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Enhancing Safety and Accessibility for Wheelchair Users in Traditional Tuna Fishing Boats

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ABSTRACT

Traditional Sekoci tuna boats lack accessibility features, creating significant challenges for wheelchair users. This study addresses these limitations by applying universal design principles to redesign Sekoci boats, emphasizing accessibility, safety, and operational efficiency. Key innovations include wheelchair-specific safety features, ADA-compliant ramps, hydraulic lifts, wider pathways, and optimized cabin and restroom layouts. Using Bentley Maxsurf Academic Software for stability and motion, stability analysis confirmed compliance with IMO standards under full-load conditions. Seakeeping analysis evaluated vessel motion in head seas and quartering head seas at 0 and 7 knots, ensuring stability and usability under varying conditions. The results demonstrate that the redesigned vessel enhances accessibility and safety without compromising operational performance, offering an inclusive solution for wheelchair users. This study advances barrier-free design in small-scale fisheries, promoting equity and inclusivity in maritime operations. Future research should focus on real-world testing to refine the design and establish guidelines for accessible fishing vessels.

1. INTRODUCTION

Fishing vessels, such as Sekoci tuna boats in Indonesia, are vital to coastal livelihoods but often lack accessibility features for individuals with disabilities, including wheelchair users. Key challenges include narrow pathways, uneven decks, and inadequate safety measures, with adaptations for wheelchair users remaining underexplored [1]. Assistive technologies must align with specific contexts, making their application in fishing vessels critical [2]. Progress in accessibility design for public spaces suggests potential for similar advancements in maritime applications, supported by policy-driven reforms promoting inclusive practices [3, 4].

Universal design principles, when applied to marine environments, require theoretical extension and practical adaptability to account for dynamic conditions, including wave-induced motion and limited spatial configurations [5]. Inclusive design must address unique ergonomic challenges to develop user-centric solutions tailored to marine contexts [6]. Adaptability mechanisms, such as modular and adjustable features, are crucial to ensuring the feasibility and resilience of these designs in varying maritime conditions [7].

Accessibility features like anti-slip surfaces, handrails, ramps, and accessible pathways enhance inclusivity and improve safety and operational efficiency. However, structural limitations in traditional vessels pose challenges, emphasizing the need for feasibility studies to validate performance [8]. Economic and educational barriers further hinder the adoption of universal design, with multi-mold designs prioritizing cost-effectiveness often conflicting with accessibility needs [9]. Limited training in universal design principles and the prioritization of technological features, such as navigation systems, further complicate integration [10, 11].

Research in other fields shows that universal design can lead to high satisfaction rates exceeding 80% among disabled users when prioritizing comfort and effectiveness [12, 13]. However, moderate satisfaction levels (60–70%) highlight the need for improvements in maneuverability and durability [14, 15]. Features like accessible pathways and stable handrails improve perceived security and usability, leading to better satisfaction outcomes [16]. Although specific data on wheelchair users in marine environments is limited, statistical evaluations of redesigned vessel schemes can provide persuasive evidence of their adaptability and effectiveness.

Despite the recognition of universal design principles, their application in traditional fishing vessels remains underexplored. This study addresses this gap by applying universal design principles to redesign Sekoci tuna boats for greater inclusivity while maintaining operational efficiency. Innovations include wheelchair-specific safety features, such as anchoring systems and accessible fishing tools, validated through computational modeling and stability analyses.

The purpose of this study is to enhance the accessibility and safety of Sekoci tuna fishing boats for wheelchair users. By developing inclusive vessel designs aligned with international safety standards, this research addresses critical barriers to accessibility in small-scale fisheries. These findings contribute to promoting equity and inclusivity in the maritime sector and aim to set a model for barrier-free fishing vessel design, fostering greater participation of disabled individuals and advancing the global agenda for inclusive maritime practices.

2. METHOD

This study employed a comprehensive approach combining parametric design and computational simulation to enhance the accessibility and safety of traditional Sekoci fishing boats for wheelchair users. The methodology is structured to ensure reproducibility and clarity, with detailed descriptions of the design process, computational modeling, simulation analysis, and validation procedures.

2.1 Data collection and redesign process

The research began with a field survey to collect data on the existing Sekoci design, focusing on usability challenges such as narrow pathways, uneven decks, and inadequate safety features [17]. Measurements of vessel dimensions were recorded, and usability issues were documented. Interviews and feedback sessions with wheelchair users and local fishing communities identified user requirements and operational challenges [18]. This information informed the redesign process.

The parametric design utilized CAD software to optimize the deck layout for wheelchair accessibility while maintaining the vessel's original dimensions, including length and beam. Key variables included wheelchair dimensions, maneuvering radius for turns, and minimum pathway width. A railing wheelchair system was selected due to its reduced spatial requirements compared to conventional wheelchairs. Four alternative vessel layouts were proposed, incorporating features such as anti-slip surfaces, ramps, widened pathways, handrails, and wheelchair anchoring systems. These modifications were conceptualized based on universal design principles, with adjustments for maritime contexts [19, 20].

2.2 Computational modeling and simulation

The feasibility of the redesigned vessel layouts was verified through computational modeling and simulation using Bentley Maxsurf Academic Software for stability and motion. These tools provided quantitative analyses of the vessel's stability and seakeeping performance under various conditions [21, 22].

(1) Stability Analysis:

Stability analysis was conducted under a full load condition, including five crew members, one wheelchair user, and a fish load of 2.5 tons. The analysis followed IMO stability criteria (A.749(18), Ch. 3), assessing parameters such as GZ curves, righting moments, and angles of vanishing stability to ensure the vessel maintained adequate safety margins under calm water conditions.

(2) Seakeeping Analysis:

Seakeeping performance was analyzed under two vessel speeds:

·0 knots (representing a stationary vessel in port or during fishing operations).

·7 knots (representing the vessel at full operational speed).

