based on the methodology proposed by Panero et al. [15] and Pheasant et al. [14]. A total of 16 anthropometric dimensions relevant to the ergonomic design of the ladder hoist were measured. These dimensions were selected to represent the body characteristics associated with reach, clearance, working posture, and equipment operation. The definitions of the measured dimensions are summarized in Table 2.

These measurements were subsequently analyzed to determine the mean, standard deviation, and selected percentiles, which were used to establish the ergonomic dimensions of the proposed ladder hoist design.

3. Results and Discussion

The portable mini ladder hoist was developed using a morphological analysis approach within a Research and Development (R&D) framework. This section presents the design process, concept selection, and technical considerations of the proposed design.

3.1. Synthesized design concepts

The morphological analysis generated four feasible design concepts by combining alternative solutions for the drive system, frame material, structural configuration, and mobility system. Each concept represents a different balance between structural performance, operational efficiency, portability, and manufacturing cost. The synthesized design concepts are summarized in Table 3.

Alternative A emphasizes simplicity and low manufacturing cost through a manual lifting mechanism and stationary structure. Alternative B combines an electric hoist with a lightweight hollow-steel frame and wheel-mounted configuration to improve mobility and ease of operation. Alternative C prioritizes lifting capacity and structural strength through a hydraulic drive system and larger frame section. Alternative D employs a pneumatic drive system with a portable frame configuration, offering an alternative solution for applications requiring reduced electrical dependency. These concepts were subsequently evaluated using a weighted decision matrix to determine the most suitable design for further development.

3.2. Weighted decision matrix evaluation

The design concepts generated from the morphological analysis were evaluated using a weighted decision matrix, as shown on Table 4. The evaluation criteria consisted of safety (25%), structural strength (20%), portability and mobility (15%), ease of operation (15%), manufacturing cost (10%), corrosion resistance (5%), and load capacity (10%). Alternative B achieved the highest weighted score of 4.45, followed by Alternative C (4.10), Alternative D (3.20), and Alternative A (2.55). Alternative B was selected as the final design because it provides the best balance between safety, structural performance, portability, operational efficiency, and load-carrying capability.

Table 3. Synthesized design concepts

Alternative	Design Configuration
A	Manual drive system, frame U-channel steel frame, raised boom, stationary frame
B	Electric hoist, 40 × 40 mm rectangular hollow steel, fixed boom, portable wheel-mounted frame
C	Hydraulic drive system, 80 × 40 mm rectangular hollow steel frame, fixed boom, portable wheel-mounted frame
D	Pneumatic drive system, C-channel steel frame, fixed boom, portable wheel-mounted frame

Table 4. Concept selection matrix for portable mini ladder hoist.

Evaluation Criteria	Weight (%)	Alternative A	Alternative B	Alternative C	Alternative D
Safety	25	2	5	4	3
Structural Strength	20	3	4	5	4
Portability & Mobility	15	1	5	4	4
Ease of Operation	15	2	5	4	3
Manufacturing Cost	10	5	3	2	2
Corrosion Resistance	5	3	3	3	3
Load Capacity	10	2	4	5	3
Weighted Score	100	2.55	4.45	4.1	3.2
Ranking		4	1	2	3

Although Alternative A offers the lowest manufacturing cost, its limited mobility and dependence on manual operation reduce its suitability for loading and unloading activities. Alternative C provides excellent lifting performance but requires a more complex hydraulic system with higher manufacturing and maintenance costs. Alternative D offers acceptable mobility but is less practical due to its dependence on a compressed-air supply system. Therefore, Alternative B was selected for further detailed design, engineering calculations, and ergonomic evaluation.

3.3. Anthropometric analysis

A summary of the anthropometric measurements obtained from 20 stevedores is presented in Table 5. The data are reported as the mean, standard deviation (SD), and the 5th and 95th percentiles, which were used as the basis for ergonomic design. The measured dimensions represent the body characteristics of the target user population and provide the design envelope for the proposed ladder hoist.

