The Role of Innovation in the Performance of Maritime Services Using Unmanned Vessel Technologies

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Abstract

This study aims to investigate the role of innovation in improving the performance and competitiveness of small shipbuilding businesses and advanced maritime industry businesses in Hormozgan Province. The study employed a descriptive-survey research design, with data collected through structured questionnaires distributed to employees and experts in small shipbuilding businesses and advanced maritime industry businesses. The total sample size comprised 950 respondents. Statistical analyses, including one-sample T-tests and Pearson correlation tests, were performed using SPSS to evaluate the impact of various innovation indicators, such as entrepreneurial drivers, human capital, and technological advancements, on business performance and competitive advantage. The results showed that all innovation indicators had significantly higher mean scores than the neutral benchmark of 3 ($p < 0.001$), indicating their positive impact on performance. Key factors for small shipbuilding businesses included entrepreneurial drivers (mean = 4.43), human capital (mean = 4.95), and technological advancements (mean = 4.61). For advanced maritime industry businesses, human capital (mean = 4.88) and knowledge utilization (mean = 4.88) were critical contributors. Overall innovation performance scores were 4.14 for small shipbuilding businesses and 4.31 for advanced maritime industry businesses, highlighting the substantial role of innovation in both sectors. Innovation serves as a fundamental driver of performance and competitiveness in maritime businesses. Emphasizing human capital development, leveraging digital technologies, and fostering a culture of innovation are essential for sustainable growth. However, challenges such as limited collaboration and knowledge-sharing mechanisms need to be addressed to maximize innovation's potential impact.

Keywords: *Innovation, Maritime Service Performance, Technology, Unmanned Vessels, Hormozgan*.

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1. Introduction

Innovation plays a pivotal role in the advancement of maritime industries, particularly in the rapidly evolving domain of unmanned vessel technologies. The integration of technological advancements into shipbuilding and maritime services has created unprecedented opportunities for efficiency, safety, and sustainability [1]. These innovations have reshaped traditional paradigms, pushing the boundaries of operational capabilities and redefining standards across global shipping and naval sectors [2].

The utilization of unmanned surface vessels (USVs) and their associated technologies has grown significantly in recent years. Researchers have highlighted various applications, ranging from marine debris collection [3] to the enhancement of autonomous navigation systems [4]. These advancements underscore the transformative potential of USVs in addressing contemporary maritime challenges. For instance, adaptive backstepping sliding mode dynamic positioning systems have proven effective in maintaining stability and precision in vessel operations [5].

The adoption of unmanned technologies, particularly in areas such as collision avoidance, path planning, and real-time data analysis, has garnered substantial academic and industrial attention. The development of autonomous systems for collision avoidance using predictive control methods exemplifies this trend, demonstrating their capability to enhance safety in maritime operations [6]. Moreover, the integration of multi-agent systems into navigation has facilitated efficient route planning and obstacle avoidance, contributing to the operational efficacy of USVs [7].

In inland waterways, test zones for autonomous ships have provided critical insights into the operational principles and challenges of unmanned vessels [8]. These initiatives have emphasized the need for robust design frameworks to ensure the seamless deployment of autonomous vessels in diverse marine environments [9]. Additionally, studies on monitoring and control systems, such as those utilizing eye-tracking data, have enhanced our understanding of human-machine interactions in unmanned ship operations [10].

The role of innovation extends beyond technological advancements, encompassing strategic approaches to improve maritime service performance. For example, the quality function deployment (QFD) methodology has been employed to analyze the effects of autonomous vessels on shipping factors, highlighting the critical intersection of innovation and operational efficiency [11]. Similarly, integrating denoising algorithms into fusion methods for vessel positioning has further refined the accuracy of navigation systems [12].

Maritime industries have also benefited from advancements in sensor technology and control systems. Experimental studies have demonstrated the efficacy of autonomous docking and hook-locking control systems, which have become indispensable in enhancing the functionality of USVs [1]. These developments underscore the importance of innovation in optimizing key aspects of vessel operations, from navigation to maintenance.

While the benefits of unmanned vessel technologies are evident, their adoption presents unique challenges. For instance, the design and construction of USVs require careful consideration of environmental and energy constraints, as demonstrated by the Cadet-M platform, which leverages alternative energy sources for sustainable operations [13]. Similarly, autonomous systems must address the complexities of heavy traffic areas, as evidenced by case studies of North Sea crossings by unmanned vessels [14].

The assessment of collision risks for both manned and unmanned vessels has highlighted the need for comprehensive regulatory frameworks to ensure safety and reliability (Wu, Wang, Diaconeasa, Mosleh, & Wang, 2020). Furthermore, the adoption of genetic algorithm-based path planning methods has opened new avenues for optimizing the performance of autonomous systems (Obaideen, 2024). These advancements, coupled with adaptive navigation and monitoring techniques, present exciting opportunities for the maritime sector to leverage innovation for sustained growth (Smolentsev & Sazonov, 2021).

