Framework for Dealing with Uncertainty in the Port Planning Process: An Icelandic Case of the Ports of Isafjordur Network

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2021

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Reykjavik, June 2021

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Adaptive Port Planning.
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Bibliographic information:
Eskafi, M., 2021, *Framework for Dealing with Uncertainty in the Port Planning Process: An Icelandic Case of the Ports of Isafjordur Network*, Ph.D. dissertation, Faculty of Civil and Environmental Engineering, University of Iceland, 217 pp.

ISBN: 978-9935-9579-9-3
Author ORCID: 0000-0002-4697-4754

Printing: Haskolaprent ehf.
Reykjavik, Iceland, June 2021

Abstract

Ports have always been evolving to satisfy the new or changing demands of stakeholders. In this unstable world, ports as dynamic systems are developed under a high degree of uncertainty. Furthermore, black-swan events, for instance, the financial crisis in 2008, the avalanche in Flateyri (Iceland) in 2020, the COVID-19 pandemic in 2020-2021 make successful port planning a challenging task. Indeed, the ever-increasing complexity of a port system and its long technical lifetime make uncertainty considerations inevitable in the planning process. Therefore, this research presents a structured framework to deal with uncertainties, including opportunities and vulnerabilities, in the port planning process. To this end, a structured stakeholder analysis is performed to effectively and timely engage stakeholders in the planning process. Fuzzy logic 3-dimensional decision surface is used to identify the salient stakeholders. Subsequently, the success of the future port is defined in terms of the specific objectives of the stakeholders. To develop this definition, a problem structuring method and fuzzy multi-attribute group decision-making method are synthesized. Then, a port throughput forecast is conducted that accounts for epistemic uncertainty, including model and parameters uncertainties, and thus increases the reliability of forecast results. The method identifies the influencing macroeconomic variables on port throughput by mutual information and then applies the Bayesian statistical method to forecast the port throughput. Effective actions are planned to seize opportunities and manage vulnerabilities that manifest in the projected lifetime. Therefore, the port can adapt or better withstand the vagaries of the future. The nonlinearity of dealing with uncertainty by application of the framework provides a robust and better plan toward its success. The framework supports decision making under uncertainty and facilitates adaptive port planning. The framework is applied to the Ports of Isafjordur Network in Iceland. The results indicate that the uncertainties mainly present opportunities in the short-time horizon, while in the middle-time horizon the port network is confronted with multiple vulnerabilities.

Útdráttur

Hið öfluga og sívaxandi flókna eðli hafnarkerfa í margbreytilegum heimi skapar mikla óvissu varðandi þróunaráætlanir hafna. Enn fremur þá leiða óvæntir atburðir, svonefndir svartir svanir, eins og til dæmis efnahagshrunið 2008, snjóflóðið á Flateyri 2020 og COVID-19 faraldurinn, til þess að skipulagsgerð hafna er sérstaklega krefjandi verkefni sem er háð mikilli óvissu. Flækjustig hafnarkerfa og óvissa á löngum líftíma hafna gerir það óumflýjanlegt að taka tillit til óvissu í skipulagsferlinu. Þessi rannsókn setur fram skipulagsramma til að takast á við óvissu, þar á meðal tækifæri og veikleika, í skipulagsferli hafnar. Þessi rannsókn kynnir skipulagða hagsmunagreiningu til að virkja hagsmunaaðila hafna tímanlega í skipulagsferlinu. Þrívíddar ákvörðunaryfirborð byggt á loðinni (e. fuzzy) rökfræði er notað til að bera kennsl á mikilvæga hagsmunaaðila með mismunandi áhrif og hagsmuni. Í kjölfarið er árangur skipulagsins skilgreindur út frá markmiðum hagsmunaaðila og með samtvinnun eldri aðferðar og loðinnar rökfræði. Notuð er aðferð við gerð spár fyrir flæði um höfnina sem tekur tillit til þekkingaróvissu og eykur þannig áreiðanleika niðurstaðna spárinnar. Aðferðin skilgreinir þjóðhagslega áhrifaþætti á afkastagetu hafna með aðferð gagnkvæmra upplýsinga (e. mutual information) og beitir síðan Bayesískri tölfræði til að spá fyrir um afköst hafnarinnar. Árangursríkar aðgerðir eiga að geta nýtt tækifæri og takmarkað veikleika á áætluðum líftíma hafnarinnar, þar sem höfnin getur aðlagast eða þolað duttlunga framtíðarinnar betur. Sá ólínuleiki í að takast á við óvissu með því að beita skipulagsrammanum stuðlar að betra hafnarskipulagi. Skipulagsamminn styður ákvarðanatöku í óvissu umhverfi með því að auðvelda sveigjanlega skipulagsgerð fyrir hafnir. Skipulagsrammanum er beitt á hafnir Ísafjarðar. Helstu niðurstöður benda til þess að óvissan feli aðallega í sér tækifæri til skamms tíma, en til lengri tíma stendur hafnarkerfið frammi fyrir veikleikum.

To my beloved Family.

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Peer-Reviewed Journal Publications

Eskafi, M., M. Kowsari, A. Dastgheib, G. F. Ulfarsson, G. Stefansson, P. Taneja, and R. I. Thorarinsdottir. 2021. "A Model for Port Throughput Forecasting Using Bayesian Estimation", *Maritime Economics and Logistics*, 23 (2), pp. 348-368. https://doi.org/10.1057/s41278-021-00190-x

Eskafi, M., M. Kowsari, A. Dastgheib, G. F. Ulfarsson, P. Taneja, and R. I. Thorarinsdottir. 2021. "Mutual Information Analysis of the Factors Influencing Port Throughput", *Maritime Business Review*, 6 (2), pp. 129-146. https://doi.org/10.1108/MABR-05-2020-0030

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Eskafi, M., R. Fazeli, A. Dastgheib, P. Taneja, G. F. Ulfarsson, R. I. Thorarinsdottir, and G. Stefansson. 2020. "A Value-Based Definition of Success in Adaptive Port Planning: A Case Study of the Port of Isafjordur in Iceland", *Maritime Economics and Logistics*, 22 (3), pp. 403-431. https://doi.org/10.1057/s41278-019-00134-6

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Eskafi, M., M. Kowsari, A. Dastgheib, and G. F. Ulfarsson. 2020. "Forecasting Container Throughput Using a Bayesian Model", *PIANC Asia Pacific Conference*, Fremantle, Australia, December 1-3.

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Glossary

2-D	2-Dimensional
3-D	3-Dimensional
ACPI	Average yearly Consumer Price Index
AHP	Analytic Hierarchical Process
APP	Adaptive Port Planning
AUD	Addressing Uncertain Development
Bits	2-based logarithm
CI	Confidence Interval
COVID	Coronavirus
CPI	Consumer Price Index
Dits	10-based logarithm (log)
EFQM	European Foundation for Quality Management
EIA	Environmental Impact Assessment
FFF	Fertilizer and Fish Feed
FIS	Fuzzy Inference System
FOL	Fuel Oil
GDP	Gross Domestic Product
INM	Industrial Materials
ISK	Icelandic Krona
JICA	Japan International Cooperation Agency
LUD	level of Uncertain Development
MAP	Marine Products
MCA	Multi-Criteria Analysis
MEL	Maritime Economics and Logistics
MI	Mutual Information
Nats	Natural logarithm (ln)
NGDP	National Gross Domestic Product
NPOP	National Population
OPP	Opportunity
OR	Operational Research
PDCA	Plan Do Check Act
PIANC	World Association for Waterborne Transport Infrastructure
PSM	Problem Structuring Method
PT	Port Throughput
RCM	Road Construction and Maintenance materials
SCA	Strategic Choice Approach
SGC	Small General Cargo
SODA	Strategic Options Development and Analysis
SSM	Soft Systems Methodology
SWOT	Strengths Weaknesses Opportunities Threats
T	Tonne
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
USD	United States Dollar
VFT	Value-Focused Thinking
VNET	Volume of National Export Trade
VNIT	Volume of National Import Trade
VUL	Vulnerability
WGDP	World Gross Domestic Product

Acknowledgments

First and foremost, I would like to express my sincere appreciation to my supervisor Prof. Guðmundur Freyr Úlfarsson for his invaluable advice throughout my Ph.D. I deeply thank him for his devoted countless hours to me, and his continuous efforts to support my Ph.D.

I dedicate many special thanks to my co-supervisor Dr. Ali Dastgheib for his professional guidance on my Ph.D. research which provided me valuable insight into different aspects of port planning and infrastructure design. I sincerely appreciate the immense knowledge that he shared in our numerous meetings.

I would like to acknowledge that much of my inspiration comes from the pioneering work of “the flexible port” by Dr. Poonam Taneja at the Delft University of Technology. I wish to thank Dr. Taneja for her significant guidance on my Ph.D. research.

I appreciate the valuable suggestions and insightful comments on my Ph.D. research by Prof. Gunnar Stefánsson.

I would like to express my gratitude to Prof. Ragnheiður Inga Þórarinsdóttir for believing in me and giving me this opportunity to start my Ph.D. under her supervision. I am grateful for her fruitful remarks on my research.

I would like to thank Dr. Reza Fazeli and Dr. Milad Kowsari for their contributions that enriched and strengthened my Ph.D. research.

I would also like to thank Maurits van Schuylenburg, from the Port of Rotterdam for his valuable input to my research.

I am indebted to Guðmundur Magnús Kristjánsson, the Director of the Ports of Isafjordur Network, for providing me data and facilities at the Port Office. I am thankful for his support from the very first time, and his valuable contribution to my Ph.D. research.

I would like to especially thank the Mayor of the Municipality of Isafjordur, Birgir Gunnarsson, and other staff in the municipality, particularly, Axel Rodriguez Överby who provided support and shared information and data for my Ph.D. research.

I would like to thank the former Mayors of the Municipality of Isafjordur, Gísli Halldór Halldórsson, and Guðmundur Gunnarsson. I owe a debt of gratitude to their genuine support and positive attitude.

And finally, I am grateful to my family for their never-ending and whole-hearted supports. Words are not enough to describe my gratitude to them.

I wish to acknowledge the generous support of the Municipality of Isafjordur (Ísafjarðarbær) Fund. This study was supported by a Doctoral grant from the University of Iceland Research Fund (Rannsóknasjóður Háskóla Íslands), and also the Icelandic Road and Coastal Administration Research Fund (Rannsóknasjóður Vegagerðarinnar).

1 Introduction

1.1 Developments in the Port Sectors

Ports are dynamic and complex engineering systems that have always been evolving to satisfy the new or changing demands of stakeholders. Some of the components of a port system (i.e., physical, technical, operational, and institutional) themselves represent complex systems that indicate their emergent and non-linear behaviors with different evolution patterns (Taneja 2013). In port development projects, decision makers are being faced with fast-paced, transformative, and often unexpected changes. The long technical lifetime of (mostly) indivisible port infrastructure, huge capital investments with a long payback period, their changing function (e.g., transport, industrial, distribution), and changes in type and volume of cargos face decision makers with many uncertainties in the planning process (Taneja, Ligteringen, and Van Schuylenburg 2010). Decision making under uncertainty is challenging. Indeed, in this volatile environment, ports are developed under a high degree of uncertainty including opportunities and vulnerabilities.

Vessel traffic has been significantly growing in ports all around the world due to world globalization and containerization (Bellsolà Olba et al. 2017). This growth has increased the number of port calls (UNCTAD 2016), and vessels' size (increased by 1200% vessel capacity in 50 years) (Dulebenets 2018). This sustained growth of containerized cargos has also been shown in Iceland (Eskafi et al. 2020a). Furthermore, climate change has been creating new opportunities for maritime transportation across the Arctic Ocean (Tavasszy et al. 2011) as the Arctic region may offer ice-free sea routes in summer seasons by 2030 (Wright 2013). Shipping companies deploy large vessels to benefit from economies of scale, emission reduction, and a decrease in fuel consumption per unit during the voyage (Bellsolà Olba et al. 2017). However, the deployment of large vessels imposes pressure on port infrastructure, operation, and services. Limited or insufficient port infrastructure to cater for larger vessels (that demand deeper water, larger cranes, longer berths, and larger yards) leads to congestion, safety and efficiency issues at ports (Bellsolà Olba et al. 2019). For instance, the Suez Canal is one of the World's busiest waterways, and about 12% of global trade passes through the Canal. The Canal provides the shortest sea link between Asia and Europe by connecting the Mediterranean Sea to the Red Sea. However, a new generation of an ultra-large vessel (i.e., the Ever Given with 400 m long and 59 m wide) ran aground and blocked the path across the Canal in 2021. This caused a traffic jam, and many vessels were stuck in lines in both directions and waiting to pass through the Suez Canal.

In addition, the growth in cargo volumes over the last few decades has led to a port capacity shortage both at land and sea sides. However, new or changes in policies and legislation at international, regional, and national levels on safety and security create restrictions for the expansion of port infrastructure, operation, and services.

Breakthroughs in science and technology present innovative solutions to increase productivity and efficiency (e.g., new cargo handling and logistic concepts) and also address a whole variety of issues, related to operational efficiencies, environmental conditions, safety, and security (Johansen 2007). However, these pose challenges to port authorities by introducing new functional, organizational, and procedural requirements in port development projects. For instance, the rapid increase in terminal productivity because of developments in information and communication technology leads to congestion if infrastructure (e.g., road capacity) is insufficient in a port or its hinterland. Automation and robotizations have resulted in intense pressures on infrastructure and operations, in terms of planning, design, and associated investments.

Accounting for three dimensions of sustainability (i.e., economic, social, environmental) has become a high-profile objective of decision making in port planning. Increase attention to global warming and climate change, depletion of energy sources, and degradation of the environment have created a greater emphasis on the environmental impact of port development projects. Port projects might be hampered due to constraints by new or changing environmental regulations. Port expansion should be in harmony with the surrounding towns to maintain the social license to operate and grow, responsible for the natural environment, and fulfill strict environmental regulations, while promoting economic development (PIANC 2014). Growth in container/cargo volume and increasing focus on sustainability induce a modal shift toward a more environmentally friendly form of transport and logistics from road haulage to short-sea shipping and/or inland shipping. However, reliability, capacity, frequency, and cost of modal choice create a highly volatile intermodal market (Notteboom 2009).

In North America and Europe, the cruise sector has been growing faster than other segments of the travel industry. This growth has not only affected cruise ship fleets with a greater number of itineraries and larger vessel sizes (Tsamboulas, Moraiti, and Koulopoulou 2013) but also is expected to continue for the next 10 to 20 years in Europe (Van Dorsser, Taneja, and Vellinga 2018). Also, cruise companies are increasingly looking for new destinations, diversified itineraries to unvisited, smaller, less-well-known, and less-frequented ports of call. However, port infrastructure restrictions have limited (relatively) large cruise ship calls (Ros Chaos et al. 2020). In this vein, neighboring ports of call can be complementary in offering services to cruise calls (Tsamboulas, Moraiti, and Koulopoulou 2013). Until recently, the cruise sector had been the fastest-growing and the most dynamic segment of transportation and tourism in the world. However, due to the COVID-19 pandemic in 2020-2021, many countries closed their borders while cruise vessels sought a port to dock, and thus thousands of passengers were kept at sea. The pandemic had a significant financial impact on the revenue of cruise operators. Many cruise ships were (temporarily) withdrawn from service. Furthermore, ports of call around the world that rely on tourism, heavily affected by the disturbance to the cruise industry.