·The analysis evaluated vessel motion in two wave conditions:

·Head seas (waves approaching directly from the bow).

·Quartering head seas (waves approaching at a 45° angle from the bow).

Parameters such as heave, pitch, and roll responses were measured at different wave frequencies to assess motion characteristics and their implications for wheelchair users. Repetitions were conducted under various conditions to analyze the most critical scenarios for stability and seakeeping performance. The readiness of the design for real-world application on fishing vessels will be validated through experimental testing on actual vessels in future research phases.

2.3 Stakeholder feedback and validation

Stakeholder feedback was integrated into an iterative evaluation process to ensure the practicality and usability of the designs. Fishing community members and accessibility experts reviewed the proposed layouts and provided insights to refine the designs. A comparative analysis of the four alternative designs was conducted to identify the optimal balance between safety, operational efficiency, and user satisfaction [23]. Modifications to fishing tools, including fishing pole holders, strong-arm supports, harness systems, and electric reels, were evaluated for usability by wheelchair users [24].

2.4 Study limitations

At this stage, the research is limited to computational modeling and simulation. Experimental testing, including physical prototypes and trials with wheelchair users, is planned for future research phases to validate real-world performance and usability. This systematic approach ensures that the proposed methods are transparent, reproducible, and aligned with international safety standards.

3. RESULTS AND DISCUSSIONS

3.1 Traditional design (Existing design)

The current design of Sekoci fishing boats in Sendangbiru (Figure 1) presents significant challenges for wheelchair users due to its traditional layout. These boats feature narrow pathways, uneven deck surfaces, and a lack of safety features, such as handrails or anchoring points, which are critical for ensuring mobility and safety for individuals with disabilities. The absence of ramps and other accessibility considerations further limits the usability of these vessels for wheelchair users.

The redrawn design of Sekoci fishing boats (Figure 2) incorporates features such as anti-slip surfaces, widened pathways, handrails, and accessible ramps to enhance usability for wheelchair users. The redesign also includes wheelchair anchoring systems, ensuring secure positioning during operations in varying sea conditions. Stability analyses validate that these modifications do not compromise vessel performance, maintaining balance and seakeeping capabilities even with added features.

This contrast between the existing and redesigned vessels highlights the critical need for inclusive designs in traditional fishing boats. The improved layout ensures that the boats are not only safe and accessible for wheelchair users but also maintain operational efficiency. These findings underscore the importance of addressing accessibility in maritime design, promoting equity and safety in fishing operations.

Figure 1. Line fishing vessel in Sendangbiru

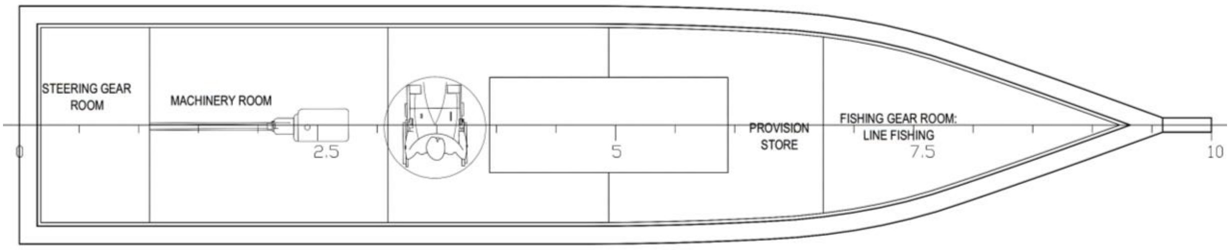

Figure 2. Wheelchair user on existing fishing vessel deck

3.2 Deck layout

The redesigned deck layout addresses significant accessibility barriers by ensuring adequate maneuvering space for wheelchair users. The existing deck configurations with narrow pathways and obstructions limit mobility and participation in fishing operations [25]. By implementing wider pathways and removing unnecessary obstacles, the redesign allows sufficient turning radii for wheelchairs, which is critical for independent mobility. For instance, Figure 2 illustrates the insufficient space in the current layout, highlighting the challenges wheelchair users face in turning or maneuvering effectively.

Studies emphasize the importance of spatial standards to support maneuverability in confined environments (Figure 3). For example, standardized dimensions play a crucial role in ensuring safety and performance, directly relating to maneuverability in confined spaces [26]. Furthermore, it is noted that many wheelchairs exceed standard dimensions, leading to insufficient space for maneuvering in securement areas [27, 28]. This advancement makes the design more inclusive compared to traditional fishing vessels, where spatial constraints often hinder wheelchair accessibility.

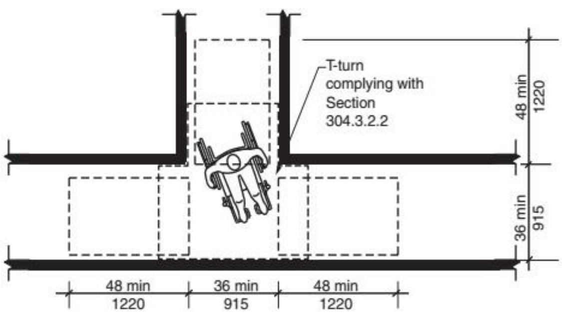

Figure 3. Maneuvering access of wheelchair [28]

3.3 Access points

The addition of ramps and hydraulic lifts significantly enhances accessibility and safety for wheelchair users, addressing challenges posed by steep steps and limited entry points in traditional Sekoci fishing boats. However, effective implementation of these features requires careful consideration of design standards and user needs. Research highlights that while ramps are intended to facilitate access, poorly designed ramps can inadvertently create barriers. For instance, inappropriate slopes or construction can lead to increased musculoskeletal strain and physical exertion for users [29, 30]. Steep ramps can also exacerbate usability issues, making boarding and disembarking more challenging for wheelchair users [31].