The results indicate that the workers had a mean stature of 167.0 cm, an elbow height of 104.6 cm, a standing hand-grip height of 192.6 cm, and a forward reach distance of 72.0 cm. The observed variability among workers highlights the need for a design that accommodates a wide range of body dimensions. Therefore, the 5th and 95th percentile values were adopted to ensure that the equipment can be safely and comfortably operated by the majority of users.

In the design process, the anthropometric dimensions were translated into engineering parameters. Reach-related dimensions, such as forward hand reach and standing hand-grip

Table 5. Results of Analysis of Mean, SD, P5 and P95

No	Measurement	Mean	SD	P5	P95
1.	Height	167.0	6.9	156.0	177.6
2.	Eye Height	157.3	6.8	147.0	169.0
3.	Shoulder Height	139.0	5.2	130.1	148.2
4.	Elbow Height	104.6	7.6	87.4	115.4
5.	Hip Height	84.6	4.3	77.8	93.9
6.	Waist Height	94.0	6.5	83.7	106.8
7.	Bone Height (Middle Body)	73.2	5.7	64.0	83.0
8.	Fingertip Height	62.7	4.8	54.7	73.1
9.	Knee Height	46.9	4.4	42.3	57.4
10.	Hand Grip Height When Standing	192.6	14.0	170.1	212.0
11.	Forward Hand Reach	72.0	4.4	63.3	77.9
12.	Shoulder Length to Forward Grip	65.3	4.9	57.2	71.5
13.	Forward Grip Length	71.1	4.2	63.1	77.3
14.	Hand Reach to the Side	168.8	8.1	157.3	183.3
15.	Elbow Span Length	85.5	4.6	76.9	93.0
16.	Weight	66.2	16.3	49.8	87.7

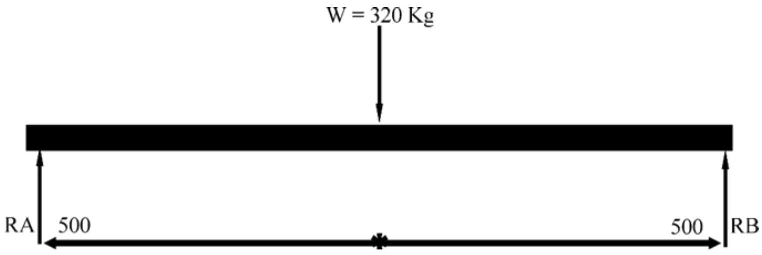

Figure 2. Frame free body diagram.

height, were used to determine the operating zone and handle locations, while stature, shoulder height, and elbow height were considered in establishing the overall geometry and working posture requirements. The percentile-based approach was selected because ergonomic compatibility is determined by the ability of a design to accommodate user variability rather than by statistical significance testing.

3.4. Ladder frame structural design

The selected ladder hoist was designed to safely lift a nominal payload of 250 kg under typical loading and unloading operations. To account for dynamic effects during lifting, an additional design allowance of 10% was applied, resulting in a design load of 275 kg. Including the weight of the trolley assembly (45 kg), the total lifting load was determined to be 320 kg (3.14 kN).

The wire rope system was designed in accordance with ASME B30.9 recommendations. Considering pulley and rope transmission efficiencies of 0.951 and 0.971, respectively, the maximum rope tension was calculated as 346.7 kg. A safety factor of 3 was adopted for rope selection, resulting in a minimum required breaking load of 1,040 kg. Based on these requirements, a 6×19 steel wire rope with a diameter of 4 mm and a rated breaking load of 12.5 kN was selected.

The pulley diameter was determined using the standard relationship between pulley diameter and rope diameter:

$$D_{pulley} = k\, D_{rope} \tag{1}$$

where (k=20) is the design factor recommended for lifting applications and D_{rope}= 4 mm. The resulting pulley diameter was 80 mm.

The lifting system is powered by a 1 HP (745.7 W) electric hoist, which satisfies the power requirement for lifting the design load. To enhance operational safety, the hoist system incorporates limit switches and an emergency stop mechanism.