Growth in industrial fisheries, sustainable aquaculture including fish farming, and further processing (e.g., packing, freezing) have affected fishing ports. These ports have been continuously developed to provide new infrastructure requirements of modern fishing vessel berthing, their off-loading facilities, repair and service of sophisticated equipment, and specialized terminal (Ligteringen 2017; PIANC 1998). Furthermore, fishing activities are seasonally influenced and also depend on the availability of fish. Therefore, peaks and lows in fishing activities are observed, when the majority of the fishing fleet is either at the sea or the port, respectively. Fishing ports should meet the needs for value-added activities (e.g., processing, warehousing, marketing, and distributing) of marine/aquaculture products and comply with environmental and safety criteria. Thus, fishery activities might be separated from commercial port activities (Ligteringen 2017). Nevertheless, the changing port functions/activities due to changes in fishing quotas, political and environmental regulations surrounding aquaculture activities, and national infrastructure developments add to the uncertainties in the development of fishing ports.

Additionally, numerous stakeholders with different temporal and spatial objectives, and changing salience in the projected lifetime of a port are involved in the planning process (Eskafi et al. 2019a). Port planning is highly affected by the influence and concern of multiple heterogeneous key stakeholders. Their objectives are in most cases divergent and even conflicting. The difficulty of reaching a consensus on the goals of port planning among the diverse stakeholders further adds challenges in the port planning process (Eskafi et al. 2020b).

Moreover, black-swan events (Smil 2012) that represent low probability but high impact events, for instance, the financial crisis in 2008, natural disasters, such as the avalanche in Flateyri (Iceland) in 2020, and the volcanic eruptions in Iceland in 2010, the Hurricanes Katrina and Rita in 2005, the Indian Ocean earthquake and tsunami in 2004, show that ports are developed for an uncertain and unpredictable future. Commensurate with the volatile circumstances at the time of writing this dissertation, the outbreak of the Coronavirus disease (COVID-19) pandemic has significantly affected maritime sectors, cruise ship calls have slumped, and there is a concomitant decline in cargo throughput (Zhang, Gong, and Yin 2020). The present uncertain situation in maritime sectors due to the COVID-19 pandemic was not anticipated.

Port sectors are in a state of radical changes, and the major challenge in port planning is to deal with confronting uncertainties that appear during a port's long technical lifetime (Taneja et al. 2012). Uncertainty in port planning projects implies that decision making is based on incomplete knowledge about the projects. Uncertainty is categorized by its level, nature, and location. These three categories meaningfully affect the choice of uncertainty handling methods. The level of uncertainty expresses the degree or severity of uncertainties. Walker, Marchau, and Kwakkel (2013) presented a range for the level of uncertainties from complete certainty to total ignorance and 4 intermediate levels. The nature of the uncertainty can either be due to a lack of knowledge or it is inherent to a phenomenon. These are referred to as epistemic and aleatory uncertainties, respectively. The location of uncertainty refers to where the uncertainty manifests itself in the system under consideration. This uncertainty is relevant to the external forces on the system, response to the forces, and the valuation of the outcome (Taneja 2013).

Long-term planning implies a high degree of uncertainty. Taneja et al. (2012) stated that the main reason for unsuccessful port development projects is inadequate consideration of uncertainty in the planning process. Unsuccessful port projects may result in a loss of investment, failure of the projects, congestion in the port area or hinterland, redundancy and obsolescence of ports, and costly regular adaptations of port infrastructure, operational facilities, and services (Taneja et al. 2012; Taneja, Ligteringen, and Walker 2012). It might be ineffective or uneconomical to change a port's function during its projected lifetime. Flexibility is to be the most important uncertainty management concept for port projects (Taneja 2013). Taneja (2013) presented Adaptive Port Planning (APP) to develop a flexible port that can adapt to changing conditions (e.g., market demand) under which the port must operate. Thus, APP provides functionality, capacity, and service quality over a longer time horizon (Ligteringen 2017). APP acknowledges the importance of dealing with uncertainties in port planning processes.

However, dealing with uncertainties that manifest during the projected lifetime of the plan is a challenging task and requires qualitative and quantitative analyses. Therefore, the present dissertation, which is in line with APP's steps, proposes a framework for dealing with uncertainties in the port planning process, and seize opportunities and manage vulnerabilities in the projected lifetime. The presented framework facilitates adaptive port planning. In this dissertation, port planning deals with the development of a new port (green-field port development) and/or the expansion or conversion of an existing port (brown-field port development) (Ligteringen 2017).

Uncertainties and the existing, prevailing, and emerging trends that directly or indirectly affect a complex port system should be examined in the planning process (Taneja 2013). Van Dorsser, Taneja, and Vellinga (2018) pointed out that forecasts do not perform well under a volatile and uncertain market environment. The capability of forecasting models to account for the effects of disruptions is limited (De Langen, Van Meijeren, and Tavasszy 2012). Forecast models include an inherent uncertainty that increases over time (Manzo, Nielsen, and Prato 2015). Furthermore, forecast models have uncertainties associated with input data and models (Rasouli and Timmermans 2014). Although forecast reduces uncertainty, it focuses on a specific uncertain development (Lempert 2019). However, port development only based on a single-issue focus of dealing with an uncertain development may not be sufficient due to the complexity of a port system (Habegger 2010). A linear planning approach based on a deterministic projection of demand is insufficient in a dynamic world. Walker, Haasnoot, and Kwakkel (2013) echoed that a static plan using a single most likely future may fail if another future materializes. Furthermore, scenario planning, as an alternative approach to predict the future, may not seize opportunities offered by the transitions in port planning projects (Van Dorsser, Taneja, and Vellinga 2018). Scenarios cannot capture trend-break/breakthrough developments. Herder et al. (2011) pointed out that instead of investing efforts to reduce uncertainties, different methods at different time horizons should be applied to coexist with uncertainties.

The developments in the port sectors have always been forcing ports to evolve. Despite the challenges confronting the rapidly changing and volatile market environment, dealing with uncertainties in port planning is still limited.

1.2 Research Questions

The complexity of a port system and the concomitant uncertainties during its projected lifetime signify the importance of dealing with uncertainty in the port planning process. Hence, this dissertation proposes a structured framework to systematically address uncertainties and deal with them in the planning process. It formulates various planning strategies and actions aimed at protecting the plan against (market) failure and moving it toward success in the projected lifetime. The framework provides building blocks to improve the quality of port planning under different uncertainties. The framework can be readily employed by port authorities to identify and deal with uncertainties in their port planning projects.

The research objective is to present methods to identify the uncertainties, including opportunities and vulnerabilities, that manifest during the projected lifetime of the plan and to deal with them in the planning process. Therefore, the main research question is formulated as follows:

How can uncertainties in a projected lifetime of a port be identified and dealt with in the port planning process?

To answer this main question, the following research questions are addressed in this dissertation:

1- How can stakeholders be prioritized for their effective and timely engagement in the port planning process?
2- How can consensus be reached among stakeholders on the definition of success in the port planning process?
3- What are the main influential parameters for forecasting port throughput?
4- How can epistemic uncertainty be accounted for in a port throughput forecast?
5- How can uncertainties be dealt with in the port planning process?

1.3 Organization of the Dissertation

The research approach is to pursue the sequence of steps directly linked to the research questions. The research questions are answered in the chapters discussed below. Each chapter (i.e., chapter 2 to chapter 6) is based on a published peer-review ISI journal article.

Chapter 1: Introduction:

The dissertation is organized into eight chapters. The current chapter sets the background and presents the motivation of the research. It introduces the main research question. The outline of the dissertation, the research approaches, and methods are briefly provided. Finally, it describes an Icelandic port that represents the many ports that could have served as a case to demonstrate the methods presented in this dissertation.

Chapter 2: This chapter addresses research question #1:

- *How can stakeholders be prioritized for their effective and timely engagement in the port planning process?*

The complex nature of a port system involves a wide range of stakeholders with a broad spectrum of involvement. The port planning is highly affected by the temporal and spatial changing power and interests of stakeholders. It is necessary to understand and assess the dynamic nature of power and interests of the key stakeholders. They drive decision making in the port planning process and thus their engagement is a vital part of planning. This chapter presents a structured framework of stakeholder analysis for effective and timely engagement of the key stakeholders in the port planning process. The framework deals with a systematic procedure of identification, grouping, and then the static mapping of stakeholders using a power-interest matrix. Furthermore, a fuzzy logic 3-dimensional (3D) decision surface is developed for dynamic salience mapping of the stakeholder groups. A survey and face-to-face interviews are conducted as tools to collect input for the stakeholder analysis based on their objectives of the port planning. The 3D decision surface manifests the dynamic attributes of stakeholder groups and their latent salience. The results of the decision surface show different salience of key stakeholders, including legislation and public policy, internal, and external groups in the port planning. Thus, different strategies of engagement with them should be applied. The decision surface indicates the internal stakeholder group possesses a high degree of attributes and consequently salience in the port planning process.

Chapter 3: This chapter addresses research question #2:

- *How can consensus be reached among stakeholders on the definition of success in the port planning process?*

Multiple stakeholders with a wide range of objectives are engaged in a port system. Port planning processes should start with defining success in terms of the specific objectives of stakeholders. Based on the definition of success, port authorities should determine the necessary decisions in the port planning process. Success is achieved if the outcome of planning fulfills the objectives of the stakeholders. In this chapter, a decision-support approach is presented to formulate a definition of success. The approach synthesizes an appropriate problem structuring method with stakeholder analysis and combines these with a fuzzy logic method to reach a consensus among multiple stakeholders on the definition of success in the planning process. Values of stakeholders about port planning are structured around the Value-Focused Thinking method (VFT) to identify stakeholders' objectives. The highest level of agreement on the objectives, which is viewed as a success in port planning, is revealed by the fuzzy multi-attribute group decision-making method. Success is defined by prioritizing an increase in competitiveness among other planning objectives, such as effective and efficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, better environmental implications, flexibility creation, and increasing positive economic and social impacts.

Chapter 4: This chapter addresses research question #3:

- *What are the main influential parameters for forecasting port throughput?*

The selection of promising cargo for a port characterizes the strategy and direction of port planning projects. Appropriate investment in port capacity development, based on the promising cargos, helps to grow market share and strengthen the competitive position of the port. Cargo flow analysis is a complex task as it is interwoven with a variety of cargos handled in the port which are in turn influenced by numerous factors including macroeconomic variables. In this chapter, mutual information is applied as a quantitative method to determine the dependencies between different types of cargo and port throughput and identifies the prominent cargos that would heuristically describe the port throughput. Furthermore, mutual information measures the level of correlation between port throughput and macroeconomic variables by quantifying the amount of information held between them. The results for the Icelandic case show that marine products are the main export cargo, whereas most imports are fuel oil, industrial materials, as well as marine product cargos. The aggregation of these cargos meaningfully determines the non-containerized port throughput. The non-containerized throughput shows a strong relation to the national gross domestic product. The volume of national export trade is the key influencing macroeconomic variable to the containerized throughput. Application of the mutual information effectively reduced epistemic uncertainty in the port throughput analysis by identifying the main cargos and key influencing macroeconomic variables.

Chapter 5: This chapter addresses research question #4:

- *How can epistemic uncertainty be accounted for in a port throughput forecast?*

An investment decision to develop port capacity should be supported by growing demand. Demand is changing and uncertain in the volatile market environment. Forecasting models themselves are associated with epistemic uncertainty due to model and parameter uncertainties. In this chapter, a Bayesian statistical method is applied to account for model uncertainties in the port throughput forecast. The parameter uncertainties are handled by selecting influencing macroeconomic variables based on mutual information analysis. The Bayesian statistical method is an effective approach that allows the combination of knowledge about parameters in a synthesis of prior knowledge with the available data. The macroeconomic variables are considered random variables and their associated uncertainties are quantified by the posterior distribution. A forecast model is presented that not only gives a point forecast which has the highest probability but also offers a range of port throughput forecasts with confidence intervals. The model meaningfully increases the reliability of forecast results. It provides support for informed decision making in port capacity planning and management to develop flexibility and create a buffer to satisfy changing and uncertain demand. The results for the Icelandic case show a forecasted constant linear growth of containerized throughput during 2020-2025. Non-containerized throughput is forecasted to decrease rapidly but the decline gradually slows during the forecast period.

Chapter 6: This chapter addresses research question #5:

- *How can uncertainties be dealt with in the port planning process?*

The ever-growing complexity in port sectors in a volatile environment creates a high degree of uncertainty in port planning projects. In this chapter, a structured framework is presented to deal with uncertainties in the port planning process. Based on three components, uncertain developments that are manifested during the projected lifetime of the plan are identified. The components are: 1- stakeholder analysis to a) identify key port stakeholders, b) disclose stakeholder objectives and consequently define the success of port planning, and c) identify uncertain developments around stakeholder activities and objectives, and determine different planning horizons by face-to-face interviews with key stakeholders and literature review; 2- different methods to systematically address uncertain developments in the port planning; and 3- SWOT analysis to identify opportunities and vulnerabilities derived from uncertain developments. Taking the strengths and weaknesses of the port into consideration, in conjunction with uncertain developments, opportunities and vulnerabilities are recognized. Effective actions are planned to seize opportunities and manage vulnerabilities aimed at moving the plan toward its success. The framework supports decision makers for informed decision making by enabling them to choose a preferred course of action in the face of uncertainty. The value of this framework lies in the nonlinearity of dealing with uncertainties in different time horizons. The results for the Icelandic case show that demand for aquaculture and cruise activities create the main uncertainties for the port network. Uncertainties mainly present opportunities in the short-term horizon, while in the middle-term horizon the port network is confronted with multiple vulnerabilities.

Chapter 7: This chapter concludes the dissertation with overall findings.

Chapter 8: This chapter proposes recommendations for future research.

The reference list accumulates all references in the dissertation, including the published papers.

The appendix gives the list of stakeholders as well as interviewees, the survey for stakeholder analysis based on their objectives, the port functions, the port SWOT analysis, and the summary of addressed uncertainties.

Figure 1.1 outlines this dissertation along with the contributions of each chapter.