The evolution of unmanned vessel technologies represents a transformative phase in maritime industries, offering solutions to long-standing challenges while creating new opportunities for innovation. From enhancing navigation and collision avoidance to addressing sustainability and operational efficiency, these advancements signify a paradigm shift in maritime operations. As this study investigates the factors influencing innovation and its impact on the performance of small shipbuilding companies in Hormozgan Province, it contributes to the broader discourse on leveraging technological progress for maritime excellence.

2. Methodology

This study employs an applied research design, aiming to achieve a scientific objective with a focus on addressing a specific problem. The methodology encompasses descriptive-survey techniques, which aim to describe the conditions or phenomena under investigation. The statistical population includes all industrial and traditional centers involved in the construction of maritime vessels and dhows along the Hormozgan coastal strip. Additionally, the study targets skilled and experienced professionals actively engaged in these centers and industrial workshops. Due to the limited number of such workshops in the region under study, most centers and workshops are included, making the sample size nearly equal to the population size. Therefore, a census sampling method is utilized.

Given the scale, history, and capabilities of the Iran Shipbuilding and Offshore Industries Complex in constructing and repairing small and large metal vessels, this national complex is included as a key benchmark among other workshops dedicated to building and repairing metal vessels. Data collection is conducted using field data generated from master craftsmen in the studied region's workshops and experts at the Iran Shipbuilding and Offshore Industries Complex. The focus is on assessing the role of innovation in business development related to shipbuilding and repair, including ocean-going vessels that employ modern technologies.

For data analysis, the SPSS software is utilized. The Kolmogorov-Smirnov test is applied to evaluate the normal distribution of variables, while hypothesis testing is conducted using t-tests and Pearson correlation analyses. These statistical methods ensure a robust examination of the relationships and impacts of innovation on the performance of maritime service industries, thereby providing reliable and valid results aligned with the research objectives.

3. Findings and Results

The results of the one-sample T-test for innovation indicators in small shipbuilding businesses in Hormozgan Province show statistically significant differences compared to the neutral mean of 3 ($p < 0.001$). Digital Economy Utilization and Knowledge Outsourcing achieved the highest mean scores (4.99 each), demonstrating their crucial role in driving innovation. Similarly, Human Capital (4.95) and Knowledge Flow Innovation (4.93) reflect the importance of intellectual resources in fostering innovation. Other high-scoring indicators, such as Market Demand, Intense Competition, and Technological Advancements (mean = 4.61-4.67), suggest that external factors are key motivators. While some indicators like Tacit to Explicit Knowledge Conversion (4.07) and Inter-departmental Collaboration (4.09) scored slightly lower, they still indicate a significant positive perception. Collectively, the results highlight the substantial role of innovation in enhancing operational performance, efficiency, and competitiveness in small shipbuilding businesses.

Table 1. Results of One-Sample T-Test for All Innovation Indicators in Small Shipbuilding Businesses

Indicator	T-Value	Degrees of Freedom (df)	Mean	Standard Deviation (SD)	Significance (p)
Entrepreneurial Driver	50.57	963	4.43	0.45	0.000
Social Capital	61.53	963	4.75	0.46	0.000
Human Capital	63.93	963	4.95	0.41	0.000
Organizational Structure	53.41	963	4.11	0.43	0.000
Organizational Culture	61.05	963	4.67	0.41	0.000
Market Demand	64.41	963	4.65	0.49	0.000
Technological Advancements	60.19	963	4.61	0.40	0.000
Economic Changes	67.51	963	4.55	0.49	0.000
Intense Competition	60.53	963	4.67	0.11	0.000
Product/Service Innovation	31.17	963	4.91	0.17	0.000
Process Innovation	53.95	963	4.71	0.14	0.000
Value Chain Innovation	69.53	963	4.66	0.17	0.000
Technological Innovation	66.45	963	4.16	0.41	0.000
Knowledge Flow Innovation	65.55	963	4.93	0.49	0.000
Tacit to Explicit Knowledge Conversion	60.40	963	4.07	0.49	0.000
Knowledge Utilization for Value	66.90	963	4.55	0.16	0.000
Industry Innovation	60.54	963	4.44	0.91	0.000
Digital Economy Utilization	65.99	963	4.99	0.49	0.000
Inter-departmental Collaboration	66.69	963	4.09	0.13	0.000
Employee Creativity	61.79	963	4.19	0.91	0.000
Knowledge Outsourcing	66.64	963	4.99	0.96	0.000