The main structural members consist of U-channel steel (UNP 80 × 45 × 5 mm) manufactured from S235 structural steel in accordance with ASTM A36 and SNI 07-0052-2006. The frame stand and trolley structure use 40 × 40 × 2 mm hollow steel sections. Structural analysis indicated that the maximum reaction force acting on each side of the frame was approximately 1.6 kN.

The structural capacity of the selected material was evaluated based on its yield strength:

$$F_y = \sigma_y\, A \tag{2}$$

where σ_y= 235 MPa and A = 975 mm^2. The calculated yield load capacity was 229.1 kN, which is substantially greater than the maximum design load of 3.14 kN.

Therefore, the selected frame material provides an adequate margin of safety for the intended operating conditions. The design was evaluated using the following criteria: (1) load-carrying capacity of at least 320 kg, (2) compliance with the required structural safety factor, (3) ergonomic suitability based on anthropometric dimensions and REBA assessment, (4) ease of operation, and (5) potential improvement in loading and unloading efficiency. Under these criteria, the proposed ladder hoist satisfies the mechanical and operational requirements for medium-scale port applications.

3.5. Final design configuration

The selected ladder hoist design was developed based on the highest-scoring concept obtained from the morphological analysis and weighted decision matrix evaluation. The final

Table 6. Summary of key design parameters.

Features	Specification
Design payload	250 kg
Dynamic load allowance	10%
Total design load	320 kg (3.14 kN)
Wire rope type	6×19 steel wire rope
Wire rope diameter	4 mm
Minimum required breaking load	1,040 kg
Selected rope breaking load	12.5 kN
Pulley diameter	80 mm
Motor power	1 HP (745.7 W)
Frame material	S235 Steel
Main frame section	UNP 80 × 45 × 5 mm
Secondary frame section	40 × 40 × 2 mm hollow steel
Yield load capacity	229.1 kN
Safety factor	2–3

configuration consists of a wheel-mounted portable frame fabricated from S235 steel, a 1 HP electric hoist, a 6×19 steel wire rope with a diameter of 4 mm, and an 80 mm pulley system. The structure incorporates safety features including limit switches and an emergency stop mechanism to improve operational safety during lifting activities.

Table 6 summarizes the principal design parameters of the proposed ladder hoist. The design is capable of supporting a total lifting load of 320 kg, including the payload and lifting accessories, while maintaining the required structural safety margin. The selected materials and component specifications were chosen to satisfy the requirements for strength, portability, ease of fabrication, and operation in a marine environment.

Figure 3 illustrates the major structural components of the ladder hoist, including the fit plate, main frame, frame stand, and goods bin. The complete assembly is presented in Figure 4. The final design provides a compact and portable lifting system suitable for loading and unloading operations at medium-scale ports, where conventional lifting equipment may be unavailable or economically impractical.

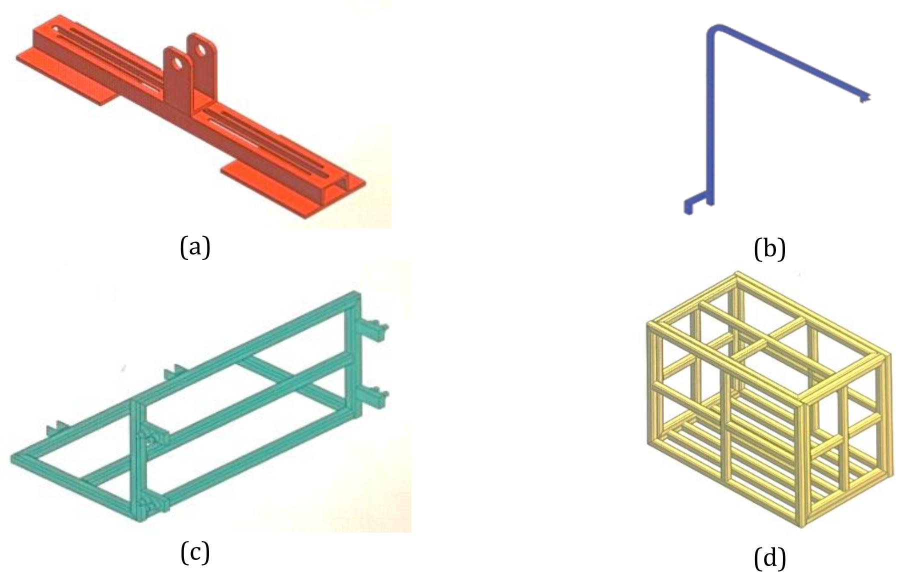

Figure 3. Components of the proposed portable mini ladder hoist: (a) Fit plate used for component connection and reinforcement, (b) Main frame supporting the lifting structure, (c) Frame stand providing structural stability, and (d) Goods bin used for load handling during lifting operations.