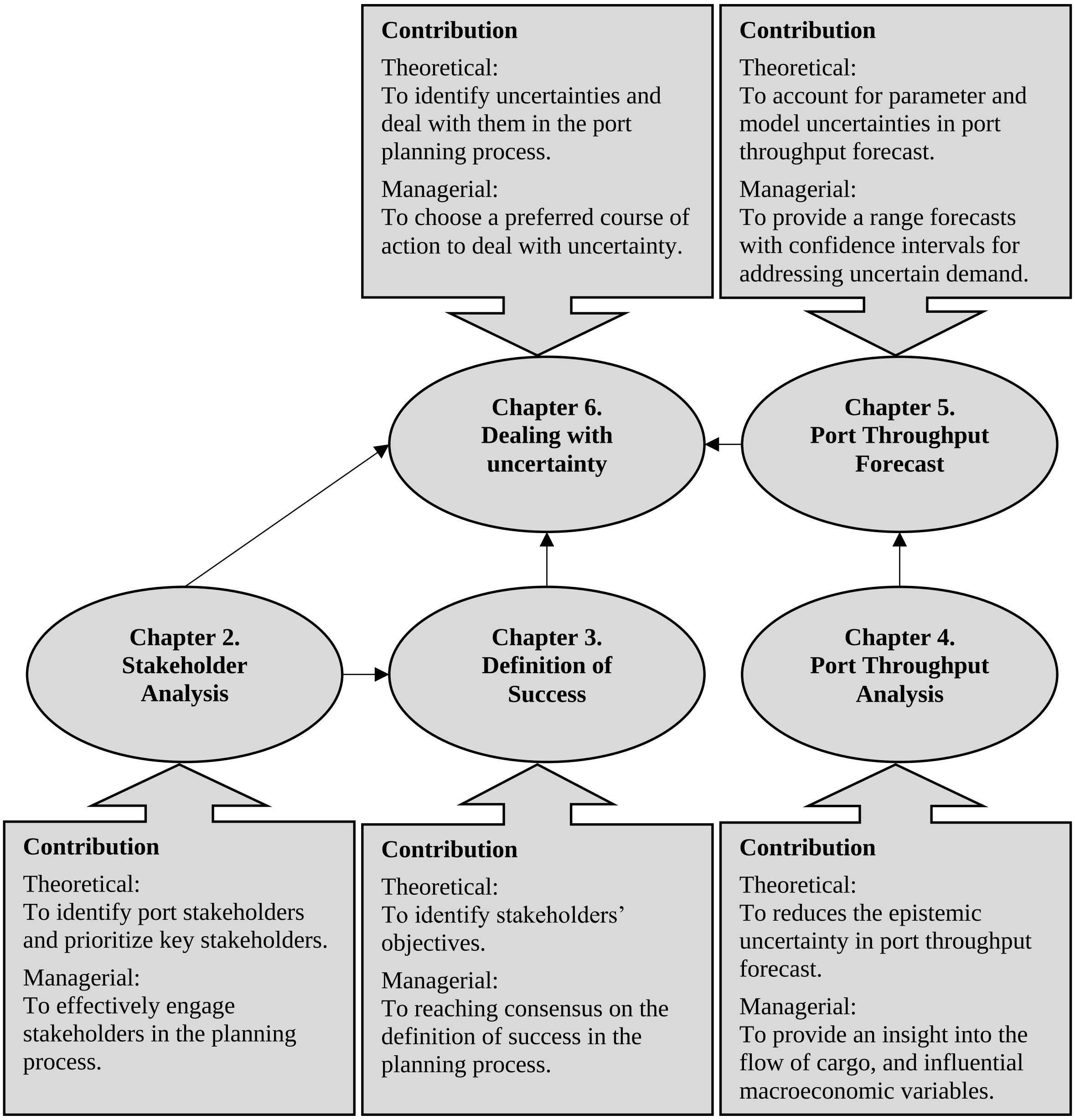

Figure 1.1 Schematic outline of the dissertation

1.4 Theory and Methods Used

This subchapter outlines the theory and methods used in this research.

1.4.1 Stakeholder Prioritization in the Port Planning

A port system involves a variety of stakeholders with a broad spectrum of involvement. Although stakeholder analysis categorizes stakeholders, it has been criticized because it is often ad-hoc and relinquishes the spatial and temporal changing attributes of stakeholders. A framework is presented to map stakeholders' salience using a fuzzy logic 3-dimensional (3D) decision surface for their effective and timely engagement in the planning process.

Identification of Stakeholder

Stakeholder identification and their engagement in a project is an important task. Focus groups, expert interviews, forums, questionnaires, stakeholder circle methodology, surveys, workshops, brainstorm have been used for stakeholder identification. However, through literature reviews and focus groups, only an initial list of stakeholders is developed. A project manager or a group alone may not have the skill and resources to identify all stakeholders. Snowball technique is a suitable method for stakeholder identification (Lienert, Schnetzer, and Ingold 2013) as it benefits from the knowledge and experience of (professional) networks. It assures a variety of suggestions from different perspectives for the identification of stakeholders (Colvin, Witt, and Lacey 2016). Using this method, most likely all stakeholders can be identified (Yang 2014). In this research, the snowball technique is used to identify port stakeholders.

Engagement of Stakeholder

Decision making can be enriched about the drivers of port development by engaging stakeholders. Stakeholders can be engaged through questionnaires, interviews, email, phone, focus groups, surveys, Delphi approach, forums, workshops. In this research, the stakeholders are contacted first by email and phone call to provide general information about the project, and then face-to-face interviews to gather information about the objective of port planning (see: 1.4.2 Definition of Success in the Port Planning). To aggregate the input data for salience measurement, a written survey is developed. Survey has several advantages in comparison to other methods of data gathering from stakeholders such as expert views, workshops, meeting, etc. A survey engages stakeholders in a task-oriented manner. It encourages stakeholders to express their thought and provides a range of perspectives. Furthermore, it gives privacy to stakeholders for independent information sharing.

Differentiation and Grouping of Stakeholders

In this research, stakeholders are categorized into groups based on similarities in their roles, characteristics, contributions, interests, and influence. Therefore, stakeholders in a group can be viewed with a common area of interest and power to the port planning. The groups can be unbundled in several sub-groups based on the overarching nature of engagement undertaken and the interrelations of stakeholders together and to the port planning. In this research to (sub)group stakeholders, a literature review on stakeholders' categorization is carried out.

Identification of Stakeholders' Objectives

Interviews can provide valuable qualitative and quantitative information about the objective of different stakeholders (Mason et al. 2015). However, the outcome of conducting interviews is acceptable if stakeholders are able or willing to share their objectives (Jepsen and Eskerod 2009). Also, it might be expected that the information is restricted to the limited interviewees' experiences and knowledge (Mccarthy, Van Iddekinge, and Campion 2010). Thus, to ensure the validity of information and data gathering, it is important to consider the education, experience, and position of each interviewee (Hartwell, Johnson, and Posthuma 2019). Furthermore, to increase the reliability of the result, the number of interviews should be taken into account (Fifić and Gigerenzer 2014). In this research, to identify stakeholders' objectives, semi-structured open-ended face-to-face interviews were conducted with the widest possible range of stakeholders who are well informed about the interests, and influence of their organization/institute/company into the planning. Using separate interviews increases the possibility of stakeholders' participation for providing input and more comfortable and honest information sharing (Phuong Vu, Grant, and Menachof 2019). Interpretation and elicitation of the objectives were based on the Value-Focused Thinking (VFT) method (see: 1.4.2 Definition of Success in the Port Planning).

Stakeholder Mapping

Stakeholder mapping using a power-interest matrix is a management tool to categorize stakeholders by their power and interest. It provides a better picture of key stakeholders that should be prioritized in a project. However, a power-interest matrix does not differentiate between stakeholders within one quadrant and assumes they have the same characteristics. It does not give priority to stakeholders in the same quadrant. This limitation face decision makers with challenges for effective engagement of stakeholders (Elsaid, Salem, and Abdul-Kade 2017). Stakeholders may play different or changing roles in a plan (Missonier and Loufrani-Fedida 2014). However, a power-interest matrix assigns stakeholders to only one predefined category as the result of a specific time point, which is a shortcoming (Poplawska et al. 2015). To ensure in-depth consideration of power, interest, and salience of stakeholders in decision making, stakeholders are mapped based on fuzzy logic. The Fuzzy Inference System (FIS) is applied to implement fuzzy logic, and the Mamdani-type inference system is selected because it permits suitable modeling of human input (Munda, Nijkamp, and Rietveld 1994). The FIS relates input (power, interest) and output variables (salience), to develop the decision surface. The five main steps of FIS include defining the membership functions of fuzzy sets; the fuzzy if-then rules; the unit of decision making; the fuzzification interface; and the defuzzification interface (Muñoz, Rivera, and Moneva 2008). Using the fuzzy logic approach, the stakeholders receive a degree of membership instead of a discrete class. To analyze the stakeholders based on the 3D decision surface, the following steps are conducted:

Step 1- The result of the survey is aggregated by the average of given weight to the attributes of the stakeholder group on the objectives of port planning.

Step 2- The stakeholders' attribute profile is calculated by minimum, average and maximum aggregated weights in step 1, as follows:

$$Power\ (P_{min}, P_{avg}, P_{max}) \tag{1.1}$$

$$Interest\ (I_{min}, I_{avg}, I_{max}) \tag{1.2}$$

Step 3- The salience of the stakeholder group is calculated by averaging the values of the attribute profiles in step 2 for a group, as follows:

$$Salience\ \left(\frac{(P_{min}+I_{min})}{2}, \frac{(P_{avg}+I_{avg})}{2}, \frac{(P_{max}+I_{max})}{2}\right) = (S_{min}, S_{avg}, S_{max}) \tag{1.3}$$

Step 4- The degree of membership of the stakeholder group is defined in a fuzzification process based on the membership functions of power and interest attributes.

Step 5- The rule of stakeholder to the attributes is generated based on the result of step 1.

Step 6- The salience function of the stakeholder group is defined in a defuzzification process and obtained by:

$$Y = \frac{(X_{min} + 2 \times X_{avg} + X_{max})}{4} \tag{1.4}$$

where X_{min} is the minimum value, X_{avg} is the average value, and X_{max} is the maximum value calculated from step 1.

Step 7- Using the Fuzzy Logic Toolbox in MATLAB, the 3D decision surface is created by multiplying membership functions of power and interest developed in step 4.

Step 8- The stakeholders are positioned on the decision surface based on their average power, interest, and salience calculated in steps 2 and 3 as:

$$Central\ point = (P_{avg}, I_{avg}, S_{avg}) \tag{1.5}$$

1.4.2 Definition of Success in the Port Planning

Multiple stakeholders with a wide range of objectives are engaged in port planning. In this research, an integrated framework is presented to reach a consensus on the definition of success in port planning among stakeholders with different interests, influences, and objectives. The framework synthesizes a problem structuring method with the stakeholder analysis (see: 1.4.1 Stakeholder Prioritization in the Port Planning) and combines these with the fuzzy logic to support decision makers in formulating a definition of success in port planning.

Value-Focused Thinking (VFT) Method

Belton and Stewart (2010) stated that in the first step of decision making among multiple stakeholders, problems should be identified, understood, and structured. Problem Structuring Methods (PSM) facilitate decision-making processes by identifying and structuring a problem to reach a consensus on a solution among decision makers (Ackermann 2012). In this research, to formulate a definition of success, the VFT method is selected as an appropriate PSM. The main reason is that stakeholders care about the values of port development. Arecco et al. (2016) and Slinger et al. (2017) emphasized that the values of port development should be identified, evaluated, harmonized, and then prioritized in the planning process. Therefore, a decision situation should begin with the elicitation of values (Alencar, Priori Jr., and Alencar 2017). The VFT method provides a systematic approach for identification and specification of values, structuring and categorizing these values, converting them to the means objectives, recognizing the relationships among objectives, prioritizing the means objectives to achieve the fundamental objective (Keeney 1996; Sheng, Nah, and Siau 2005). To identify values, face-to-face semi-structured open-ended interviews are conducted (see: 1.4.1 Stakeholder Prioritization in the Port Planning).

Fuzzy Multi-Attribute Group Decision-Making Method

To define the final level of agreement among the preferences of stakeholders regarding the fundamental objective, the fuzzy multi-attribute group decision-making method is used. The model provides a common decision from different stakeholders with a multiplicity of objectives. In the model, *n* stakeholders have a preference ordering of P_k, where $k \in n$ and a set of means objectives, *X*, are ordered. Preference *S* is defined as a fuzzy binary in terms of membership grade function, as:

$$\mu s: X \times X \rightarrow [0,1] \tag{1.6}$$

where the membership grade $\mu s(x_i, x_j)$ is the degree of preference of the means objective x_i over x_j. Individual preferences are aggregated by the relative popularity method (Kahraman, Ruan, and Doğan 2003). The relative popularity of means objective x_i over x_j was calculated by dividing the number of individuals who preferred means objective x_i to x_j, shown as $\mathrm{N}(x_i, x_j)$, by the total number of individuals, *n*:

$$\mu s(x_i, x_j) = N(x_i, x_j) n \tag{1.7}$$

Based on the relative popularities of the means objectives, two clusters of high and low importance were defined. After defining the fuzzy relationship *S*, the non-fuzzy preference is obtained from the component of *S* as:

$$S = U_\alpha \alpha S_\alpha \tag{1.8}$$

where α-cuts of the fuzzy relation S form the crisp relations S_α, and $\alpha \in A_S$ is measured by α, where α is the level of agreement among the individual key stakeholders on a crisp ordering S_α.

To maximize the final level of agreement among the key stakeholders' preferences for the means objectives, the classes of crisp total orderings are intersected with the pairs in the α-cuts S_α with smaller values of α. This process is continued until a single crisp total ordering is obtained. The pairs (x_i, x_j) that lead to an intransitivity is eliminated. The maximum level of agreement among key stakeholders for the preference is obtained from the largest value α for a specific ordering.

1.4.3 Port Throughput Analysis

Port throughput analysis is a complex task as a variety of cargos is handled in a port, and numerous factors including macroeconomic variables influence the flow of cargos. In this research mutual information analysis is applied to evaluate the dependencies of port throughput to different types of cargo, and then identify the influential macroeconomic variables on port throughput.

Mutual Information Analysis

As there are nonlinear relations between port throughput and macroeconomic variables, a single linear model or application of traditional regression methods may result in inaccurate analysis performance (Gökkuş, Yıldırım, and Aydin 2017). Furthermore, the correlation coefficient is only able to detect linear dependencies (Sagar and Guevara 2005). In information theory, mutual information measures the amount of information that one variable contains about the other. It identifies the linear and nonlinear dependence between variables and thus overcomes the limitations of Pearson correlation in variable selection (Steuer et al. 2002). Mutual information does not have the limitation of chi-squared tests (Pethel and Hahs 2014) and the max-dependency method, as it does not require much data and has relatively high computational speed (Peng, Long, and Ding (2005). It also has an advantage over a Markov Chain Monte Carlo method for parameter selection (Zuur et al. 2003). Mutual information gives better test performance and faster computation efficiency than Wrapper methods (Li, Xie, and Goh 2009) in variable selection especially when the number of variables is large.

For a pair of random variables (X, Y) with marginal probability distributions of $\mu_x(x)$ and $\mu_y(y)$, mutual information uses the Kullback-Leibler measure to determine the distance between the joint probability distribution, $\mu(x, y)$, and the distribution associated with the case of complete independence (i.e., $\mu_x(x)\mu_y(y)$):

$$(X, Y) = \iint \mu(x, y) \log \frac{\mu(x,y)}{\mu_x(x)\mu_y(y)} dxdy \qquad (1.9)$$

Mutual information is related to the concept of information entropy (Shannon 1948). It quantifies a random variable (X) with possible outcomes (x_i), each with probability $p(x)$:

$$H(X) = -\int_{x \in X} p(x) \log_2 p(x) dx \qquad (1.10)$$

Mutual information is calculated as:

$$\begin{aligned} I(X, Y) &= H(X) + H(Y) - H(X, Y) \\ &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X) \end{aligned} \qquad (1.11)$$

where $H(X)$ and $H(Y)$ are the entropy of random variables X and Y, respectively, $H(X, Y)$ is their joint entropy and $H(X|Y)$ and $H(Y|X)$ are their conditional entropy and obtained by:

$$H(X|Y) = -\iint \mu(x, y) \log \mu(x|y)\, dxdy \qquad (1.12)$$

where $\mu(x, y)$ is the joint probability distribution. The conditional entropy $H(X|Y)$ is the amount of uncertainty left in X when knowing Y. Thus, from these equations, the $I(X, Y)$ is interpreted as the reduction in the uncertainty of the random variable X by the knowledge of another random Y (Maes et al. 1997). Mutual information gives zero value iff the two random variables are statistically independent.

