CHAPTER 7

IMPLICATIONS, CONCLUSIONS, AND LIMITATIONS

This chapter presents the research implications of the study along with concluding remarks, and limitations of the current study. The literature review suggests that digital technologies have the potential to revolutionize the industry, making it more sustainable and efficient. To explore this potential, we conducted three types of analyses: descriptive, predictive, and prescriptive. Ultimately, our study provides comprehensive insights and practical recommendations for the maritime freight industry. These insights are particularly focused on increasing sustainability and efficiency through the adoption of digital technologies.

7.1 Implications from the study

As our study is conducted in three phases; descriptive, predictive, and prescriptive, we present the implications of each analysis phase as follows:

7.1.1 Implications of Descriptive analysis

The following outlines the theoretical and managerial implications derived from the descriptive analysis.

- **Theoretical Implications**

The descriptive analysis of the present study sheds light on critical factors influencing the implementation of key digital technologies namely; Blockchain technology, Bigdata & AI, and IoT adoption in maritime freight system, particularly within the Asian context. This research fills a gap in the existing literature by offering insights into digital technologies adoption in maritime freight in an Asian setting, which has been less explored compared to other regions such as Nigeria (Orji et al., 2020a, 2020b; Liu et al., 2021). The study benefits academics in several ways:

The statistical verification of individual factors through the integrated SEM and ANN approach provides a methodological advancement for analysing the crucial factors affecting BCT adoption. Categorizing the identified factors into technological and infrastructural, organizational, social, and institutional dimensions contributes to ongoing discussions on BCT adoption processes, as supported in a study by Nilashi et al. (2016). By systematically identifying and categorizing these factors, the study enriches the existing literature on technology adoption within the maritime sector.

Furthermore, the determinants employed in our research stem from prominent adoption theories, further enriched by the integration of the TOE model. This holistic approach allows for a comprehensive understanding of the adoption phenomenon, both from an organisational and environmental perspective. In this manner, our study contributes to the progression of technology adoption literature by putting a unified model to the test. By doing so, we bridge a critical gap in the existing literature, advancing our knowledge of blockchain adoption within maritime freight with a balanced and comprehensive outlook.

Moreover, the study employs fuzzy AHP and PROMETHEE II to identify and rank obstacles to adopting big data and AI in the maritime freight industry. Researchers can benefit from this approach by understanding how these methods can be applied to analyse and rank bottlenecks in other contexts or industries. The ranking & weightage of constraints provides researchers with a starting point for further research and investigation.

- **Managerial implications**

This analysis has a number of crucial implications for managers who are concerned with maritime freight enterprises. By identifying the key factors influencing the adoption of digital technologies, namely; sustainability-enabled digital freight training, initial investment costs, trust in digital technology, perceived benefits, and government policy and support, our study provides maritime managers and policymakers with a comprehensive framework tailored to the industry's unique challenges. This framework not only highlights the critical factors that need attention but also serves as a strategic guide for decision-making. By understanding these factors, stakeholders can make informed choices regarding policy development and resource allocation, which are crucial for fostering a conducive environment for digital technologies' integration. Moreover, this structured approach helps to mitigate potential obstacles that may arise during the transition process, ensuring that organizations can adopt new technologies more effectively. Ultimately, the insights gained from this research can facilitate smoother implementation, drive innovation, and enhance the overall efficiency and sustainability of maritime operations in an increasingly digital landscape.

7.1.2 Implications of Predictive analysis

The predictive analysis offers several important implications for managers of the maritime industry, particularly in the context of CO_2 emissions management and the application of advanced machine learning models. The superior performance of the ANN model in predicting CO_2 emissions underscores its potential for practical application in maritime operations. Whereas, the comparative analysis of the algorithms provides valuable insights into the strengths and weaknesses of different modelling techniques. Managers can leverage these insights to choose the most appropriate predictive model based on the specific characteristics of their dataset and operational requirements. For instance, while ANN offers higher predictive accuracy, DT and RF provide robust performance with greater interpretability, making them suitable for scenarios where ease of understanding is crucial.

The study emphasizes that the accuracy of CO_2 emission predictions is highly dependent on the availability and quality of data. Managers must prioritize the development of comprehensive data collection methodologies to gather high-quality datasets.

7.1.3 Implications of Prescriptive analysis

The prescriptive analysis has yielded valuable insights for maritime industry managers, providing them with valuable takeaways to inform their decision-making and strategic planning. To address anchorage waiting costs and promote sustainability in the maritime freight industry, maritime freight managers can implement strategic approaches. One effective strategy involves investment in advanced allocation strategies like predictive scheduling. Another approach is to carefully adjust the vessel speeds to reach their ideal efficiency levels. Thereby, they can simultaneously lower operational costs, anchorage waiting costs, and reduce carbon emissions, fostering a more eco-friendly and cost-effective maritime transportation sector.

Simultaneously, operational time of vessels at berths can be reduced by using some techniques.

Such as; Implementing technology solutions such as port management software, RFID systems, and automation can enhance operational efficiency. These systems can help track cargo, equipment, and vessel movements in real-time, allowing for better coordination. Other can be investment in efficient cargo handling equipment and well-trained personnel. Because quicker turnaround times reduce fuel consumption and labour costs. In the same vein, collaborating with other stakeholders in the supply chain, including shippers, consignees, and port authorities, can lead to smoother operations, reducing handling costs for all parties involved.