Additionally, poorly designed ramps can negatively affect the sense of security and social inclusion among wheelchair users, highlighting the psychological impact of inadequate accessibility measures [32]. To genuinely improve usability, ramps must adhere to proper slope gradients and ergonomic standards, ensuring smooth and safe transitions. Furthermore, the inclusion of hydraulic lifts provides an alternative for scenarios where ramps may not fully meet user needs, offering a more adaptable solution for varying wheelchair dimensions and operational conditions.

Some vessels have successfully implemented ramp doors and hydraulic systems manufactured specifically for wheelchair access, demonstrating the practicality of these features in real-world applications. Examples of such systems are shown in Figure 4 and Figure 5, illustrating their effectiveness in facilitating seamless boarding and disembarking for wheelchair users.

Figure 4. Hydraulic lift for disabled [33]

Figure 5. Ramp for access point wheelchair [34]

3.4 Interior design

The interior redesign of cabins and restrooms prioritizes accessibility by incorporating wider doorways and optimized layouts to allow wheelchair users to navigate independently. However, research emphasizes that adhering solely to minimum accessibility standards may not suffice to meet the diverse needs of all wheelchair users. For instance, what works for younger or less impaired wheelchair users may be unsuitable for older individuals or those with severe disabilities, underscoring the limitations of a one-size-fits-all approach [35].

Restroom designs also pose significant challenges. Features like push doors can hinder independence, revealing persistent barriers even in improved designs [36]. Similarly, many existing room layouts fail to go beyond legislative requirements, falling short of ensuring true accessibility [37]. These findings suggest that effective interior redesigns must go beyond compliance with standards, addressing the diverse physical abilities and preferences of all wheelchair users. By adjusting equipment placement to reachable heights and refining layouts, the redesigned interiors aim to provide a more inclusive and user-friendly environment. However, achieving genuine accessibility requires a comprehensive and user-centered approach that considers the varying needs of wheelchair users across different scenarios. Figure 6 showcases the redesigned interior layout, highlighting expanded doorways and strategically positioned equipment for improved accessibility. These improvements ensure greater independence and usability for wheelchair users, offering a distinct advantage over previous designs and meeting modern accessibility standards.

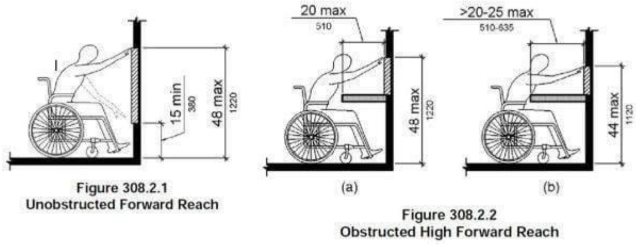

Figure 6. Interior design and placement equipment for wheelchair users [28]

3.5 Safety features

Key safety features include the integration of wheelchair anchoring systems, handrails, and non-slip flooring, which address critical risks during vessel operations. Traditional designs lack secure anchoring systems, increasing accident risks for wheelchair users, particularly in dynamic sea conditions [38]. Advanced anchoring systems enhance user stability during vessel movement, especially in rough sea conditions, by preventing unwanted displacement of wheelchairs [39]. The addition of handrails and non-slip flooring further ensures safety, reducing the risk of falls and improving user confidence during operations [40]. Figure 7 highlights these critical safety features, showcasing their implementation on the redesigned vessel to create a safer and more stable environment for wheelchair users. The redesign provides significant safety improvements compared to conventional vessels, ensuring better compliance with modern accessibility and safety standards [41].

Figure 7. Anti slip deck and ramp for wheelchair users [42]

3.6 Control stations

The redesigned control stations integrate flexible and wireless control technologies, enabling wheelchair users to operate the vessel independently from their seated position. Traditional navigation systems on vessel decks present significant challenges for wheelchair users due to inaccessible heights, confined spaces, and environmental barriers [43]. The inclusion of wireless control systems allows users to access and operate navigation instruments remotely, significantly enhancing usability and independence. For instance, wireless interfaces reduce the reliance on fixed panels and facilitate navigation even in complex environments, as demonstrated in maritime accessibility studies [44].

Research has shown that inadequate infrastructure often limits wheelchair accessibility on vessels, with environmental factors like uneven surfaces and obstacles exacerbating these challenges [45, 46]. Intelligent wheelchair navigation systems have been introduced to address these limitations but remain less effective in crowded or dynamically changing environments, such as vessel decks [47, 48]. The redesigned control stations address these issues by incorporating adaptive height-adjustable panels and ensuring that all controls are within ergonomic reach for seated users.

Figure 8 illustrates the redesigned control station layout, highlighting accessible navigation boats for wheelchair users. These innovations align with findings from previous research, which emphasize the importance of user-centered design in improving accessibility for wheelchair users in maritime settings [49, 50]. The redesign advances inclusivity by addressing key barriers to accessibility while maintaining operational efficiency, setting a new standard for control station design on vessels.

Figure 8. Accessible navigation boats for fishing [51]

3.7 Stability and seakeeping

Structural modifications, such as ramps and wider pathways, introduce significant changes to the vessel's layout, accompanied by alterations in weight distribution. These modifications impact the vessel's center of gravity and stability, necessitating a thorough evaluation to ensure safety and performance. Stability and seakeeping analyses were conducted as integral parts of the standard design process to maintain both safety and comfort. The stability analysis was performed under multiple load cases to assess variations in weight distribution, while the seakeeping analysis considered different vessel speeds, wave directions, wave heights, and wave shapes. These assessments were carried out using computational modeling with Bentley Maxsurf Academic Software, ensuring that the redesigned vessel complies with IMO stability standards [52].

