UNIVERSITI TEKNOLOGI MARA

A MULTIOBJECTIVE HIERARCHICAL MODEL FOR ENVIRONMENTALLY SUSTAINABLE PORT MANAGEMENT IN MALAYSIA

MUHAMAD SAFUAN BIN SHAMSHOL BAHRI

Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy in Transport and Logistics

Malaysian Institute of Transport

December 2025

ABSTRACT

Ports play a critical role in facilitating global and national trade, however its operations generate significant environmental impacts such as greenhouse gas emissions, high energy consumption, and waste generation. Malaysia ports such as Westport, Port of Tanjung Pelepas (PTP), Johor Port and Sabah Port are under growing pressure to implement environmentally sustainable practices while maintaining efficiency and competitiveness as the ports are responsible for over 90% of the nation's trade. However, their progress has been inconsistent due to a lack of standardized frameworks for assessing port sustainability, fragmented governance structures, and the limitations of existing models in addressing uncertainty in expert evaluations. One of the biggest challenges today if the need to evaluate multiple environmental initiatives under conflicting objectives while still maintaining operational reliability. Moreover, dependence on traditional performance indicator and deterministic decision-making approaches often produces incomplete outcomes. Therefore, a solution that integrates expert-driven prioritization with quantitative performance assessment is necessary to address this gap and provide decision-makers with reliable tools for evaluating and enhancing port sustainability. Thus, this study develops a multi-objective hierarchical model that integrates the Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) to address uncertainty in expert evaluations and Mixed Integer Linear Programming (MILP) to compute port-specific sustainability scores. The IF-AHP results indicate that landlord and regulatory functions possess the highest weights with 0.298 and 0.281 respectively, followed by operator with 0.265 and community function with 0.156. The MILP evaluation indicates that Port Klang and Port of Tanjung Pelepas exhibit the highest sustainability scores of 0.812 and 0.796, respectively highlighting a significant performance gap between leading and developing ports within the national network. In contrast, Penang Port and Kuantan Port achieved scores of 0.711 and 0.678, respectively highlighting variations in policy enforcement, technology adoption, and environmental initiatives. The comparative analysis indicates that the proposed IF-AHP-MILP model surpasses traditional AHP and Neutrosophic AHP methods by achieving Spearman correlation values above 0.8 and demonstrating robustness in sensitivity analysis with outcome variations limited to ±0.2. The proposed model provides a data-driven framework that allows Malaysian ports to benchmark performance, prioritize resources, and align with the International Maritime Organization's Net-Zero 2050 agenda and the United Nations Sustainable Development Goals. This integrated method enhances port sustainability assessment by combining methodological rigor with practical application, thus providing academic contributions and actionable guidance for policymakers and port authorities.

ACKNOWLEDGEMENT

Alhamdulillah, all praise and gratitude are due to Allah SWT for granting me the strength, patience, and perseverance to complete this doctoral journey. Without His guidance and blessings, the successful completion of this thesis would not have been possible.

First and foremost, I would like to express my deepest and most sincere gratitude to my supervisor, Assoc. Prof. Ts. Dr. S. Sarifah Radiah Shariff, for her invaluable guidance, continuous encouragement, and unwavering support throughout the course of this research. Her profound academic insight, constructive feedback, and meticulous supervision have been instrumental in shaping the direction, rigor, and overall quality of this study. Her dedication to scholarly excellence and commitment to my intellectual development have significantly enriched my doctoral journey.

I would also like to extend my sincere appreciation to the faculty members and academic staff of the university for their assistance, administrative support, and the provision of a conducive research environment. My heartfelt thanks go to all experts, practitioners, and respondents who generously shared their time, experience, and professional insights, which greatly contributed to the robustness and practical relevance of this research.

Special appreciation is extended to my best friend, Muhammad Ezhar Yusuf, for his steadfast support, encouragement, and understanding throughout this journey. His constant presence, meaningful discussions, and belief in my abilities provided motivation and strength, particularly during challenging moments.

My deepest gratitude is reserved for my beloved parents, Shamshol Bahri bin Salleh, for their unconditional love, prayers, and sacrifices. Their continuous moral and emotional support has been the foundation of my perseverance and determination. This achievement is as much a reflection of their dedication and guidance as it is my own.

Finally, I acknowledge that any limitations or shortcomings in this thesis remain entirely my own. It is my sincere hope that this work will contribute, even in a modest way, to the advancement of knowledge and practice in the field.

TABLE OF CONTENTS

		Page
CONFIRMATION BY PANEL OF EXAMINERS		**ii**
AUTHOR'S DECLARATION		**iii**
ABSTRACT		**iv**
ACKNOWLEDGEMENT		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**xi**
LIST OF FIGURES		**xvi**
LIST OF ABBREVIATIONS		**xviii**
CHAPTER 1 INTRODUCTION		**1**
1.1	Research Background	1
1.2	Problem Statement	8
1.3	Research Questions	10
1.4	Research Objectives	11
1.5	Research Novelty	11
1.6	Significance of Study	11
1.7	Research Scope and Limitation	12
1.8	Summary	13
CHAPTER 2 LITERATURE REVIEW		**15**
2.1	Introduction	15
2.2	Overview of Environmental Sustainability with Malaysian Ports	17
2.3	Ports and Sustainable Development	20
2.4	The Concept and Areas of Environmental Sustainability in Ports	23
	2.4.1 Core Functional Areas	26
	2.4.2 Strategic Enablers	29
2.5	Challenges in Achieving Sustainable Port Practices	34
	2.5.1 Economic and Financial Constraints	35
	2.5.2 Technological and Operational Barriers	36
	2.5.3 Stakeholder Resistance and Organizational Barriers	38
2.6	Performance Evaluation of Environmentally Sustainable Ports	39

CHAPTER 1
INTRODUCTION

1.1 Research Background

Maritime transport serves as an essential component of global trade, facilitating the movement of more than 80% of the world's goods. In developing countries, maritime transport plays a crucial roles by representing 55% of global seaborne exports and 61% of imports. Ports serve as critical access points within this system, promoting economic growth, enabling international trade, and aiding national development. As the global economy becomes increasingly interconnected and vulnerable to climate disruptions, the development of resilient and sustainable port infrastructure is essential (World Bank, 2023).

In this evolving landscape, ports have evolved from simple cargo-handling facilities to complex and technologically advanced logistics hubs. Modern ports integrate maritime shipping with road, rail, and air networks, facilitating faster and more efficient global supply chains (Rodrigue et al, 2022). However, climate change is already affecting port infrastructure and maritime chokepoints as deep-sea shipping seeks to mitigate its contribution of roughly 3% to global greenhouse gas emissions. Increasing sea levels, severe weather events, and interruptions to essential transportation routes jeopardize the continuity of global trade. Ports must enhance physical resilience, adopt smart digital technologies, and support the transition to zero-carbon fuels, including green hydrogen. This energy transition creates new opportunities for development in the renewable energy and heavy industry sectors (World Bank, 2023).

To meet these growing challenges, the concept of a “Sustainable Port” has emerged to address these increasing challenges, redefining the port as a multifunctional, environmentally responsible, and digitally connected transport node. This method is consistent with the United Nations’ Sustainable Development Goals (SDGs) and highlights the importance of strategic integration within global, regional, and local logistics systems (Haraldson et al., 2023). At its core, a sustainable port is built on the three pillars of sustainability which are economic, environmental, and social.