1.4.4 Port Throughput Forecast

Port throughput forecasting plays an important role in port capacity planning and management. To increase the reliability of forecasts, the epistemic uncertainty of the forecast due to model and parameter uncertainties should be accounted for (Liu and Duru 2020). Therefore, a Bayesian statistical method is used to account for model uncertainties, while parameter uncertainties are handled by selecting influential macroeconomic variables based on mutual information analysis (see: 1.4.3 Port Throughput Analysis).

Bayesian Method

The Bayesian statistical method allows the combination of knowledge about parameters, in a synthesis of prior knowledge with the available data. The Bayesian method in port throughput forecasting provides acceptable results with a sparse or relatively small number of input observations. In addition to the point estimate with the highest probability, the model offers a range of port throughput forecasts with confidence intervals. Consequently, the model delivers useful information for developing flexibility in capacity planning to satisfy the changing and uncertain needs of port users. Furthermore, the model has an adaptive learning capability to be updated over time based on new information and provides a continuously updated port throughput forecast. In the Bayesian method, a posterior probability density is proportional to the likelihood function on the data, multiplied by the prior probability density. Using the Bayesian method, a prediction model can be linearized as:

$$\log y_i = C_0 + C_1 x_1 + C_2 x_2 + C_3 x_3 + C_4 x_4 + C_5 x_5 + C_6 x_6 \qquad (1.13)$$

where the dependent variable (y_i) is the annual port throughput; the independent variables (x_i) are the macroeconomic variables; and the coefficients C_0–C_6 are estimated by Bayesian regression. If $y_i = (y_i, \dots, y_n)$ is a vector of historic data, with n number of available observations, the matrix of explanatory variables (X) is expressed as:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix} \qquad (1.14)$$

If the dependent variable (y_i) is assumed a conditional normal distribution, and given the explanatory variables (X), the mean of the normal distribution has a linear function as:

$$\mathrm{E}(y_i | \theta, X) = \theta_1 x_{i1} + \cdots + \theta_k x_{ik} \qquad (1.15)$$

where $\theta = (\theta_i, \dots, \theta_k)$ is a vector of unknown parameters. This means the dependent variable follows a normal distribution, $y_i \sim N(X\theta, \sigma^2 I)$, with a mean of $X\theta$ and variance of $\sigma^2 I$ where I is the $n \times n$ identity matrix.

The posterior distribution describes updated information about the unknown parameter (θ) and is calculated by multiplying a prior distribution by a likelihood function as:

$$p(\theta|y) \propto p(\theta)p(y|\theta) \tag{1.16}$$

where $p(\theta)$ is the prior distribution and $p(y|\theta)$ is the likelihood function.

If the logarithm of the port throughput follows a normal distribution (Ding and Teo 2010), then:

$$p(y|\sigma^2, \theta, X) = \prod_{i=1}^{N} \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{(y_i - (X\theta)_i)^2}{2\sigma^2}) \tag{1.17}$$

where N is the number of available historical observations, y is the vector of the logarithm of the port throughput data, $(X\theta)_i$ is the i-th element of the vector $X\theta$ representing the mean value of the prediction model, and σ is the standard deviation. If a non-informative prior for the unknown parameters, i.e., $p(\theta, \sigma^2|X) \propto \sigma^2$, is assumed, the joint posterior distribution of θ and σ^2 is calculated by:

$$p(\theta, \sigma^2|y, X) \propto p(\theta, \sigma^2|X)p(y|\sigma^2, y, X) \propto \sigma^2 \prod_{i=1}^{n} N(y_i|(X\theta)_i, \sigma^2) \tag{1.18}$$

The posterior distribution of the unknown parameters θ is obtained by using Equation (1,18).

1.4.5 Dealing with Uncertainty in the Port Planning

The long technical lifetime of port infrastructure in the volatile environment makes uncertainty consideration an important task in the planning process. A framework is presented to identify the uncertainties during the projected lifetime of the port plan and deal with them in the planning process aimed at increasing the success of the plan. To develop the framework the following methods are jointly used:

1- Stakeholder analysis to a) identify port stakeholders (see: 1.4.1 Stakeholder Prioritization in the Port Planning, b) disclose stakeholder's objectives and consequently define the success of port planning (see: 1.4.2 Definition of Success in the Port Planning), and c) identify uncertainties around stakeholders' activities and objectives, and determine different planning horizons using interviews with the key stakeholders.

2- Different methods to systematically address uncertain developments. This is because a single-issue focus of dealing with uncertainties may not be enough (Habegger 2010). Therefore, based on the four levels of uncertainties presented by Walker, Marchau, and Kwakkel (2013), uncertainties were addressed by linking them to different disciplines of the future field (Van Dorsser et al. 2018). This approach reduces ambiguity in the literature of dealing with uncertainty (Van Dorsser et al. 2018).

3- SWOT (strength, weakness, opportunity, threat) analysis to identify the strengths and weakness of the port as well as opportunities and vulnerabilities derived from uncertainties.

4- Planning effective actions to seize opportunities and manage vulnerabilities and thus deal with uncertainties. The actions protect the plan against failures and move the plan toward its success (Lempert 2019). These actions are mitigating, hedging, shaping, and seizing actions (Dewar (2002); Taneja (2013); Kwakkel, Walker, and Marchau (2010b)).

SWOT Analysis

Fundamental assumptions are explicit and implicit assumptions that are made in the planning process (Dewar 2002). Fundamental assumptions are opportunities if they are in favor of the plan and move the plan toward its success. Vulnerabilities are thus that cause the plan to fail or hinder achieving the success (Haasnoot et al. 2013). A port SWOT analysis is carried out to identify the opportunities and vulnerabilities. SWOT analysis is a straightforward and commonly used method to recognize the capability and inability of a system (e.g., (Van Dorsser and Taneja 2020)). The port SWOT analysis is first developed by desk research and literature review and then improved by a group of experts with knowledge about port planning and development. Furthermore, to benefit more from different perspectives and knowledge, the interviewed stakeholders are asked to enrich the SWOT analysis.

1.5 A Case of the Ports of Isafjordur Network

The Port Association of Iceland includes 70 ports under 34 port authorities. Most of the ports are relatively small fishing ports that provide services to fishing vessels and relevant activities. Industrial activities and cargo/container handling, distribution, and storage are the main business of larger ports. Most exports from Iceland are manufacturing products (e.g., aluminum, ferrosilicon), marine products (e.g., fresh and frozen, processed and unprocessed marine catch), and agricultural products to the European market (Statistics Iceland Office 2021). A total of 2.26 million tonnes were exported from Icelandic ports in 2019 and 40% of the exports were from the main port, Faxaflóahafnir, in the capital of Iceland. In the same year, 92% of imports to the country were to four Icelandic ports, whereas half of the imports were to the main port in the capital. In 2019, 71.5% of total revenue from Icelandic ports was from six port authorities, namely Faxaflóahafnir (39.4%), Fjarðabyggðarhafnir (9.7%), Hafnasamlag Norðurlands (7.1%), Hornafjarðarhöfn (6.8%), Vestmannaeyjahöfn (4.7%), and Hafnir Ísafjarðarbæjar (3.5%) (Port Association of Iceland 2020).

The methods in this dissertation were demonstrated for an Icelandic case to establish their feasibility for real cases. The application of the proposed framework for the case study not only illustrates its potential use in practice but also gives an opportunity to transparently explore its capability in dealing with uncertainty in the port planning process.

This study was carried out for the Ports of Isafjordur Network (Hafnir Ísafjarðarbæjar) including the Port of Isafjordur (Ísafjarðarhöfn), the Port of Sudureyri (Suðureyrarhöfn), the Port of Flateyri (Flateyrarhöfn) and the Port of Thingeyri (Þingeyrarhöfn), located in the northwest of Iceland. The ports are different in size, capacity, function, and navigational conditions. The geo-position of the network and spatial distribution of the ports in the northwest of the country (see Figure 1.2) give a strategic advantage to the Port Authority for better services to port users.

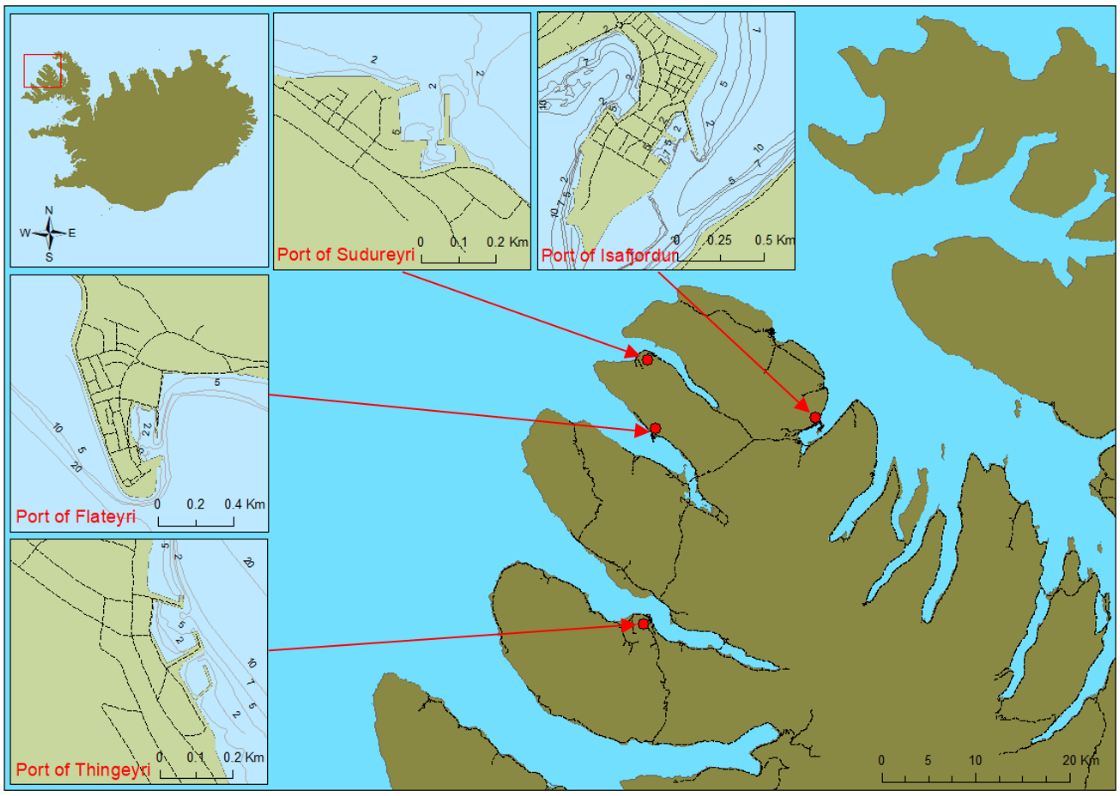

Figure 1.2 The Ports of Isafjordur Network. The study area is shown on the map of Iceland.

The network has a locational advantage as it is: 1- close to a rich fishing ground in the North Atlantic Ocean, 2- with short sailing times to the open sea, 3- located at the main axes of seaborne trade and cabotage on a regular basis, and 4- surrounded by growing businesses (e.g., aquaculture and relevant value-added productions/manufacturing) (Statistics Iceland Office 2021). Figure 1.3 shows the development of marine catch unloaded at the port network since 1995.

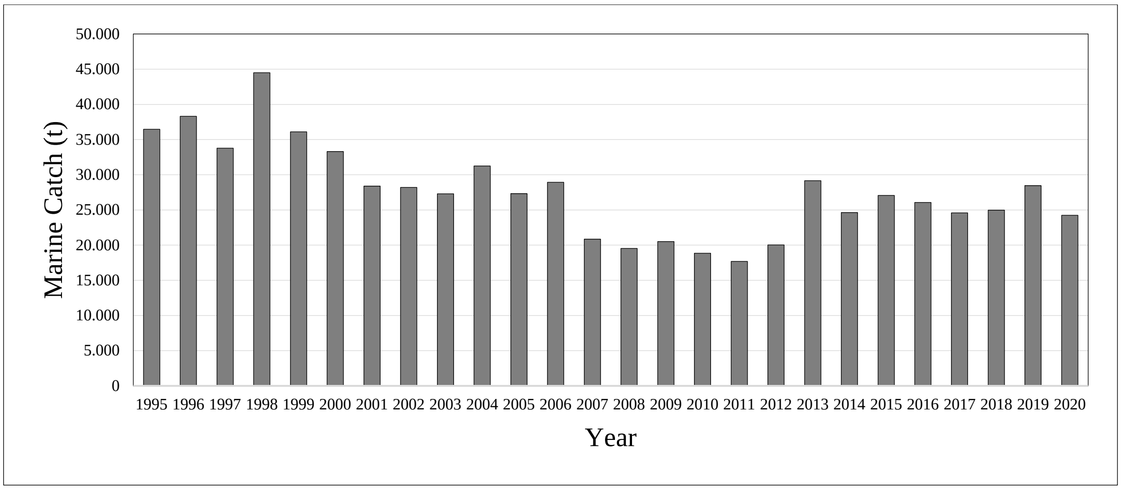

Figure 1.3 Unload of marine catch at the Ports of Isafjordur Network (Icelandic Directorate of Fisheries 2021)

The Port of Isafjordur is the biggest and premier container port in the region and the distribution center for the network. The port has a competitive advantage, due to its infrastructure and services to different types of vessels, among the other ports in the region. The other three ports (Sudureyri, Flateyri, and Thingeyri) mainly render services and accommodation to fishing boats and occasionally to smaller cruise ships, recreational boats, and cargo vessels.

The main functions of the port network are:

- Transfer and storage of containerized and non-containerized cargo;
- Industrial value-added activities, including fishing activities and marine productions;
- Recreational activities, including servicing expedition and cruise ships, sailing boats, and water sport activities.

Non-containerized cargos are mainly categorized as fuel oil, road construction and maintenance materials, fertilizer and fish feed, marine products, and industrial materials. These cargos are measured in tonnes. Containerized cargo is based on a Twenty-foot Equivalent Unit (TEU) (Eskafi et al. 2021a).

Coastal shipping and road transportation are the two transport modes that connect the port network to its hinterland, which is the whole country. The port network plays a significant role in the logistic chain of the region as well as the country.

The port network is the third busiest port of call for cruise ships in Iceland. As shown in Figure 1.4, since 1995 when the first cruise ship called at the port network, the number of calls, May-September, has been considerably increased. However, there were no cruise ship calls at the port network in 2020 due to national and international restrictions on cruise ship sailings caused by the COVID-19 pandemic.