The relationship between vessel speed, wave dynamics, and the safety of wheelchair users on deck is multifaceted. Research shows that vessel movement dynamics can significantly affect the stability and safety of wheelchair users. For instance, Erickson et al. [53] highlighted the importance of understanding the forces involved in wheelchair falls, noting that wave-induced motions on vessels can exacerbate tipping risks for wheelchair users. Additionally, the provision of assistive technology, including wheelchairs, must consider environmental factors such as vessel motion and speed to ensure user safety and accessibility during operations [54].

Furthermore, vessel speed plays a critical role in mitigating risks. Slower speeds reduce the likelihood of sudden movements caused by wave interactions, which can decrease the risk of wheelchair instability and falls. Research by Findlay et al. demonstrates that speed reduction not only minimizes collision risks but also lowers environmental disturbances, which may benefit wheelchair users by reducing unexpected motions [55]. This highlights the need for an integrated approach that incorporates vessel design, speed management, and wheelchair safety features.

The redesigned vessel achieves an optimal balance between accessibility and performance by addressing these factors. By ensuring that structural modifications accommodate the dynamics of vessel movement without compromising stability, the design overcomes challenges posed by traditional configurations. This approach enhances the overall safety of both the vessel and wheelchair users, offering a significant improvement over conventional designs [56].

3.8 Safety equipment placement

Safety equipment, such as life jackets and fire extinguishers, has been repositioned in the redesigned vessel to ensure accessibility for wheelchair users. In the current design, emergency tools are often placed out of reach, creating delays in response times during emergencies [57]. The redesign aligns with accessibility standards, ensuring that safety equipment is placed within the operational range of wheelchair users, as illustrated in Figure 9. This placement enhances emergency preparedness and ensures that all users, regardless of mobility, have equal access to critical safety resources [58].

While these changes aim to improve accessibility, evidence suggests that barriers to true usability may still exist. Studies have shown that while public spaces may meet dimensional standards for accessibility, practical usability for wheelchair users often falls short. For example, research highlights that high percentages of routes in public buildings are reported as accessible, but many fail to meet the practical needs of wheelchair users due to poor design implementation [59].

Figure 9. Safety equipments placement [60]

3.9 Line fishing equipment

The redesign of fishing tools for wheelchair users on Sekoci fishing boats aims to enhance safety, usability, and inclusivity, allowing active participation in fishing activities while minimizing risks, as shown in Figure 10. Key adaptations include strategically placed fishing pole holders for hands-free operation, strong-arm supports to reduce physical effort when handling rods, and adjustable harness systems to secure users and prevent loss of balance. Advanced tools such as Electra-Mate electric reels automate reeling, offering practical solutions for users with limited strength or mobility. Integrated restraints ensure both the wheelchair and user remain stable, even in adverse sea conditions.

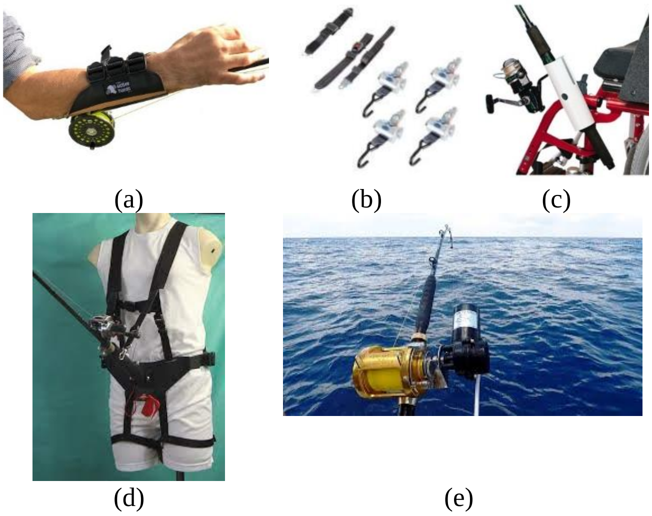

Figure 10. Fishing tools for wheelchair users' safety (a) Strong-arm, (b) Restraint (c) Adjustable harness, (d) fishing pole holders, (e) Electra-Mate electric reels automate

However, the adoption of advanced tools, like electric reels, may pose challenges due to varying technological proficiency among users with disabilities. Operating such tools often requires additional training or assistance, emphasizing the need for support personnel to bridge the gap between technology and user capabilities [61]. The effectiveness of fishing equipment depends on users' physical abilities and the specific fishing context, suggesting that accessibility improvements may inadvertently create new challenges for some users [62]. Similarly, concerns are raised about potential impacts on performance and catch efficiency when advanced tools alter traditional fishing dynamics [63].

Safety features like restraints, while designed to improve stability, must be carefully balanced. Overly rigid restraints can hinder wheelchair users' ability to react swiftly in emergencies [64]. Stakeholder inclusion is also critical; it is emphasized that without input from wheelchair users and fishing communities, adaptations may fail to address practical challenges effectively [65]. Furthermore, the importance of respecting cultural and operational traditions in fishing practices is stressed, ensuring modifications align with the socio-economic and cultural realities of the communities involved [66].

3.10 Redesign proposed

The identification of problems and recommendations for redesigning lifeboat fishing boats to accommodate wheelchair users, transitioning from traditional fishing boat designs, are outlined in Table 1. Based on this analysis, accessibility improvements in the redesign of Sekoci fishing boats are presented through four proposed design types (Figures 11-14).

The features and goals of each fishing vessel design type for wheelchair users are detailed in Table 2. Each redesign prioritizes safety, stability, and ease of mobility for wheelchair users while maintaining the vessel's operational functionality. Key modifications include widened pathways, integrated ramps, reinforced handrails, and adaptive seating arrangements to enhance accessibility and comfort.