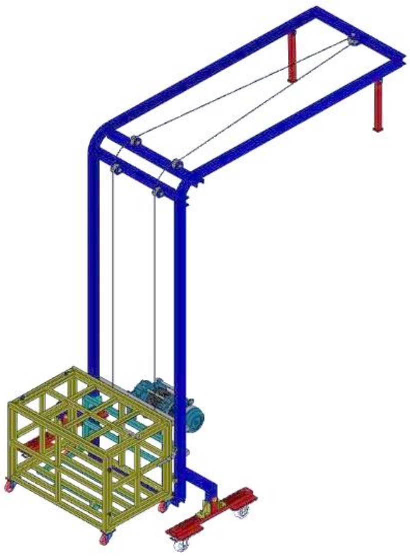

Figure 4. Complete assembly of the proposed portable mini ladder hoist showing the integration of the main frame, frame stand, lifting mechanism, mobility system, and load-handling components.

The estimated production cost of the proposed ladder hoist is presented in Table 7. The total material cost was IDR 8,282,000 based on component prices collected in 2024. The largest cost contributors were the electric hoist, caster wheels, and structural steel components, which together accounted for the majority of the total manufacturing cost.

The use of commercially available structural steel sections, standard lifting components, and conventional fabrication methods such as cutting, welding, and bolting contributes to the economic feasibility of the design. Compared with larger fixed lifting systems commonly used in industrial facilities, the proposed ladder hoist offers a lower initial investment while maintaining adequate lifting capacity and operational flexibility.

The relatively low manufacturing cost, combined with the portable configuration and moderate load capacity, makes the proposed design suitable for small- and medium-scale ports, warehouses, and loading facilities. Future studies should include prototype fabrication and field testing to quantify operational efficiency, productivity improvement, and ergonomic risk reduction under actual working conditions.

Table 7. Estimated material cost for ladder hoist fabrication (reference year 2024).

No	Type Material	Quantity	Specification	Unit Price (IDR)	Total Price (IDR)
1.	DC Electric Hoist	1 unit	1 HP	1,649,000	1,649,000
2.	Steel Rod	6 m	Ø 1 inch	151,333/m	908,000
3.	Rectangular Hollow Steel	30 m	40 × 40 × 2 mm	120,000/m	3,600,000
4.	U-Channel Steel (UNP)	12 m	80 × 45 × 5 mm	470,000/6 m	940,000
5.	V-Belt Pulley	1 pc	Ø 80 mm	657,000	657,000
6.	Bolt M12	36 pcs	M12 × 50 mm	3,500	126,000
7.	Bearing 6204	8 pcs	Standard	66,600	532,800
8.	Swivel Caster Wheel	4 pcs	Ø 3 inch	270,000	1,080,000
9.	Swivel Caster Wheel with Brake	4 pcs	Ø 3 inch	526,000	2,104,000
10.	Steel Plate	1 sheet	1200 × 2400 × 10 mm	304,500	304,500
11.	V-Belt Pulley	4 pcs	Ø 40 mm	50,000	200,000
12.	Limit Switch	4 pcs	4:00 AM	22,500	90,000
13.	Emergency Stop Switch	1 pc	Standard	31,000	31,000
				Total cost	8,282,000

The final product concept selected from the morphological analysis is a portable mini ladder hoist equipped with a 1 HP electric hoist and a wheel-mounted frame. This configuration was selected because it provides a balanced solution between lifting performance, portability, operational simplicity, and manufacturing cost. The electric hoist reduces dependence on manual lifting force, while the portable frame enables the equipment to be repositioned according to the loading and unloading location. The use of an S235 steel frame, 6×19 steel wire rope, and 80 mm pulley provides adequate structural capacity for the target design load of 320 kg.