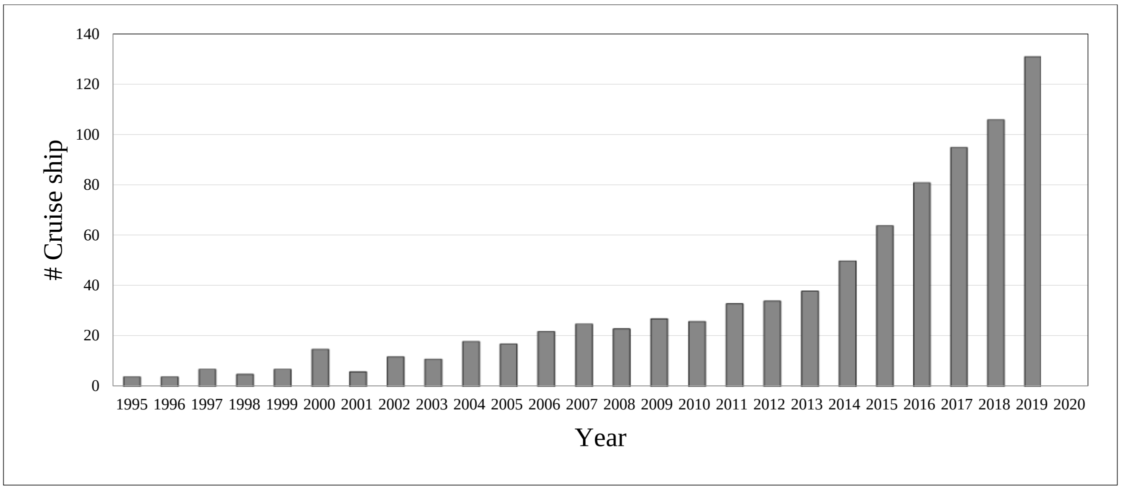

Figure 1.4 Cruise ship call at the port network (Isafjordur Port Authority 2020)

In 2018, the fourth largest cruise ship in the world, the MSC Meraviglia, had three calls at the network (Isafjordur Port Authority 2020). In the same year, the port network had the highest proportion of its revenue from cruise ships and it accounted for 46% of the port network's revenue. This income was also important for the Port Association of North Iceland (Hafnasamlag Nordurlands) since it amounts to 34% of the Association's income (Port Association of Iceland 2019). The port network is a major contributor to the economy of the municipality. In 2019, about half of the revenue (GDP) of the municipality came directly from port revenue (Isafjordur Port Authority 2020).

The seasonality of port activities, restrictions in infrastructure, operations, and services of the port network, and limited surrounding land area constrain the ports to meet the increasing demand. This might affect the competitive position of the port among the other ports in the country. In this regard, the Isafjordur Port Authority has been contemplating to strategically develop the port network to satisfy today's and future demands and position the port for sustained growth. Nevertheless, dealing with uncertainties, including opportunities and vulnerabilities surrounding port development, imposes challenges on the planning process. The proposed framework in the present dissertation addresses this concern.

2 Stakeholder Salience and Prioritization for Port Master Planning, a Case Study of the Multipurpose Port of Isafjordur in Iceland

This chapter contains the peer-reviewed journal article:

Eskafi, M., R. Fazeli, A. Dastgheib, P. Taneja, G. F. Ulfarsson, R. I. Thorarinsdottir, and G. Stefansson. 2019. "Stakeholder Salience and Prioritization for Port Master Planning, a Case Study of the Multipurpose Port of Isafjordur in Iceland", *European Journal of Transport and Infrastructure Research*, 19 (3), pp. 214-260.
https://doi.org/10.18757/ejtir.2019.19.3.4386

2.1 Abstract

The dynamic and ever-increasing complex nature of a port system involves a variety of stakeholders with a broad spectrum of involvement and objectives. In the port planning, to fulfill the objectives of the various stakeholders and manage conflicts and controversies, a stakeholder analysis is carried out. However, effective and timely engagement of the key stakeholders in the planning process is not an easy task. This chapter presents a framework of stakeholder analysis for the case study of the Ports of Isafjordur Network in Iceland to underpin the planning process. The framework deals with a systematic procedure of identification, grouping and then static mapping of stakeholders by means of the power-interest matrix. Further, the fuzzy logic 3-dimensional decision surface was adopted for dynamic salience mapping of the stakeholders. A survey and face-to-face interviews were conducted as tools to collect input for the stakeholder analysis based on the objectives of the port planning. The objectives include competitiveness, land use, environmental implication, safety and security, hinterland connectivity, economic and social impact, financial performance, and flexibility. This chapter reveals that dynamic mapping provides a more accurate stakeholder analysis in the field of port planning than do other methods. The result of the decision surface shows different saliences of key stakeholders, including legislation and public policy, and internal and external stakeholders in the planning. Thus, in order to have effective and timely stakeholder inclusion throughout the port planning process, a different strategy of engagement with them should be applied.

Keywords: Iceland, Fuzzy Logic, Port Planning, Stakeholder Analysis.

2.2 Introduction

Ports are identified as a complex set of functions that are expanded beyond their historical limits (Moglia and Sanguineri 2003). Ports enjoy their monopolistic position because of their geographic location at the beginning and end of the land transport chain. The vast array of port services connects port authorities to a broad spectrum of national and international stakeholders with specific objectives. The port planning is highly affected by the influence and concern of stakeholders where their objectives are in most cases divergent and even conflicting. They drive decision making in the port planning process and thus their engagement is the vital part of strategic planning (Heaver et al. 2010; Notteboom and Winkelmans 2001; Suykens and Voorde 1998).

In traditional port planning, the port authorities, who are considered as an internal stakeholder in this study, informed and involved the port users and other stakeholders only in the later stages of the planning process. However, nowadays, co-creation with relevant stakeholders plays a significant role in the planning process. A successful plan and its subsequent implementation should be stakeholder inclusive; otherwise, the process may fail to achieve the desired outcome. Active participation of stakeholders in the process of setting objectives for the port planning increases the acceptance and legitimacy of the plan among the stakeholders. Furthermore, key stakeholders play a critical role in galvanizing the port planning. Icelandic ports, for instance, are on the verge of a new era in maritime activities. They are servicing cruise, fishing, and cargo vessels as well as recreational marine activities, such as whale watching, yachting, and sailboats. In this context, the power, interests, and consequently, the salience of port stakeholders are considerably discrepant at the local, regional and national levels. Thus, in a planning process, engagement of all relevant port stakeholders at the same level is unlikely. Prioritization of the key stakeholders for effective and timely engagement in the planning process should be based on a precise stakeholder salience analysis.

Stakeholder inclusion in the port planning process has attracted increasing attention in the past two decades from both conceptual and practical perspectives. This is reflected in significant growth in the number of published applications which have used straightforward approaches of stakeholder analysis in the port planning. However, the challenge in port planning remains: how to prioritize the key stakeholders in the planning process for effective and timely engagement, in order to address their objectives and reconcile potential conflict. The answer to this question is the motivation for this chapter. As discussed in section 2.3, there is a lack of clarity in the scientific literature about stakeholder salience analysis in the port planning process. In this regard, the methods of stakeholder analysis and assessment of their salience in terms of power and interest are detailed in this study and applied to a practical case. This chapter presents a framework for a systematic salience analysis and prioritization of the stakeholders for port planners, researchers and practitioners, to support decision-making situations in the port planning process.

The remainder of this chapter is structured, as follows: subchapter 2.3 reviews the literature on port stakeholder analysis, subchapter 2.4 outlines material and methods by presenting the steps of the stakeholder analysis, subchapter 2.5 introduces the area of study, subchapter 2.6 presents the results and discusses the findings, subchapter 2.7 limitations of the study, and subchapter 2.8 draws conclusions on the stakeholder analysis for the Ports of Isafjordur Network in Iceland.

2.3 Literature Review and Research Gap

This section is aimed at citing a set of articles in the scientific literature which have discussed different ways of carrying out the stakeholder analysis process in port-related projects, including port planning. Although this review covers a majority of the scientific published articles to provide a good overview of the state-of-the-art, it cannot claim to be exhaustive.

Stakeholder approach (Notteboom and Winkelmans 2002), effective stakeholder relations and influencing management (Gul Denktas and Cimen Karatas 2012), and stakeholder management (Dooms, Verbeke, and Haezendonck 2013) play significant roles in sustainable port development. Sustainable port development requires an integrated and inter-disciplinary stakeholder inclusive approach that takes into account the four perspectives of engineering, ecology, economics, and governance (Vellinga, et al. 2017). In the study of Vellinga et al. (2017), stakeholders were involved to create knowledge and guidelines for improving integration and sustainability in a port development project in Ghana, the so-called NWO-UDW project. Their results showed that transparency, stakeholder engagement at different layers of port planning, and the specification of a desired goal across the entire supply chain improve the sustainability of port development. In this case, stakeholder engagement and interaction were subject to the local stakeholder based on the predefined aspects of sustainable port development. The study, however, did not disclose the stakeholder identification process and the level of involvement during the project. Also, this multi-objective stakeholder inclusive approach lacks the assessment of the stakeholders' attributes in terms of power, interest, and salience to the project.

Lockie and Rockloff (2005) performed stakeholder analysis and social mapping to address the convergence and difference in key values and aspirations of stakeholders with respect to the coastal zone. Their study carried out face-to-face interviews with stakeholders to identify the issues and conflicts in the coastal zone resources, in particular, the Port Curtis and Fitzroy catchments in central Queensland. To improve coastal decision making, Lockie and Rockloff (2005) presented some recommendations and underlying principles such as considering the impact of all decisions and actions together, instead of looking at each decision separately. This study neither described the process of stakeholder identification and categorization nor discussed the prioritization of the stakeholders to the project.

Dooms and Macharis (2003) presented a conceptual framework for inland port planning using a Multi Criteria Analysis (MCA) with the Analytic Hierarchical Process (AHP) method and applied it to different stakeholders in the Port of Brussels. In this approach, face-to-face interviews were conducted to identify the short- and long-term preferences and objectives of the stakeholders. With respect to contribution to the strategic alternative, criteria and sub-criteria of the key stakeholders were rated in a profile chart. Although Dooms and Macharis (2003) mentioned that in a stakeholder-based approach the stakeholders might change in the long-term, they overlooked consideration of temporal changes of the attributes. A similar work analyzed a variety of interests of different stakeholders for long-term port planning (Dooms, Macharis, and Verbeke 2004). They explored a process divided into 9 steps for 11 separate zones of the (inland) Port of Brussels in Belgium. The study introduced soft and hard involvements of stakeholders, where different stakeholders were interviewed, categorized and analyzed in the planning process. They stated that one stakeholder and one zone approach should be replaced with a multi-stakeholder and multi-zone approach in the port planning process, just as the present study is in line with multi-stakeholder analysis in the port planning. Dooms and Macharis (2003) and Dooms, Macharis, and Verbeke (2004) conducted the analysis with the same level of interest for different stakeholders and the same level of attributes for a long-term port planning. Also, the stakeholder engagement was subjective, spatially. These theoretical assumptions are far from real practices.

Dooms, Verbeke, and Haezendonck (2013) studied the spatial differentiation of stakeholders in the decision-making process in the strategic port planning process for the Port of Antwerp. They established a link between path dependence and spatial and temporal stakeholder preferences. A historical analysis based on the insights from stakeholder theory and the strategic planning literature, applied to the transport sector, was conducted. Dooms, Verbeke, and Haezendonck (2013) noted that stakeholder preferences toward port activities and port development change over time. However, their research did not indicate any method to capture the preferences and/or salience of the stakeholders over time.

In the port planning and design processes, stakeholder inclusion should be taken into consideration (Dooms 2018). Dooms (2018) identified major elements in stakeholder management aimed at achieving a more sustainable port development. Strategic planning of ports and design of port infrastructure is affected by the objectives and divergent perceptions of a wide range of stakeholders. Thus, in order to identify and address the stakeholders' demands regarding the project, they should be engaged in the planning process (Taneja, Ligteringen, and Walker 2012). Goss (1990) stated that the objectives of external stakeholders should be taken into account by the port authorities in port planning. This is supported by Taneja (2013) by introducing a bottom-up approach to port planning. However, in these studies, the level of engagement and changes in the stakeholders' attributes and salience during the projected lifetime of a project were not discussed.

Meyiwa and Chasomeris (2016) looked at the adoption of different port doctrines to find challenges faced by stakeholders in the South African Ports. They applied a qualitative technique called content analysis, based on existing documents and interviews, to assess the salience of various stakeholders in terms of year-to-year submissions of tariff applications. The findings indicated that to meet stakeholders' objectives, the development of the South African Ports by adopting the Asian doctrine might be a suitable option. In this study, the stakeholders' salience was measured based on the yearly level of engagement, but not based on their level of attributes in terms of power and interests. Another study on the understanding of the institutional structure of the Southern African Ports emphasized that the institutional structure is locally embedded (Fraser and Notteboom 2015). They stated that the Southern African Ports development path is enclosed in political, economic and legal construct factors. In this study, the level of attributes and the salience of the stakeholder were not discussed.

A port plan considers long-term planning and requires a consensus of planning action between port stakeholders with diverse activities and interests (Moglia and Sanguineri 2003). Moglia and Sanguineri (2003) noted that, in developing a plan, addressing all needs of local communities together with the objectives of government is not easy for a port authority. They stated that the interests of stakeholders change during the lifetime of the project. Nevertheless, they did not mention whose attributes and salience is subject to rapid change.

Ignaccolo, Inturri, and Le Pira (2018) introduced a framework of stakeholder involvement for sustainable port planning. Based on the Deming cycle Plan-Do-Check-Act (PDCA) they used an iterative four-step problem-solving model to frame stakeholder involvement at different levels. In this study, general stakeholder mapping and social network analysis were suggested as methods to take stakeholder and community involvement into account. Ignaccolo, Inturri, and Le Pira (2018) pointed out that it is necessary to understand and assess the dynamic nature of power and interests of the respective key stakeholders. They noted that their comprehensive framework should be adapted case by case. However, in their study, the level of involvement for different stakeholders and the changing attributes during the plan were not discussed.

In port developments, the power of stakeholders at all levels of hierarchy, from the port authority to the national level, should be appropriately taken into consideration (Wang, Yu Ng, and Olivier 2004). Wang, Yu Ng, and Olivier (2004) applied an in-depth analysis of key port stakeholder using interviews with various stakeholders. They suggested a theoretical framework in which the influence of stakeholders is distributed along three structural lines of the logistics chain, stakeholder communities, and jurisdictional scales. However, they did not state whether the attributes and salience of the stakeholders might change during a port development process.

Involvement of stakeholders in port development is inevitable and such collaborative contribution can be found for the many leading ports such as the Port of Melbourne (Port of Melbourne Corporation 2009), the Port of Rotterdam (Notteboom et al. 2015) and the Port of Amsterdam (Hochstenbach 2015).

The review of the literature reveals that, despite the widely acknowledged need for stakeholder engagement in port planning, the current literature is still inadequate in the systematic evaluation of port stakeholders. Although stakeholder analysis categorizes stakeholders (Grimble and Wellard 1997), it has been criticized because it is often ad-hoc with a low quality of analysis (Hermans and Thissen 2009; Reed et al. 2009). Stakeholder analysis methods in the literature are mostly based on interviews and focus groups. These general methods can be used for specific case studies without precise stakeholder salience measurement. Furthermore, such classification of stakeholders might affect the accuracy of decision making in the planning process (Pérez Vera and Bermudez Peña 2018). On the other hand, some methods are specific and depend on the temporal and spatial objective of stakeholders. Later methods relinquish the changing attributes of the stakeholder over time. These methods ignore the fact that different stakeholders have differing salience over the port planning process. The existing methods of analysis have so far overlooked stakeholder salience measurement and prioritization of the key stakeholders in a decision-making situation.