Table 1. Problems and recommendations for redesigning lifeboat fishing boats for wheelchair users

Aspect	Current Design Challenges	Impact on Accessibility	Recommendations for Improvement
Deck Layout	Insufficient space for wheelchair maneuverability (e.g., turning and accessing key areas). Narrow pathways obstruct free movement.	Restricts mobility and access to fishing spots, control stations, and restrooms.	Redesign deck layout with wider pathways and turning radii suitable for wheelchair users. Remove unnecessary obstacles.
Access Points	No ramps or dedicated entry points for wheelchair users. High steps make boarding and disembarking difficult.	Limits entry and exit for wheelchair users. Increases safety risks during boarding in rough seas.	Add ramps or hydraulic lifts for seamless boarding. Reduce step height and create sloped access areas.
Interior Design	Cabins and restrooms have narrow doors and cramped spaces. Essential equipment is placed at nonreachable heights.	Prevents wheelchair users from accessing essential facilities. Limits usability of the vessel.	Expand doorways and interior spaces to meet accessibility standards. Place equipment within reachable ranges.
Safety Features	No secure anchoring systems for wheelchairs. Absence of handrails and nonslip flooring.	Increases the risk of accidents during operations. Reduces user confidence and safety.	Install wheelchair anchoring systems. Add handrails and nonslip flooring throughout the vessel.
Control Stations	Control panels and navigation instruments are not designed for seated users. Placement is too high for wheelchair accessibility.	Prevents wheelchair users from operating the vessel independently.	Design ergonomic control systems with adjustable heights. Ensure reachability for seated operators.
Stability and Seakeeping	Modifications for accessibility (e.g., ramps, wider pathways) could affect vessel stability and seakeeping performance.	Potentially compromises vessel safety in rough sea conditions.	Conduct stability and seakeeping analyses to assess the impact of modifications. Ensure compliance with safety standards.
Safety Equipment Placement	Emergency equipment is not easily reachable for wheelchair users.	Delays response time during emergencies. Compromises overall safety for disabled users.	Strategically place life jackets, fire extinguishers, and other safety equipment within easy reach of wheelchair users.