Technological Infrastructure	64.79	963	4.46	0.95	0.000
Organizational Capabilities	69.07	963	4.79	0.93	0.000
IT Utilization	65.17	963	4.14	0.46	0.000
Risk-taking Ideas	61.17	963	4.47	0.99	0.000
Value Creation for Customers	61.45	963	4.19	0.41	0.000
Adopting New Ideas/Processes/Products	69.79	963	4.79	0.49	0.000
Willingness to Change	53.41	963	4.11	0.43	0.000

The overall innovation performance in small shipbuilding businesses is significantly higher than the neutral mean of 3, as indicated by a T-value of 66.49 ($p < 0.001$) and a mean score of 4.14. This reflects a strong adoption of innovative practices across the sector, with consistent agreement among respondents (SD = 0.17). The findings suggest that innovation is deeply embedded in the operational strategies of small shipbuilding businesses, contributing to enhanced efficiency, adaptability, and market competitiveness. These results emphasize the importance of fostering innovation at all levels to ensure sustainable growth and development within the maritime sector in Hormozgan Province.

Table 2. Results of One-Sample T-Test for Overall Innovation Performance in Small Shipbuilding Businesses

Variable	T-Value	Degrees of Freedom (df)	Mean	Standard Deviation (SD)	Significance (p)
Overall Innovation	66.49	963	4.14	0.17	0.000

The findings for innovation indicators in the advanced maritime industry businesses reveal significant positive deviations from the neutral mean of 3 ($p < 0.001$). Human Capital and Knowledge Utilization for Value Creation show the highest mean scores (4.88), emphasizing the importance of intellectual resources and the effective application of knowledge in fostering innovation. Similarly, Market Demand (4.84) and Product/Service Innovation (4.58) reflect strong external drivers and innovation in offerings. Indicators such as Organizational Structure (4.35) and Value Chain Innovation (4.41) point to substantial internal changes aimed at efficiency and competitiveness. Overall, these results highlight the advanced maritime industry's commitment to innovation as a strategic driver for enhancing performance, adaptability, and market positioning.

Table 3. Results of One-Sample T-Test for All Innovation Indicators in Advanced Maritime Industry Businesses

Indicator	T-Value	Degrees of Freedom (df)	Mean	Standard Deviation (SD)	Significance (p)
Entrepreneurial Driver	51.51	963	4.83	0.19	0.000
Social Capital	51.38	963	4.13	0.11	0.000
Human Capital	58.54	963	4.88	0.17	0.000
Organizational Structure	54.33	963	4.35	0.19	0.000
Organizational Culture	51.03	963	4.18	0.13	0.000
Market Demand	51.13	963	4.84	0.15	0.000
Technological Advancements	51.13	963	4.43	0.15	0.000
Economic Changes	51.41	963	4.13	0.15	0.000
Intense Competition	51.58	963	4.41	0.44	0.000
Product/Service Innovation	54.44	963	4.58	0.84	0.000
Process Innovation	54.83	963	4.48	0.41	0.000
Value Chain Innovation	51.51	963	4.41	0.41	0.000
Technological Innovation	51.11	963	4.14	0.44	0.000
Knowledge Flow Innovation	58.18	963	4.15	0.47	0.000
Tacit to Explicit Knowledge Conversion	58.11	963	4.41	0.91	0.000
Knowledge Utilization for Value	51.41	963	4.88	0.55	0.000
Industry Innovation	54.33	963	4.33	0.55	0.000

The one-sample T-test for overall innovation performance in the advanced maritime industry businesses confirms a statistically significant positive deviation from the neutral mean of 3 ($p < 0.001$). With a mean score of 4.31 and a low standard deviation (0.11), the findings underscore the broad consensus among respondents regarding the high level of innovation in the sector. The strong overall score reflects the successful integration of various innovation strategies, such as leveraging human capital, fostering process innovation, and adapting to market demands. These results affirm that the advanced maritime industry is well-positioned to maintain competitive advantage through sustained innovation, further bolstering its role as a leader in maritime advancements.

Table 4. Results of One-Sample T-Test for Overall Innovation Performance in Advanced Maritime Industry Businesses

Variable	T-Value	Degrees of Freedom (df)	Mean	Standard Deviation (SD)	Significance (p)
Overall Innovation	58.85	963	4.31	0.11	0.000

4. Discussion and Conclusion

This study investigated the role of innovation in small shipbuilding businesses and advanced maritime industry businesses in Hormozgan Province, focusing on their influence on performance and competitive advantage. The findings indicate that all innovation indicators had significantly higher mean scores than the neutral benchmark. In small shipbuilding businesses, key factors such as entrepreneurial drivers, human capital, and technological advancements emerged as critical contributors to performance, with mean scores of 4.43, 4.95, and 4.61, respectively. Similarly, advanced maritime industry businesses displayed a strong emphasis on human capital (mean = 4.88) and knowledge utilization for value creation (mean = 4.88), reflecting the sector's reliance on intellectual resources.