There is a knowledge gap in the literature when it comes to a rigorous and scientific port stakeholder salience analysis for effective and timely engagement in the port planning process. Therefore, this chapter presents a framework of systematic stakeholder analysis by integrating static and dynamic mapping for measuring the stakeholders' salience. The framework is applied to the case of the Ports of Isafjordur Network in Iceland. The case investigated is comprehensive and detailed and thus it can be readily extended to other ports and meet practical needs. The proposed framework is considered as a tool to identify port stakeholders and evaluate their salience for prioritization and effective and timely engagement in a port planning project.

2.4 Method of Analysis and Research Design

Stakeholder analysis is referred to a range of tools for the identification, description, and assessment of stakeholders based on their roles, power or influence, stakes or interest and relationship to each other, as well as to a system (Brugha and Varvasovszky 2000; Bryson 2004; Reed et al. 2009; Mayers 2005). Mayers (2005) stated that stakeholder analysis is an organized approach that assesses decision-making situations where resources might be limited, a variety of stakeholders have competing interests, and stakeholders' demands should be balanced and addressed. Scholars have defined the aims of stakeholder analysis as: 1- to identify and group stakeholders with an interest and/or hold power in a system, 2- to acquire the necessary knowledge and understanding about the stakeholders involved in the process, 3- to recognize the changes and conflicts between the stakeholders within the system, 4- to engage them effectively based on their power and/or interests in the system (Mumtas and Wichien 2013; Yang 2014). Brown, De Bie, and Weber (2015) notified that stakeholder analysis' tools play a critical role in the identification of stakeholder groups and their positive and negative preference and influence in a decision-making situation. Systematic stakeholder analysis facilitates decision-making processes by assessing the stakeholder's power, interests and cooperation with each other in a system. It is an important process prior to projects aimed at coming to a better decision in a complex multi-actor situation and managing possible conflict among them (Mayers 2005). Brugha and Varvasovszky (2000) stated that "Stakeholder analysis can be used to generate knowledge about the relevant actors so as to understand their behavior, intentions, interrelations, agendas, interests, and the influence or resources they have brought, or could bring, to bear on decision-making processes." Stakeholders can become less involved during the planning process as their affiliation may decrease over time. Thus, a stakeholder analysis should be conducted and updated during the projects prior to any major decision making.

Based on the aforementioned definitions and objectives of stakeholder analysis in the literature, the steps of port stakeholder analysis can be inferred. These steps are depicted in Figure 2.1 and elaborated for the purpose of the port planning for the case study of the Ports of Isafjordur Network in Iceland.

2.4.1 Identification of Stakeholder

To analyze and engage stakeholders, the first step is to search for those who are awarded stakeholder status (Bryson 2004; Miles 2017; Mitchell, Agle, and Wood 1997). Freeman (1984) stated that "A stakeholder is by definition any individual or group of individuals that can influence or are influenced by the achievement of the organization's objectives", plausibly applicable for port stakeholders. Grimble and Wellard (1997) highlighted that 'future generations', 'national interest' and 'wider society' should also be considered in the concept of stakeholders. Stakeholders are segregated by their level of interest or influence in decisions or the effect of decisions on them (Frooman 1999). Other definitions of stakeholder from the broadest to the narrowest have been noted in the literature (Elsaid, Salem, and Abdul-Kade 2017; Mitchell, Agle, and Wood 1997). In the context of transportation, Cascetta et al. (2015) defined stakeholders as people and organizations with or without a formal role in the decision-making process.

Stakeholder identification and their necessary engagement in a project is an important task (Achterkamp and Vos 2008; Pouloudi and Whitley 1997). Pouloudi and Whitley (1997) emphasized that practical techniques for stakeholder identification are limited in the literature. Focus group, expert interview (Nordström, Eriksson, and Öhman 2010), forums, interviews and questionnaires (Brugha and Varvasovszky 2000; Lienert et al. 2015; Pouloudi and Whitley 1997), stakeholder circle methodology, surveys, workshops, brainstorm (Calvert, 1995) have been used for stakeholder identification. However, Pouloudi and Whitley (1997) stated that these approaches might not be detailed to identify all stakeholders for a specific case.

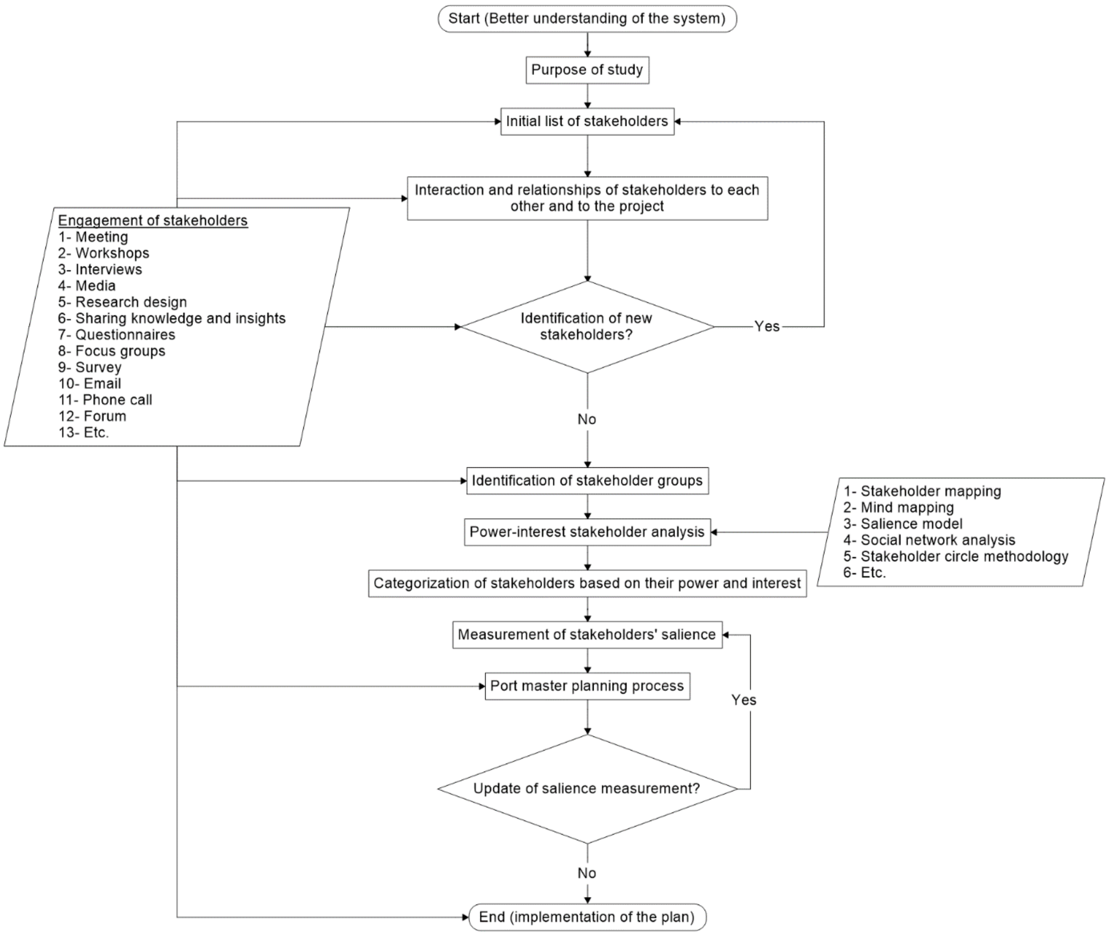

Figure 2.1 Steps in stakeholder salience analysis and prioritization

Through literature reviews and focus groups, only an initial list of stakeholders who are primary and secondary stakeholders can be developed (Clarkson 1995; Ignaccolo, Inturri, and Le Pira 2018). A group alone cannot guarantee the stakeholder identification in a project. A project manager might not have the required skill and resource to identify all stakeholders. Thus, an incomplete list of stakeholder leads to an inaccurate stakeholder analysis (Jepsen and Eskerod 2009). Le Pira et al. (2018) pointed out that identification of port stakeholders requires a broad and proper knowledge. To increase the accuracy of the stakeholder analysis for effective engagement, a whole range of stakeholders needs to be taken into account. In fact, an exploratory approach should be adopted to not only identify the broadest range of stakeholders, but also uncover dormant or latent stakeholders who might have a particular stake and influence on the project (Mitchell, Agle, and Wood 1997).

Geneletti (2010) and Lienert, Schnetzer, and Ingold (2013) stated that the snowball technique is a suitable way for stakeholder identification. Using this technique assures a variety of suggestions from different perspectives (Colvin, Witt, and Lacey 2016). Snowball sampling benefits from the knowledge gained independently and past experience through the (professional) networks for stakeholder identification (Colvin, Witt, and Lacey 2016). Yang (2014) emphasized that through such "knowledge of rationalism" most likely all stakeholders, can be identified and engaged in a project. Hence, a decision can be made with a comprehensive consideration of all stakeholders. Although snowball sampling may lead to a repetitive list of the stakeholders (Reed 2008), the suggested list can be used as a good source to finalize the stakeholder identification step (Reed and Curzon 2015). Application of the snowball technique for identification of stakeholders is prevalent in the literature (Lienert, Schnetzer, and Ingold 2013; Reed et al. 2009) as it offers a wide range of those who hold a stake or influence on (influenced by) a system (Couix and Gonzalo-Turpin 2015; Rizzo et al. 2015; Stanghellini 2010) and then stakeholders can be identified as comprehensively as possible (Rowley 1997).

As snowball sampling can be considered as a suitable technique to identify the widest range of actual and potential stakeholders, this technique was applied for the purpose of this study. In this process, an initial list of stakeholders is developed based on previous studies and inputs from experts. Notteboom and Winkelmans (2002) stated that the initial list can be developed comprising the primary and secondary stakeholders who are part of the port authority and in-situ and ex-situ economic players. In a bid to increase stakeholder representation, the identified port stakeholders in the list were contacted by phone call, emails, in meetings, etc. in order to solicit suggestions of more possible stakeholders (Lienert et al. 2015; Nordström, Eriksson, and Öhman 2010). Newly added stakeholders were analyzed by a group of experts. If they were considered as stakeholders, they were kept on the list and they were also asked to add any missing stakeholders to the list. The process was continued until no further stakeholder were suggested and a comprehensive list of stakeholders has been made.

2.4.2 Engagement of Stakeholder

Stakeholder engagement helps to uncover the drivers of port development, align research design to stakeholder-needs, develop insights and knowledge, increase the relationship with stakeholders, share information and acknowledge constructive feedback (Vellinga, et al. 2017; Chinyio and Akintoye 2008; Greenwood 2007). Scholar proposed and compared different methods of stakeholder engagement (Forester 1993; Larson, Measham, and Williams 2010). There has been a consensus that stakeholder engagement as a preparatory stage develops a common language to improve communication in a complex decision situation. Stakeholder engagement requires a proportionate effort to involve the people who hold a stake in the outcome of decision making (Soma and Vatn 2014). Decision making can benefit a range of perspective by engaging the stakeholders (Fischer et al. 2014; Hall, Ashworth, and Devine-Wright 2013). Stakeholders can actively be engaged through questionnaires, interviews, email, phone, focus groups, surveys, Delphi approach, forums, workshops. The stakeholder engagement has been applied in many case studies in literature such as in sustainable port planning (Ignaccolo, Inturri, and Le Pira 2018), urban freight transport policies (Le Pira et al. 2017) tourism management (Kajanus, Kangas, and Kurttila 2004), buffer zone management planning (Margles et al. 2010) and sustainable water infrastructure planning (Lienert et al. 2015).

Stakeholder engagement is essential for stakeholder analysis and should be taken into consideration as early as possible in a decision-making process (Yang et al. 2009; Yang, Shen, and Ho 2009). As such a participatory process enhances decision making in the port planning, the multiplicity of stakeholders' inputs was addressed in an integrative and holistic manner in the present study. To reduce possible bias and also cover a wider possible range of information that should be accounted for in the analysis, maximum effort was made to reach all stakeholders who have a stake and or influence on the planning. In this study, the stakeholders were contacted in order to provide input for the salience measurement. The contact was first made by email and phone call to provide general information about the project, followed up with a meeting to develop the relationship and knowledge, a face-to-face interview to gather required information about the objectives of port planning, and a written survey to aggregate the input data for evaluation of the stakeholders' attributes. This level of engagement would construct an acceptable basis for the salience measurement.

2.4.3 Differentiation and Grouping of Stakeholders

The stakeholders are categorized into groups based on similarities in their roles, characteristics, contributions, interests, and influence into a system (Jepsen and Eskerod 2009). There are several categorizations of stakeholders in the literature (Clarkson 1995; Philips 2003; Winch 2004). Dooms (2018) reviewed the state of art of stakeholder management and the related stakeholder categories in literature applied to ports. Clarkson (1995) introduced the primary and secondary classification of stakeholders including those who have direct and indirect interests in a company, respectively. Notteboom and Winkelmans (2002) described a port environment with different categories of stakeholders including internal stakeholders, external stakeholders, public policy stakeholders, and community stakeholders. This categorization of the stakeholders was reiterated by Gul Denktas and Cimen Karatas (2012). Further, Aaltonen and Sivonen (2009) and Winch (2004) presented the internal and external stakeholders who are entities within a system and not within a system but affect or are affected by the system, respectively.

Although it may not be important what type of categorization is used, the core concept of a group which accommodates stakeholders with common stake and influence on the project should be prioritized. Thus, the identified stakeholders can be viewed as groups with a common area of interest and power to the project. The groups can be unbundled in several sub-groups based on the overarching nature of engagement undertaken and the interrelationships of the stakeholders together and to the port planning.

2.4.4 Objectives of the Port Planning

Once the stakeholders are identified, the values of the port planning that are important from different stakeholders' perspective should be settled. There is a limited guideline for information gathering from the stakeholders for decision making (Jepsen and Eskerod 2009). Brugha and Varvasovszky (2000) stated that the required information for decision making can be acquired by conducting face-to-face interview and dialogues, thereby the real interests of stakeholders are reflected. Interviews can provide valuable qualitative and quantitative information about the objective of different stakeholders (Mason et al. 2015). However, the outcome of conducting interviews is acceptable if the stakeholders are able or willing to share their objective for the project (Jepsen and Eskerod 2009). Also, it might be expected that the information from the interviews would be restricted to the limited interviewees' experiences and knowledge (Mccarthy, Van Iddekinge, and Campion 2010). Thus, it is important to note the importance of each interviewee in terms of education, experience and position (Hartwell, Johnson, and Posthuma 2019), and differences and biases regarding gender and prior information of the interviewees (Alonso and Moscoso 2017) to ensure the validity of data and information gathered. To achieve confidence in the reliability and validity of the compiled data and information, the required number of interviews and the number of interviewers should also be taken into consideration (Fifić and Gigerenzer 2014).

To identify the main values of port planning that includes the objective of stakeholders, semi-structured open-ended face-to-face interviews with all relevant stakeholders were conducted in this study. The values were inferred during the interviews from the concerns, ideas, thoughts, needs, demands, etc., of the stakeholders for the port planning. Interpretation and elicitation of the values were based on Value-Focused Thinking (VFT) method (Keeney 1992). VFT is a proven method that provides a systematic approach for identification and specification of the actors' values, structuring and categorizing the values and then converting values to the objectives (Keeney and Raiffa 1993). The objectives were the main values of port planning in this study. The interviews were audio-recorded and transcribed for carefully processing the information based on the VFT method and for further documentation.