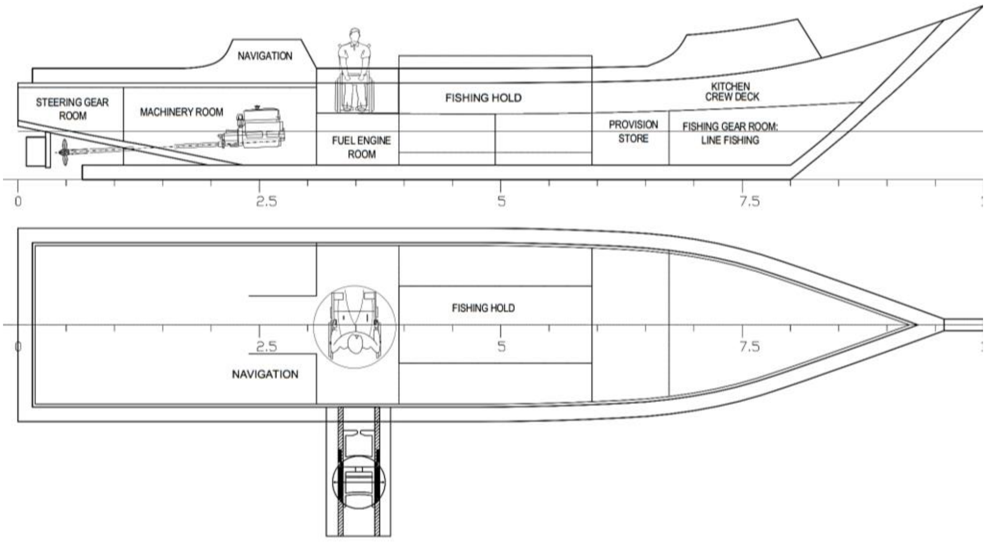

Figure 11. Redesign type 1

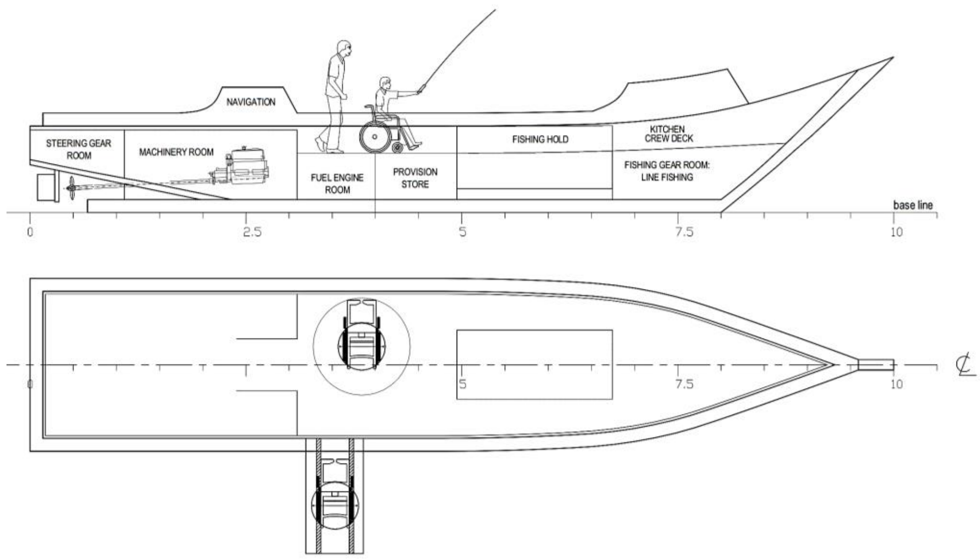

Figure 12. Redesign type 2

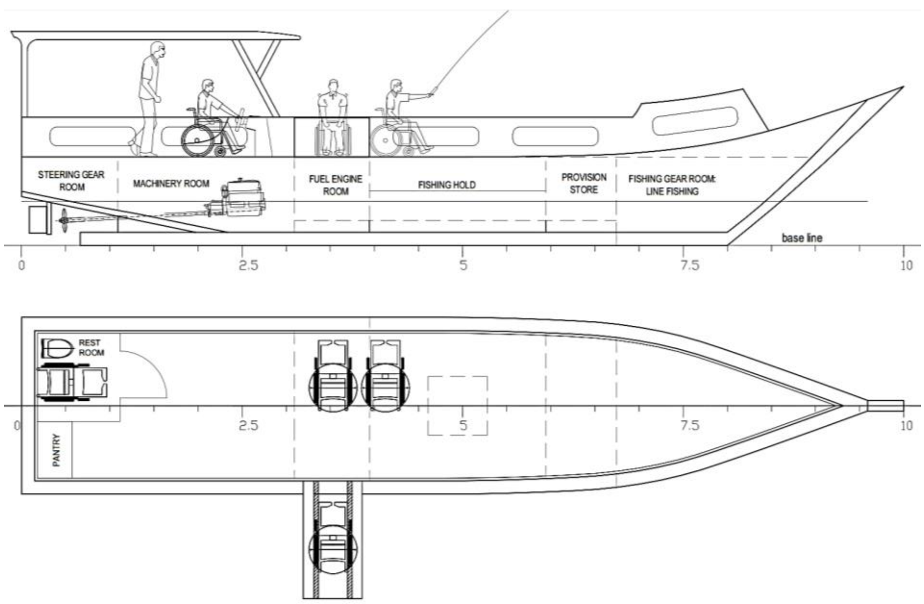

Figure 13. Redesign type 3

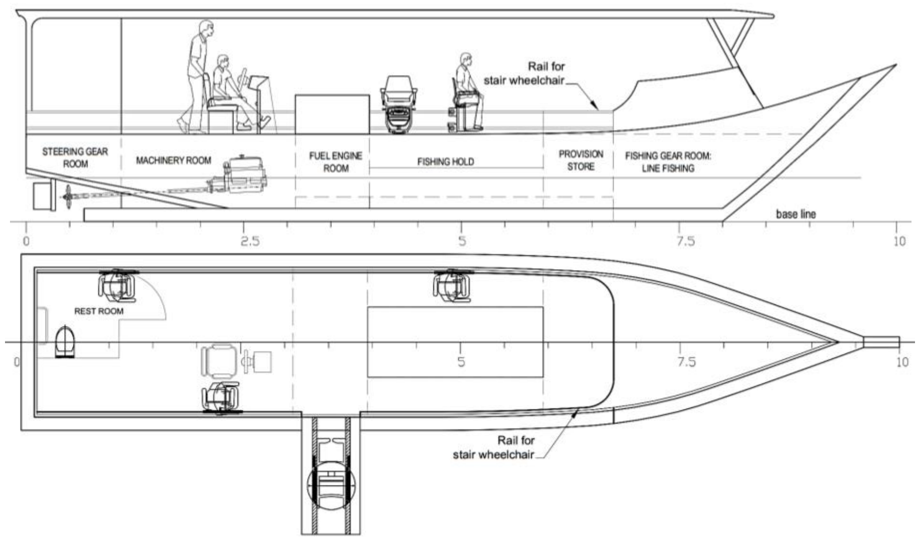

Figure 14. Redesign type 4

Table 2. Features and goal of fishing vessel designs for wheelchair users

Redesign Type	Features	Goal
Type 1: Basic Accessibility Modifications	Adjusted deck height in key areas. Anti-slip materials on the deck. Handrails and side access ramps.	Provide minimal structural changes while ensuring basic accessibility for wheelchair users.
Type 2: Enhanced Accessibility and Facilities	Wider side access (120 cm). Reconfigured central fish hold for better maneuverability. Improved deck layout.	Enhance comfort and accessibility for extended fishing trips and general usability improvements.
Type 3: Full Accessibility with Flat Deck	Completely flat deck from bow to stern. Flush fish hold eliminating barriers. Wider circulation space. Integrated facilities like a toilet and pantry.	Maximize accessibility, safety, and independence for wheelchair users through a universally designed layout.
Type 4: Advanced Safety Features	Flat deck with integrated rail systems for stability. Security straps for rough seas. Stabilizers for enhanced vessel balance.	Provide maximum safety and usability for wheelchair users, especially in challenging sea conditions.

3.11 Stair wheelchairs

The horizontally designed stair-climbing wheelchair (Figure 15) for Sekoci fishing boats addresses safety concerns by stabilizing users during vessel movement without the risks associated with vertical stair climbing. Traditional stair-climbing wheelchairs often lack stability and require additional user assistance, posing safety hazards, particularly in dynamic environments [67, 68]. By eliminating vertical movement, this design focuses on horizontal stabilization, reducing the risk of slipping and maintaining user security during transit [69, 70].

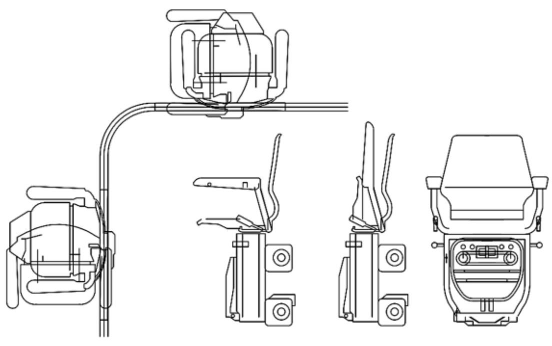

Figure 15. Stair wheelchair

This approach simplifies the mechanism, enhancing safety and usability while avoiding the operational complexity of traditional stair-climbing systems [71]. The horizontal adaptation aligns with recommendations to prioritize user stability and comfort, offering a practical and safer solution for wheelchair users in maritime settings [72]. This innovation significantly improves accessibility and minimizes risks, making it a valuable advancement for inclusive mobility on vessels.