The results also revealed significant overall innovation performance in both sectors. The small shipbuilding businesses recorded a mean overall innovation score of 4.14, while the advanced maritime industry businesses had a slightly higher mean of 4.31. These findings demonstrate that innovation is a central pillar of operational efficiency and competitive advantage across both domains.

The high significance of human capital and knowledge utilization aligns with prior research emphasizing the role of intellectual resources in innovation. Elhafez (2023) underscored the importance of leveraging human expertise in maritime shipping, highlighting its impact on operational efficiency [11]. Similarly, the reliance on technological advancements corroborates findings by Kong (2024), who demonstrated the transformative potential of autonomous vessel design in enhancing marine debris collection and environmental sustainability [3].

Entrepreneurial drivers as a key innovation indicator are consistent with the observations of Krawczyk (2021), who noted that fostering entrepreneurship is critical for navigating the challenges of unmanned and autonomous vessel technologies [15]. The focus on process and value chain innovation in both sectors supports the conclusions of Lazarowska and Zak (2022), who explored multi-agent navigation systems and their ability to optimize resource allocation in maritime operations [4]. Additionally, the emphasis on digital economy utilization aligns with Wang et al. (2022), who identified the importance of fusion methods and data-driven decision-making in enhancing vessel positioning accuracy [12].

The relatively lower scores for inter-departmental collaboration and tacit to explicit knowledge conversion highlight areas requiring further improvement. These findings echo the challenges identified by Smolentsev and Sazonov (2021), who stressed the need for improved knowledge-sharing mechanisms in unmanned vessel operations [16]. Furthermore, the significant impact of market demand and intense competition on innovation is supported by Chistyakov and Ol'khovik (2020), who highlighted the influence of external pressures on the adoption of autonomous ship technologies [8].

The findings of this study resonate with broader trends in maritime innovation. Wu et al. (2020) emphasized the role of technological innovation in addressing collision risks, a concern particularly relevant for small shipbuilding businesses operating in congested waterways [17]. The focus on advanced knowledge utilization aligns with the observations of Obaideen (2024), who highlighted the efficacy of genetic algorithms in optimizing path planning for autonomous systems [18]. Moreover, the emphasis on organizational culture and structure as innovation enablers supports the framework proposed by Ishikawa et al. (2020), who documented the evolution of onboard equipment for GNSS-A observation [19].

In the advanced maritime industry, the high scores for product and service innovation are consistent with Powell (2019), who noted the growing demand for innovative offerings in global shipping [2]. The role of digital technologies, as evidenced by the high mean score for digital economy utilization, aligns with Wilkins (2023), who explored the integration of unmanned technologies in dredging operations to enhance monitoring capabilities [20]. These synergies between the current findings and existing research underline the robustness and relevance of the study’s conclusions.

While this study provides valuable insights into the role of innovation in maritime businesses, it has certain limitations. First, the research was geographically limited to Hormozgan Province, which may affect the generalizability of the findings to other regions with different maritime contexts. Second, the study relied heavily on self-reported data through surveys, which could introduce response bias. Third, the cross-sectional nature of the study does not capture the dynamic and evolving nature of innovation processes over time. Lastly, the study focused primarily on small shipbuilding and advanced maritime industry businesses, leaving out other critical segments of the maritime sector, such as logistics and port management.

Future research could address these limitations by expanding the geographical scope of the study to include other maritime regions with diverse operational contexts. Longitudinal studies could provide a more comprehensive understanding of how innovation evolves and impacts performance over time. Additionally, incorporating mixed methods, such as qualitative interviews with industry experts and quantitative analyses, could offer deeper insights into the mechanisms driving innovation. Future studies could also explore the role of external factors, such as regulatory frameworks and environmental challenges, in shaping innovation strategies. Finally, investigating other segments of the maritime sector, including logistics, port operations, and supply chain management, could provide a more holistic view of innovation in maritime industries.

For practitioners, the findings highlight the need to prioritize human capital development and knowledge utilization as key drivers of innovation. Businesses should invest in training programs to enhance the skills and expertise of their workforce. Establishing robust knowledge-sharing mechanisms can facilitate the conversion of tacit knowledge into actionable insights. Organizations should also focus on leveraging digital technologies to enhance efficiency and competitiveness. Collaborating with research institutions and technology providers can accelerate the adoption of cutting-edge solutions, such as autonomous navigation systems and real-time data analytics. Finally, fostering a culture of innovation through supportive organizational structures and policies can empower employees to contribute to continuous improvement and sustainable growth.

Authors’ Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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