To be in line with the literature in the field of port planning, the elicitation of the terminology for the objectives of the port planning was drawn from the international laws and regulations such as PIANC, European directives, scholarly and scientific literature (e.g., (Arecco et al. 2016; Slinger et al. 2017; Taneja 2013)). These objectives were used for the evaluation of stakeholders' attributes in terms of power and interests and subsequent assessment of stakeholders' salience.

2.4.5 Stakeholder Mapping

Two-Dimensional (2D) Stakeholder Mapping (Power-Interest Matrix)

2D stakeholder mapping is a well-adopted management tool which is widely used to categorize stakeholders by the level of their power and interest, for further prioritization and appropriate engagement strategies. Various well-established techniques exist in the literature for 2D stakeholder mapping (Ackermann and Eden 2011; Bryson 2004; Eden and Ackermann 1998; Johnson and Scholes 1999; McElroy et al. 2000; Mendelow 1981). The power-interest matrix has been used in literature, for instance, in human resource development (Garavan 1995), implementation of construction projects (Olander and Landin 2005) and hydropower projects assessment (Rosso et al. 2014). The techniques produce, a priori, better picture of the key stakeholders who need specific attention in a project. Further, Mitchell, Agle, and Wood (1997) introduced the triple circle framework in which the stakeholders are categorized according to the attributes of power, legitimacy and urgency. In this framework, the most salient stakeholders possess all three attributes. In this study, 2D stakeholder mapping is discussed.

As the concepts of 2D mapping techniques are the same, in this study stakeholders are mapped based on the power-interest stakeholder matrix developed by Wright and Cairns (2011). Figure 2.2 shows a power-interest stakeholder matrix.

Stakeholder power is defined as the ability of those who have an influence on achieving the desired outcome (Salancik and Pfeffer 1974). Interests refer to the stake and concerns of the stakeholder in relation to the problem that the project is seeking to address (Maley 2012). The power-interest matrix is divided into four quadrants, representing four categories of stakeholders according to their level of power and interest (Wright and Cairns 2011). The categories can be adopted for the purpose of port planning as follow:

1- Players or key stakeholders who have significant power and interests to affect the port planning. Effective engagement of this group is crucial to the project.

2- Subjects who have a significant interest in the port planning, but little power. Although this group is considered moderate for the process of participation, the lack of power might be overcome, for instance, by improving relationships and rapport with other stakeholders.

3- Context setters who have significant power but low interest or stake in the port planning. This group is considered as a potential key stakeholder group because the high degree of power may increase their interest in the future. Thus, this group should be managed properly.

4- Bystanders who have low interest and limited power in the project.

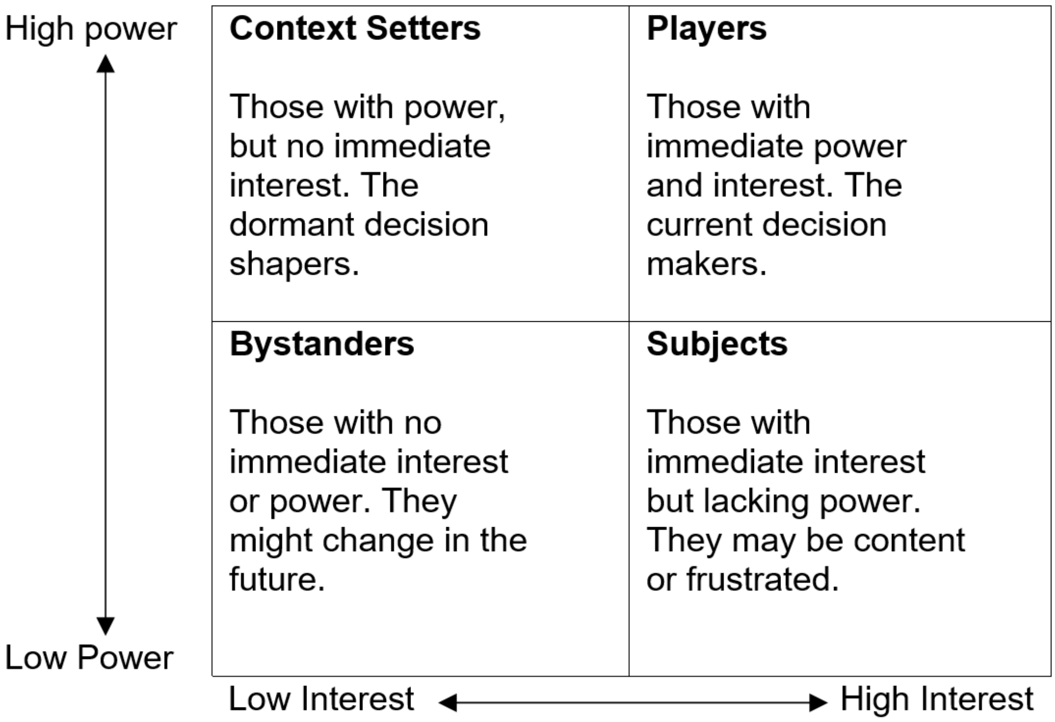

Figure 2.2 Stakeholder power-interest matrix based upon (Wright and Cairns 2011)

For instance, the stakeholder who is placed in the top-right quadrant of the matrix is considered as a player and should be effectively engaged in a decision-making process. Nevertheless, if more than two stakeholders are placed in this player quadrant both are viewed as the same player and should be similarly engaged in the decision-making process.

To proceed with the stakeholder analysis, a comprehensive and detailed survey is elaborated to evaluate the stakeholder groups' power and interests in the objectives of port planning. The survey has several advantages in comparison to other methods of data gathering about stakeholders such as expert views, workshop, meeting, etc. A survey provides a stimulating way to engage stakeholders in a task-oriented manner. The survey encourages stakeholders to express their natural thought in order to support decision making in the port planning. The result of the survey not only provides a range of perspectives, but also give the stakeholder privacy for independent decision making. The survey was sent to several stakeholders to reduce potential bias in the aggregation of results. These stakeholders are selected by a focus group based on their short- and long-term affiliation to the port planning. In the survey, the stakeholders are asked to weight each group of stakeholders from 0 to 3, where 0 is no power or interest, 1 is low power or interest, 2 is some power or interest, 3 is high power or interest.

Based on the results of the survey, the groups are mapped on a power-interest matrix. The results are aggregated by the average weights which were allocated to each stakeholder group in terms of power and interests on the objectives. To quantify the variation of the weights, the standard deviation of the aggregated results of groups' power and interests is calculated. The 2D stakeholder mapping with standard deviation is calculated with the average given weight to all objectives of port planning together in terms of stakeholder group's power and interest. The 2D stakeholder mapping is visualized separately for the objectives of the port planning to highlight differences in attributes of the groups. The advantage of this method is that decision makers can make separate judgments on the attributes of the groups for the objectives of the port planning.

From the result of the stakeholder analysis, decision makers should be able to determine what and how much consideration should be given to each stakeholder for further interaction in the project (Jepsen and Eskerod 2009). However, the power-interest matrix does not differentiate between the stakeholders within one quadrant, which is a major limitation of this method (Elsaid, Salem, and Abdul-Kade 2017). In fact, the stakeholders who are assigned in the same quadrant are assumed to have the same characteristics and thus they should be treated the same. The power-interest matrix does not give priority to competing stakeholders in the same quadrant. It only gives certain attention to the particular stakeholder(s). This is far from reality in a decision-making process, for instance, with respect to the dynamic nature of a port system or spatial and temporal characteristics of port development projects. Different stakeholders are not equally important and have different degrees of influence on achieving a goal in the decision-making process. Stevedore, fishing and transport companies might have more interest in the port planning based on their needs, but they do not have the same power as a port authority has. The government can dominate a port authority to apply the relevant regulations in port planning. However, if all these stakeholders are placed in the same quadrant, for instance player, they would be considered equally in a decision-making process.

Another shortcoming of the power-interest matrix is in assigning the stakeholders to only one predefined category without any indication of a personalized profile (Poplawska et al. 2015). Stakeholders may play different roles simultaneously or their roles may evolve over time (Cummings and Doh 2000). Thus, they may not belong to only one quadrant in the matrix at the same time. Moreover, attributes of stakeholders are variable (Mitchell, Agle, and Wood 1997) and change over time (Missonier and Loufrani-Fedida 2014). In the power-interest matrix, the dynamic contribution of each stakeholder in a project remains overlooked (Andersen, Grude, and Haug 2004). Therefore, the stakeholder analysis is viewed as the result at a specific time point. Although the matrix gives useful information to decision makers on the general picture of the stakeholder's attributes, it misses the flow of interaction of stakeholders to the project. The stakeholder analysis may fail because of inadequate attention to the various stakeholders and their respective attributes.

In order to overcome these limitations, a new framework is needed that ensures in-depth consideration of power and interest and consequently salience of each stakeholder in the decision making. In this study, a framework based on fuzzy logic was adopted to provide valuable insight in stakeholder analysis in the port planning process, and which has so far been missing in the literature.

Three-Dimensional (3D) Stakeholder Mapping (Power-Interest-Salience Decision Surface)

In order to capture precisely, visually and logically the salience of stakeholder, fuzzy logic is applied. Fuzzy logic has been used as a tool to identify the views of multiple stakeholders in the literature in the area of flood management decision making (Akter and Simonovic 2005), stakeholder prioritization (Bendjenna, Charre, and Zarour 2012), stakeholder salience management (Poplawska et al. 2015) and stakeholder identification for sustainable business (Gil-Lafuente and Barcellos Paula 2013) automatic power and interest stakeholder classification and prioritization (Elsaid, Salem, and Abdul-Kade 2017).

The Fuzzy Inference System (FIS) is applied to implement fuzzy logic and the Mamdani-type inference system is selected because it permits suitable modeling of human input (Munda, Nijkamp, and Rietveld 1994). The FIS relates input (power, interest) and output variables (salience), to develop the decision surface. The five main steps of FIS as defined by Muñoz, Rivera, and Moneva (2008) include the database, which defines the membership functions of fuzzy sets; the fuzzy if-then rules; the unit of decision making; the fuzzification interface; and the defuzzification interface. The membership function is used to illustrate attribute's uncertain values, and it can be linear, a S-curve, triangular, trapezoidal, or a "bell" shape curve as suggested by (Cox 1994). Andriantiatsaholiniaina, Kouikoglou, and Phillis (2004) pointed out that the triangular and trapezoidal functions are easy to use and calculation.

Fuzzy logic eliminates the restrictions of the 2D stakeholder mapping as the categorization of the stakeholders is not static. Using Fuzzy Logic Toolbox in MATLAB, the 3D decision surface was constructed (Sivanandam, Sumathi, and Deepa 2007). A 3D decision surface creates a dynamic stakeholder mapping by which decision makers recognize different attributes of stakeholders. The surface pattern reveals the relation between power, interest and salience of the stakeholders. By means of dynamic stakeholder mapping, the area between the stakeholder's attributes can be estimated. It helps to predict which dormant stakeholders may become salient. Decision surface is easy to understand by the decision makers to assess the salience, especially when they are in a fuzzy area (Poplawska et al. 2015). The salience is an attribute of the stakeholder in term of both power and interest together (Mitchell, Agle, and Wood 1997). In order to analyze the stakeholder based on the 3D decision surface, the following steps should be conducted:

Step 1- the result of the survey is aggregated by an average of given weight to the attributes of the stakeholder group on the objectives of port planning.

Step 2- The stakeholders' attribute profile is calculated by minimum, average and maximum aggregated weights in step 1 in the form of attribute profile (minimum weight, average weight, maximum weight). This aggregation should be carried out separately for power and interest as follow:

Attribute profile of stakeholder group x:

$$Power\ (P_{min}, P_{avg}, P_{max}) \tag{2.1}$$

$$Interest\ (I_{min}, I_{avg}, I_{max}) \tag{2.2}$$

Step 3- The salience of the stakeholder group is calculated by averaging the respective values of the attribute profiles in step 2 for a group as follow:

$$Salience\ \left(\frac{(P_{min}+I_{min})}{2}, \frac{(P_{avg}+I_{avg})}{2}, \frac{(P_{max}+I_{max})}{2}\right) = (S_{min}, S_{avg}, S_{max}) \tag{2.3}$$

Step 4- The degree of membership of each stakeholder group is defined in a fuzzification process based on the membership functions of power and interest attributes. The membership functions are defined based on the histogram of information collected from the survey, using the approach proposed by Poplawska et al. (2015). In this study trapezoidal functions are used, because of the simplicity of use and calculation (Andriantiatsaholiniaina, Kouikoglou, and Phillis 2004).

Step 5- The rule of stakeholder to the attributes is generated based on the result of step 1.

Step 6- The salience function of each stakeholder group is defined in a defuzzification process. To revert to the numerical value (defuzzification) the weighted average defuzzification method is calculated as:

$$Y = \frac{(X_{min}+2\times X_{avg}+X_{max})}{4} \tag{2.4}$$

where X_{min} is the minimum value, X_{avg} is the average value, and X_{max} is the maximum value calculated from step 1.

Step 7- Using the Fuzzy Logic Toolbox in MATLAB, the 3D decision surface is created by multiplying membership functions of power and interest developed in step 4.

Step 8- The stakeholders are positioned on the decision surface based on their average power, interest and salience calculated in steps 2 and 3 as:

$$Central\ point = (P_{avg}, I_{avg}, S_{avg}) \tag{2.5}$$

2.5 Study Area

This study was carried out for the Ports of Isafjordur Network located in the northwest of Iceland. The Isafjordur Port Authority manages four ports including the Port of Isafjordur, the Port of Sudureyri, the Port of Flateyri and the Port of Thingeyri. The Location of the ports is shown in Figure 2.3.

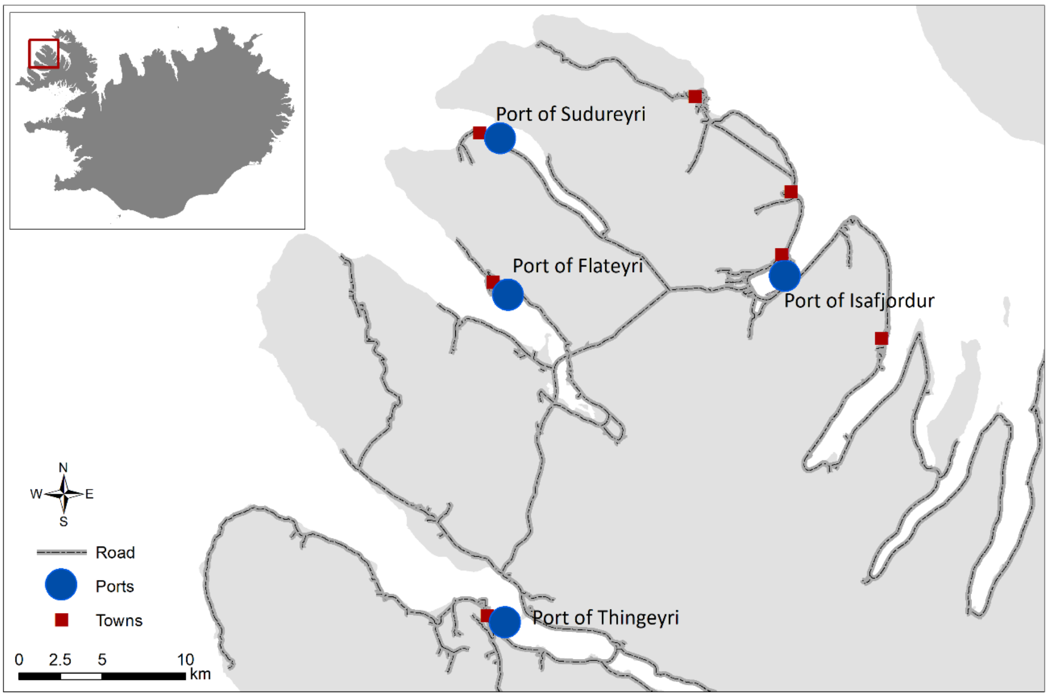

Figure 2.3 The location of the ports. The study area is depicted on the map of Iceland.