3.12 Stability and seakeeping analysis of design type 4: Advanced safety features

The stability analysis of the redesigned Sekoci Type 4 fishing vessel under full load conditions takes into account the impacts of wheelchair accessibility modifications. Adjustments such as wider pathways and ramps enhance accessibility but also affect the vessel's center of gravity and overall stability. The evaluation includes five crew members, a wheelchair user, and 2.5 tons of fish, as detailed in Table 3. The stability assessment, conducted using Bentley Maxsurf Stability, demonstrates that the redesigned vessel meets the IMO stability criteria applicable to all vessels, as shown in Figure 16 and Table 4. The GZ curve (Figure 16) and stability parameters confirm sufficient righting moments, ensuring that the vessel maintains stability even under full load conditions [73].

Table 3. Weight distribution for stability analysis

Item Name	Quantity	Unit Mass (ton)	Total Mass (ton)	Long.Arm (m)	Trans. Arm (m)	VertArm (m)
W Hull	1	3.8	3.8	6.8	0	0.95
Fish	1	2.5	2.5	7.4	0	0.7
Deck	1	1.6	1.6	7	0	1
Crew	5	0.08	0.4	5	0	3.9
Machinery	1	0.85	0.85	3.8	0	0
Fuel engine	50%	1.485	0.742	5.252	0	0.42
Water sb	50%	0.202	0.101	5.246	-1.118	0.63
Water ps	50%	0.202	0.101	5.246	1.118	0.63

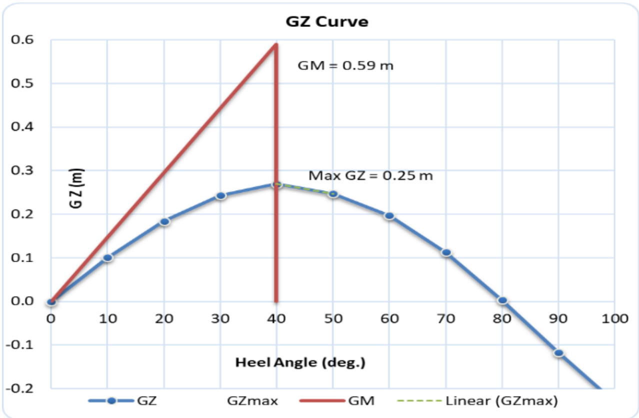

Figure 16. GZ curve for redesign type 4 full load stability analysis

Table 4. Re-design type 4 stability analysis results compare to IMO criteria (A.749(18) Ch3)

Criteria	Value	Units	Actual	Status
3.1.2.1: Area 0 to 30	3.151	m.deg	4.1	Pass
3.1.2.1: Area 0 to 40	5.157	m.deg	6.7	Pass
3.1.2.1: Area 30 to 40	1.719	m.deg	2.6	Pass
3.1.2.2: Max GZ at 30 or greater	0.2	m	0.3	Pass
3.1.2.3: Angle of maximum GZ	25	Deg	40.0	Pass
3.1.2.4: Initial GMt	0.15	M	0.6	Pass

Furthermore, the importance of considering ship dynamics and the potential for roll response in different sea states, which could be adversely affected by the changes made to enhance accessibility, is stressed [74]. Moreover, the introduction of additional weight from ramps and anchoring systems can lead to significant changes in trim and heeling, as noted in the original analysis. This aligns with findings that emphasize the critical relationship between vessel design, loading conditions, and overall operability [75].

Research indicates that even minor alterations in weight distribution can have pronounced effects on stability, underscoring the need for a balanced approach to redesign efforts that prioritize both accessibility and operational safety. However, existing literature suggests that the relationship between vessel modifications and stability is complex. It is highlighted that the risk of accidents increases as vessel length decreases, indicating that smaller vessels may face greater stability challenges, especially when modifications are made [76]. This finding suggests that while enhancing accessibility is crucial, it may inadvertently compromise stability if not carefully managed. Additionally, the need for accurate assessments of fishing vessel stability, particularly in light of varying operational conditions, which can further complicate the stability analysis of modified vessels, is emphasized [77].

The seakeeping analysis of the redesigned Sekoci tuna fishing vessels type 4 evaluates their stability and motion under varying sea conditions, emphasizing safety and accessibility for wheelchair users. In head seas, significant heave and pitch responses were observed at wave frequencies between 0–3 rad/s, stabilizing beyond 5 rad/s as shown in Figures 17 and 18. Beam seas induced pronounced rolling motions, peaking at 2–3 rad/s and diminishing at higher frequencies as shown in Figures 19 and 20. These findings align with the emphasis on roll and pitch motions as critical factors affecting operational capability and highlight the influence of wave patterns and vessel design on dynamic responses [78]. However, the challenges for wheelchair users, especially in cross-sea conditions where motion responses are more dynamic, underscore the importance of considering safety measures tailored to varying sea conditions.

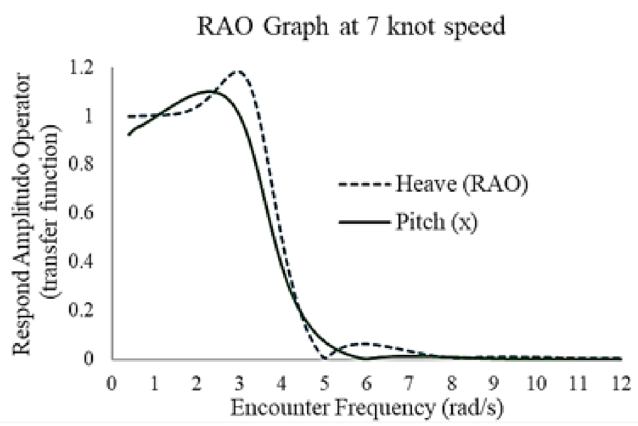

Figure 17. RAO graph at 7 knot with the wave direction from head sea

In calm waters with wave frequencies around 5-6 rad/s, wheelchair use is considered safe due to reduced motion and minimal risk of slipping. However, in rougher conditions with higher waves and lower frequencies, the vessel's dynamic motion poses significant safety challenges for wheelchair users, consistent with findings on motion-induced interruptions and the importance of safety culture [79]. Varying loading conditions can significantly alter vessel motion, suggesting that wheelchair safety depends on both wave conditions and load distribution [80]. To mitigate these risks, additional safety measures such as safety straps, locking systems for securing mobility devices, and reinforced handrails are recommended.