The selection of a powered lifting mechanism is consistent with the objective of reducing physical workload in manual material handling. Previous studies have shown that manual lifting activities are strongly associated with biomechanical overload, awkward posture, and musculoskeletal disorder risk, especially when workers repeatedly lift, carry, or transfer loads under non-ergonomic conditions [1], [2], [3], [4]. Giannini et al. [3] emphasized that workers involved in manual material handling are exposed to high biomechanical risk, while Leggieri et al. [2] highlighted the importance of ergonomic assessment methods such as NIOSH, RULA, and related posture-based tools to reduce the risk of work-related musculoskeletal disorders. Therefore, transferring the lifting task from the worker to the hoist mechanism provides a logical ergonomic improvement because it reduces direct manual force and minimizes unsafe body posture during loading activities.

Compared with fixed or rail-mounted hoist systems, the proposed ladder hoist offers better operational flexibility. Fixed hoists are effective for repetitive lifting along a defined path, but they require permanent installation and are less adaptable to variable loading points. Waseem et al. [13] reported that hoists are useful for transferring heavy loads from one point to another, but their installation is commonly linked to fixed rails or defined movement paths. In contrast, the proposed design uses a wheel-mounted frame, making it more suitable for small- and medium-scale ports where loading points may vary and permanent lifting infrastructure may not be available.

The design selection process is also consistent with studies on material-handling equipment selection, which emphasize that equipment should be chosen based on multiple criteria rather than lifting capacity alone. Telek and Košťál [19] stated that material-handling equipment selection should consider the handling task, operating limitations, and equipment parameters. Similarly, Chatterjee and Chakraborty [20] noted that selecting suitable material-handling equipment is complex because criteria such as cost, safety, flexibility, serviceability, and speed must be considered simultaneously. In this study, the selected concept was evaluated using criteria including safety, structural strength, portability, ease of operation, manufacturing cost, corrosion resistance, and loading capacity. This strengthens the justification for selecting the electric wheel-mounted ladder hoist as the final concept.

In comparison with scissor lift systems and larger lifting platforms, the proposed ladder hoist has a simpler mechanical configuration and lower fabrication complexity. Scissor lifts provide vertical lifting capability but generally require more complex linkages, a larger platform structure, and more precise fabrication. The proposed design uses a simpler frame-hoist configuration, making it more feasible for local manufacturing, maintenance, and operation in port environments with limited facilities. This supports the intended application of the design as a practical and economical lifting aid for medium-scale port loading and unloading operations.

4. Conclusions

This study developed an anthropometric-based ergonomic portable mini ladder hoist for loading and unloading operations at medium-scale ports using a Research and Development (R&D) approach. Anthropometric measurements of 20 stevedores were analyzed using a percentile-based method and integrated into the engineering design process through morphological analysis, concept selection, and mechanical design evaluation. The selected design consists of a portable wheel-mounted frame fabricated from S235 steel and powered by a 1 HP electric hoist. The proposed system was designed to safely support a total lifting load of 320 kg with a lifting height of 3 m while satisfying the structural and safety requirements specified in Permenaker No. 8 of 2020 and ASME B30.9. The application of the 5th and 95th percentile anthropometric approach ensured that the equipment dimensions accommodate the majority of port workers. Ergonomic evaluation using the REBA method indicated a reduction in occupational risk from the high-risk category associated with manual handling to the medium-risk category after implementation of the proposed design. The study demonstrates that integrating worker anthropometry with mechanical design principles can produce a safer and more ergonomic lifting aid for port operations. The proposed ladder hoist provides a practical and economically feasible solution for loading and unloading activities in ports and similar material-handling environments with limited mechanization. Future work should focus on prototype fabrication, experimental load testing, and field validation to quantify improvements in productivity, operational efficiency, and ergonomic performance under actual working conditions.

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