As governments intensify their efforts to enforce stricter carbon emission control regulations, the cost dynamics within the maritime freight sector will experience significant transformations. Due to large amount carbon emissions caused by vessels using the considerable fuel consumption, leading to a high carbon emission cost. To omit this high cost of emission, operators can explore eco-friendly vessel technologies and alternative fuels to reduce emissions and comply with environmental regulations. In this context, managers need to carefully assess the trade-offs between operational costs, waiting expenses, and emissions-related costs to strike a harmonious equilibrium between economic efficiency and sustainability objectives. The study underscores the potential benefits of adopting advanced technologies for berth and crane allocation. Implementing digital solutions, predictive analytics, and automation can significantly improve decision-making and reduce costs.

7.2 Conclusions

The first phase of the study i.e. descriptive analysis identifies key factors essential for the successful adoption of digital technologies in the maritime freight industry, including Sustainability-Enabled Digital Freight Training, Initial Investment Cost, Trust in Digital Technology, Perceived Benefits, and Government Policy and Support. By following a sequenced adoption route, managers can derive valuable insights that facilitate the effective integration of these technologies. Prioritizing these factors is crucial for developing robust implementation strategies that enhance operational efficiency and sustainability. Overall, the descriptive analysis strengthens the planning phase by providing a sequential list of key factors influencing the adoption of digital technologies in MFT. It also highlights their interrelations - for example, fluctuations in a causal category factor like "Availability of technology-specific tools " will impact its corresponding effect category factor. Essentially, the descriptive analysis prepares maritime industries to be ready for embracing digital technologies. Once this readiness is established, the study progresses to predict CO_2 emissions by utilizing the best-performing ML model. This is why we have conducted predictive analysis to forecast CO_2 emissions and evaluate the best-performing ML model.

Therefore, the predictive analysis emphasizes the significance of employing machine learning methodologies to predict CO_2 emissions from ships during various port activities. Through comparative analysis, it was evident that the ANN and DT models outperformed SVM and RF, showcasing superior accuracy in CO_2 emission prediction. Particularly, the ANN model demonstrated exceptional performance with R-squared value of 0.96360, warranting its recommendation for practical application in estimating total CO_2 emissions from maritime ships. By addressing data gaps and offering insights into emission patterns, the ANN model contributes to advancing our understanding of maritime emissions and promotes sustainable practices within the industry. Along with this, the decision tree model, with an R-squared value of 0.95530, also demonstrates strong accuracy in predicting CO_2 emissions from vessels. Overall, the predictive analysis supports port managers and decision-makers by offering an ANN model followed by a DT model to assess emissions effectively. This approach also provides valuable insights for policymakers to develop strategies that help industries balance operational efficiency with environmental sustainability. Moreover, the study highlights the potential extension of this predictive approach to model other greenhouse gases globally, leveraging evidence from regions such as Asia. Once maritime industries have evaluated their emissions, they can implement the prepared model to optimize their sea-side operations. Therefore, the prescriptive analysis comes into play, offering managers and decision-makers a mixed-integer nonlinear model that optimizes both costs and emissions from quay cranes and vessels.

The findings of the prescriptive analysis reveal that a 25% variation in operational costs results in a significant 14.22% change in optimal costs. Additionally, lowering the unit tax rate by 25% leads to a 10.54% reduction in optimal costs, and conversely, an increase in the unit tax rate by the same percentage would result in an increase of 10.54% in optimal costs. Moreover, reducing the time required to handle each container by 25% can result in a substantial 24.72% decrease in optimal costs, while conversely, increasing the handling time by the same percentage would lead to a similar increase in optimal costs. This relationship is mirrored when adjusting the number of containers: decreasing the number by 25% leads to a 24.72% decrease in optimal costs, whereas increasing the number of containers by the same percentage would yield a corresponding increase in optimal costs. These insights emphasize the importance of strategic cost management, which is pivotal in advancing operational efficiency while simultaneously fostering environmental sustainability within the maritime industry. By implementing the strategies derived from our findings, maritime managers can not only improve their organizations' economic performance and efficiency but also contribute positively to broader sustainability goals in the sector.

7.3 Limitations

The reliance of the presented work on the personal judgement of experts and biased data may be its limitation. And, the aggregation of values given by experts can be called its second limitation. For predictive analysis, the study's efficacy heavily relies on the availability and quality of data. Limited datasets may constrain the accuracy of CO_2 emission predictions. The study's findings may be specific to the dataset and conditions analysed, limiting their generalizability to other maritime regions. While, the mathematical model's focus has primarily centred on Berth Allocation Problem and Quay Crane Allocation Problem. The present model is limited to the ideal conditions.

7.4 Future Scope

- To enhance the richness and accuracy of our dataset, it is crucial to engage a greater number of experts.
- Focusing on a specific country can provide more localized insights and applicability, making the findings more relevant and actionable.
- Additionally, including factors such as weather conditions, vessel specifications, fluctuations in fuel prices, international trade policies, economic conditions and

regulatory frameworks will help create more robust and comprehensive predictive models for CO_2 emissions.

- Addressing the inherent uncertainties in maritime operations can be achieved by applying probabilistic or stochastic models.
- Combining actual datasets on digital technology use cases will further enhance the accuracy and relevance of our models.