The redesigned Sekoci tuna fishing vessels prioritize enhanced safety for wheelchair users by incorporating non-slip surfaces, reinforced handrails, wheelchair anchoring systems, and optimized pathways. These modifications comply with international maritime safety standards and significantly improve onboard safety. However, the quality and reliability of wheelchairs themselves influence safety, as poorly matched or malfunctioning wheelchairs can exacerbate risks [81, 82]. Existing guidelines may inadequately address the unique challenges faced by wheelchair users in marine settings, suggesting the need for more robust safety protocols tailored to dynamic environments [83].

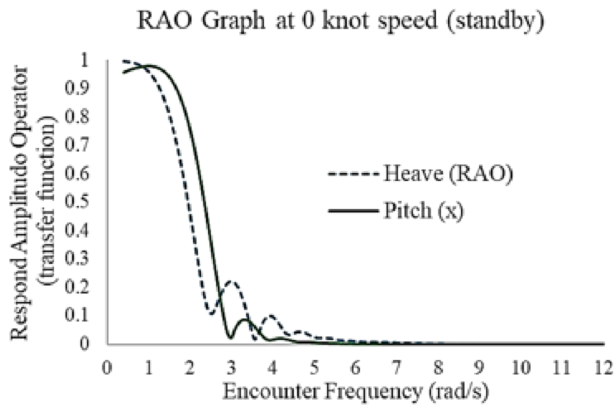

Figure 18. RAO graph at 0 knot with the wave direction from head sea

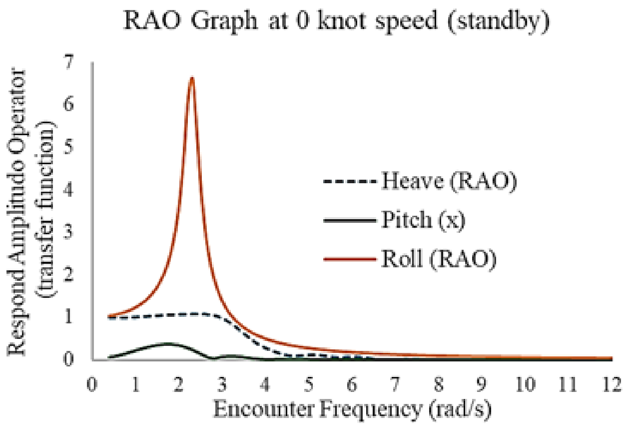

Figure 19. RAO graph at 0 knot with the wave direction from side beams sea

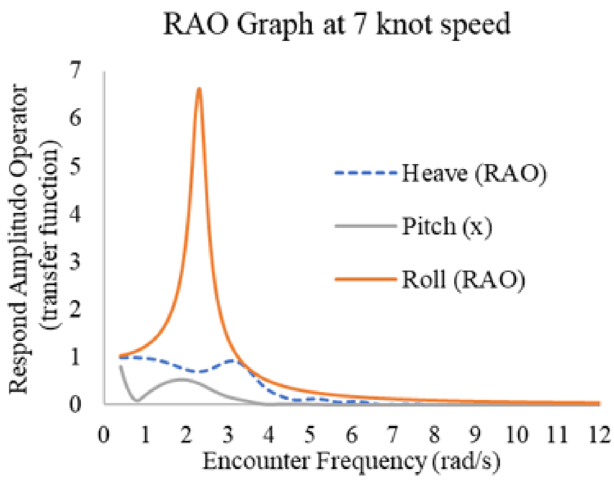

Figure 20. RAO graph at 7 knot with the wave direction from side beams sea

Future research should focus on experimental validation of wheelchair user safety and stability on fishing vessels under varying sea conditions. Controlled hydrodynamic lab tests and real-world sea trials in calm, moderate, and rough waters will provide crucial data on motion effects, stability, and accessibility for wheelchair users. Trunk stabilization is critical for user stability under vessel movement conditions [84]. The impact of wave-induced motion on wheelchair usability, comfort, and safety requires detailed analysis. Inadequate wheelchair fit can lead to discomfort and instability, which may be worsened in dynamic marine environments [85]. Additionally, boarding and alighting phases present higher risks, indicating that secure restraint systems and accessibility improvements must be rigorously tested in these scenarios [86].

Integrating sensor-based motion tracking can further improve safety assessments by providing real-time feedback on stability and motion response [87]. By bridging theoretical design improvements with practical application, this research will ensure fishing vessels are safe, accessible, and operationally efficient for wheelchair users in various marine environments. Advancing experimental studies in this field will strengthen maritime accessibility standards, supporting safer and more inclusive fishing operations.

4. CONCLUSIONS

This study presents innovative redesigns of Sekoci tuna fishing boats to enhance accessibility and safety for wheelchair users, addressing critical gaps in traditional designs. Key advancements include the integration of wheelchair-specific safety features, optimized pathways, and ADA-compliant ramps and hydraulic lifts, validated through computational simulations to ensure compliance with IMO stability standards while maintaining operational efficiency. The study's unique contribution lies in promoting barrier-free vessel design, enabling wheelchair users to actively participate in fishing operations and setting a benchmark for inclusivity in small-scale fisheries. By prioritizing user-centric solutions, this research aligns with global efforts to advance inclusive maritime safety standards. Future work should focus on real-world testing under varying sea conditions to validate these designs further and establish guidelines for accessible fishing vessels, fostering broader adoption of universal design principles in the fishing industry. This study lays a strong foundation for creating more inclusive and sustainable maritime practices.

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