The geo-position and distribution of the ports in the northwest of the country give a strategic advantage to the Port Authority for better services to the port users including fishing, transport and tourism industries as well as recreational activities. The ports are unequal in size, function, geographical and navigational conditions. The port network is the third busiest port of call for cruise ships in Iceland. In summer season 2018 (May-September) the port serviced 106 cruise ships, including three arrivals of the fourth largest cruise ship in the world, the MSC Meraviglia (Isafjordur Port Authority 2020). The port is located at the main axes of seaborne trade known as coastal shipment around the country. The regional and national hinterland of the ports encourages many companies and industries to start their business in the area. In 2017, more than 24.5 thousand tons of marine catch unloaded at the ports (Icelandic Directorate of Fisheries 2021).

The Port of Isafjordur is a regional center and offers 24-hour unloading, repair of small vessels and ships, customs, expert servicing of the fishing fleet, accommodating different vessel types including recreational and sailing boats, general cargo, dry and liquid bulk, and container ships. The Ports of Sudureyri, Flateyri, and Thingeyri occasionally service smaller cruise ships, recreational boats and cargo vessels. However, the core business of these ports is related to fishing activities.

Seasonality of port activities, depth and quay restrictions and limited surrounding land area constrain the ports to satisfy the increasing demand. In this regard, the Isafjordur Port Authority has been contemplating to strategically plan the port areas to increase the port capacity aimed at satisfying stakeholders' demands. However, long-term port planning is faced with uncertainties in terms of opportunities and vulnerabilities in the different layers of the port, including service, operation, and infrastructure (Taneja, Ligteringen, and Walker 2012). In 2012, the Port Association of Iceland (Hafnasamband Islands) discussed the revision of the Icelandic Port Act and the formulation of long-term policy for the ports in the country. The Association emphasized the engagement of port stakeholders in order to meet their concerns and interest in port development plans (Port Association of Iceland 2014), just as the purpose of this study is effective and timely stakeholder inclusion throughout the port planning process.

2.6 Results and Discussion

The list of stakeholders was completed using an iterative process of the snowball sampling technique. Four main groups of port stakeholder were defined initially: 1- internal stakeholder, 2- external stakeholder, 3- legislation and public policy stakeholder, and 4- community stakeholder. However, an academic stakeholder group was added, because academics play a significant role in the port planning through their research and development of new knowledge (Slinger et al. 2017). The resultant list of stakeholder groups as a representation of stakeholders for the Ports of Isafjordur Network Planning in Iceland is shown in Appendix A.

A total of 51 face-to-face interviews (one refused to be interviewed) were conducted, to identify the objectives of port planning. Some interviews included more than one person. To the knowledge of the authors, this exhaustive effort of face-to-face interviews across all possible port stakeholders was carried out for the first time in the country. Collectively, 7 objectives of the port planning were identified through the interviews with the stakeholders. These were: competitiveness, use of land, environmental implication, safety and security, connection with the hinterland, economic and social impact, and financial performance. Moreover, an additional objective was revealed inter alia, notably those concerns, ideas, thoughts, needs, demands related to future uncertainties and changes surrounding the port development. The emergent objective is hereafter termed “flexibility”.

The survey (Appendix B) was sent to 17 stakeholders to evaluate the attributes of stakeholder groups in terms of power and interests. The survey was sent to at least three representatives from each of the five main groups. These three or more representatives in the main group were selected from different subgroups to ensure consideration of views across diverse stakeholders. As the average of the given weights was used for the next steps of the stakeholder analysis, engagement of more than one stakeholder from each main group in the survey can limit the bias. Therefore, the result of the survey was assumed to be without considerable bias or incorrect information. All stakeholders responded to the survey. Table 2.1 shows the aggregated result of the survey. The numbers in Table 2.1 are the average of given weights by the 17 stakeholders to the attributes of the objectives of the port planning.

Table 2.1 The aggregated result of the survey.

Stakeholder group	Attitude	Objective of the port planning							
		CO	UL	EI	SS	HC	ES	FL	FP
Internal	Power	2.82	2.82	2.65	2.82	2.18	2.65	2.59	2.65
	Interest	2.76	2.71	2.47	2.71	2.82	2.53	2.53	3.00
External	Power	1.82	1.88	1.94	1.82	1.59	2.06	1.53	1.88
	Interest	2.41	2.47	2.00	2.47	2.29	1.88	2.18	2.12
Legislation and public policy	Power	2.47	2.18	2.59	2.65	2.06	2.12	1.94	1.88
	Interest	1.76	1.88	2.53	2.53	2.00	2.12	2.00	1.71
Academic	Power	0.94	0.82	1.47	1.06	1.00	1.00	1.06	0.65
	Interest	0.76	0.82	1.88	1.59	1.24	1.29	1.18	0.59
Community	Power	1.41	1.47	1.76	1.41	1.19	1.41	1.00	0.94
	Interest	1.88	1.82	2.41	2.24	1.94	2.24	1.59	1.69

The abbreviations in Table 2.1 stand as CO: competitiveness, UL: use of land, EI: Environmental implication, SS: safety and security, HC: hinterland connectivity, ES: economic and social impact, FL: flexibility, FP: financial performance.

2.6.1 2D Stakeholder Group Mapping of the Objective of Port Planning

Competitiveness

The legislation and public policy, internal and external stakeholder groups showed high power and interest in this objective, as shown in Figure 2.4. These groups are identified as major drivers of increasing competitiveness in the port planning process. To have a competitive port, the active, efficient and effective engagement of these groups is essential in any decision-making situation in the planning process. These groups can enhance the competitiveness of the ports with their knowledge, power, and demands through the three layers of port including infrastructure, port service, and port operation. As can be seen from Figure 2.4, the internal stakeholder group is the most important player in the competitiveness objective of the port planning. Community stakeholders are also interested in this area of concern because this group surrounds the port area and might benefit from an active port. For this objective, the academic stakeholder group is identified as bystanders and they are recognized as having both low influence and a low stake.

Use of Land

For the objective of the use of land, the legislation and public policy, internal and external stakeholder groups had significant interests and power, as depicted in Figure 2.4. They could be the drivers behind any decision making in terms of land use in the port planning. Thus, the important role of these groups must be considered the highest concerning land use. Although the community stakeholder group is identified as a subject group, this group might stand as a player in the future when their power may have slightly increased. The port areas are under immense land use pressures related to port activities such as general cargo, containers and cruise passengers. The scarcity of land around the port area might be the reason for the high interest of most of the groups in this objective. Also, in the port cities, the community stakeholder group influences on (or being influenced by) this objective in the port planning. In order to increase the positive (or decrease the negative) influence of players through this use of land, a collaborative stakeholders' engagement should be taken into consideration during the port planning. Such engagement safeguards the limited surrounding land for any future port or city expansion.

Hinterland Connectivity

The legislation and public policy, internal and external stakeholder groups are identified as players with high influence and interest in this objective. As one of the major concerns in the port planning, close attention should be paid to these player groups during the whole planning process. As hinterland connectivity is highly affected by the players' attributes, they should be fully engaged in the decision making in the planning process. Figure 2.4 shows the high interest of the community stakeholder group in this objective of the port planning. The academic stakeholder group, contrast, is identified only as a bystander in terms of hinterland connectivity.

Safety and Security

As illustrated in Figure 2.4, the high interest of all groups in this objective of the port planning indicates that they should be involved during the planning process. The internal stakeholder group can have a tremendous influence in terms of safety and security on the port planning process, both positively and negatively. Players, including the legislation and public policy, internal and external stakeholder groups, should be directly and fully engaged in the decision making on safety and security in the planning process. Both the academic and community stakeholder groups are identified as the subject group. This indicates a high level of concern by these groups toward the safety and security in the port planning. This area of concern plays a vital role in this study because of heavy port activities in the area. These two groups should be kept informed about this objective of the planning process. The community stakeholders, however, might be identified as a player in cases where this group is highly affected by an increase in port activities in the future.

Environmental Implication

All groups were classified with high power and interest in environmental implication. This corresponds to the importance of this objective in the port planning. Although all stakeholder groups were identified with high power and interest in this objective, the academic stakeholder group had a weaker position in comparison to other groups. This is the only objective in this study that all stakeholder groups played significant roles and should be fully engaged in decision making in the planning process. As can be seen from Figure 2.4, the legislation and public policy stakeholder group had close power and more interest than internal stakeholders in this objective. This is because this group has legislative authority over environmental law and regulations. Therefore, the internal stakeholder group is obligated to implement the relevant law and regulations in the planning process. The result reveals the relative influence of the internal stakeholder group on this objective of planning. Open and trustworthy communication among the stakeholder groups is essential because it plays a key role in this area of concern; otherwise, conflict can arise in any given decision-making situation.

Economic and Social Impact

As can be seen in Figure 2.4, the legislation and public policy, internal and external stakeholder groups are highly influential and directly affect (or are affected by) this objective in the port planning. These groups should be fully engaged in decision making in order to address the objective of economic and social impact in the planning. The power and interest associated with the internal stakeholder group are ranked the highest in this objective compared to the other groups. The community stakeholder group is identified as a subject group. This group must be kept informed about this objective during the port planning process. The community stakeholder group might be more affected by economic and social impact in the future and become a player, and at that time this group should then be fully engaged in the process. The academic stakeholder group, on the other hand, was identified as a bystander group on this objective in the port planning.

Flexibility

Flexibility is considered a new term in the port planning. As shown in Figure 2.4, the legislation and public policy, internal and external stakeholder groups were considered as players with high power and interests in flexibility in the port planning. To address flexibility in the planning, these groups should be fully engaged. The internal stakeholders have the highest power in this objective of port planning. Thus, close collaboration with the internal stakeholder group, as well as other players, should be a part of any decision making in the port planning process. These players are highly affected, have enormous influence, and great concern and interest in flexibility in the port planning. The community stakeholder group, as a subject group, should be kept informed about this objective of the port planning. The academic stakeholder group is identified as a bystander group and they should be informed with limited effort; however, this group potentially has a great capacity for interest in this objective of planning and could readily become a subject group in the future.

Financial Performance

As depicted in Figure 2.4, the interest of the internal stakeholder group was dominant in financial performance in the port planning. The internal stakeholder group also had the strongest influence on this objective in comparison to the other stakeholder groups. As players, the legislation and public policy, internal and external stakeholder groups had great interests in financial performance. These groups are in prime positions to affect (or be affected by) this objective of the port planning. These players should be fully engaged in decision making with the greatest efforts to make them satisfied with respect to financial performance. The community stakeholder group had an interest in financial performance as well. This group should be informed about this objective in the port planning process. The academic stakeholder group was identified as a bystander group for this objective of the port planning.

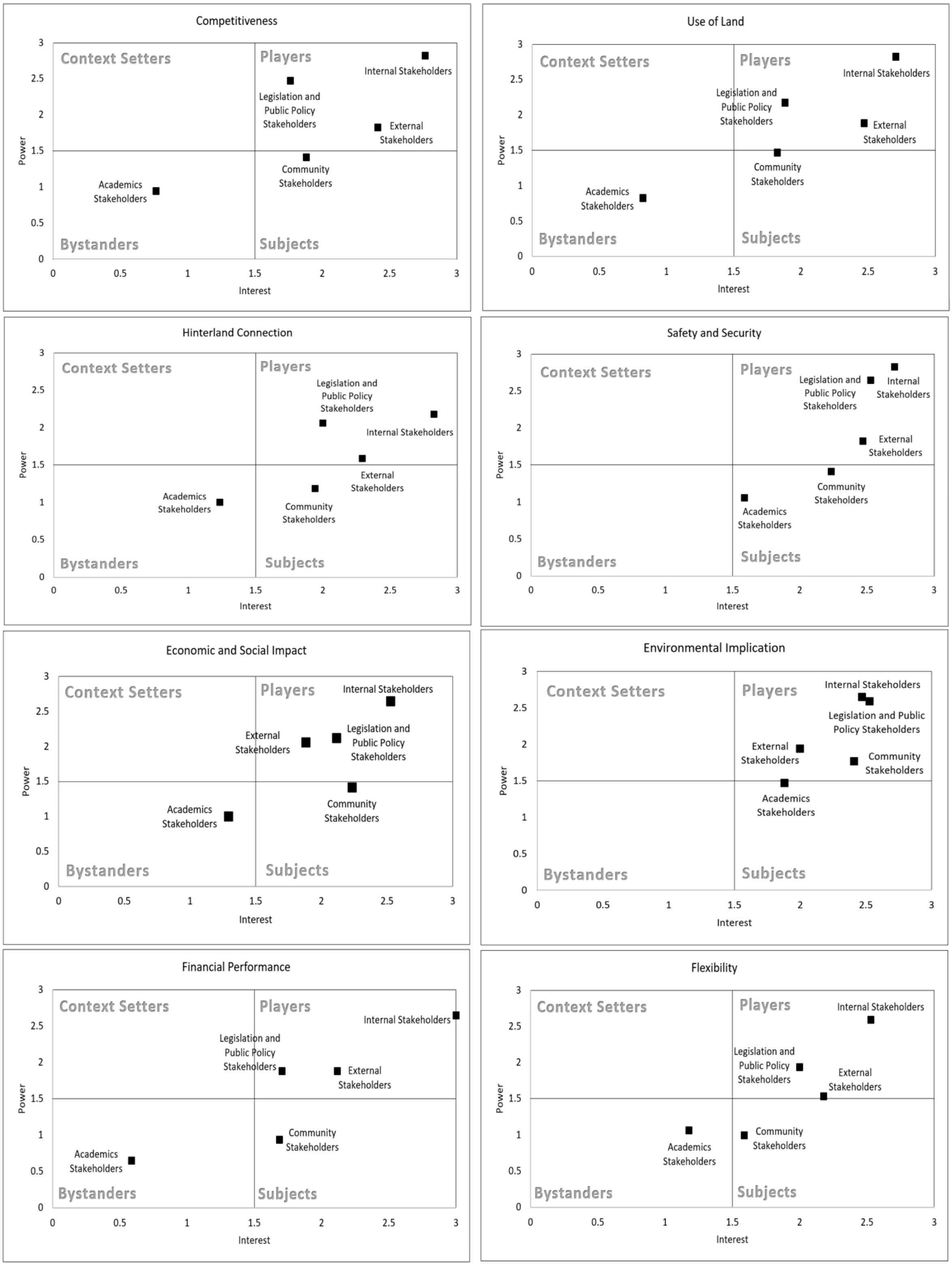

Figure 2.4 Power-interest matrix for the objectives of the port planning

Standard deviation of the stakeholder groups on the objectives of the port planning

To have a better overview and understanding of stakeholder' attributes, the standard deviation of the stakeholder groups was calculated, as shown in Figure 2.5.

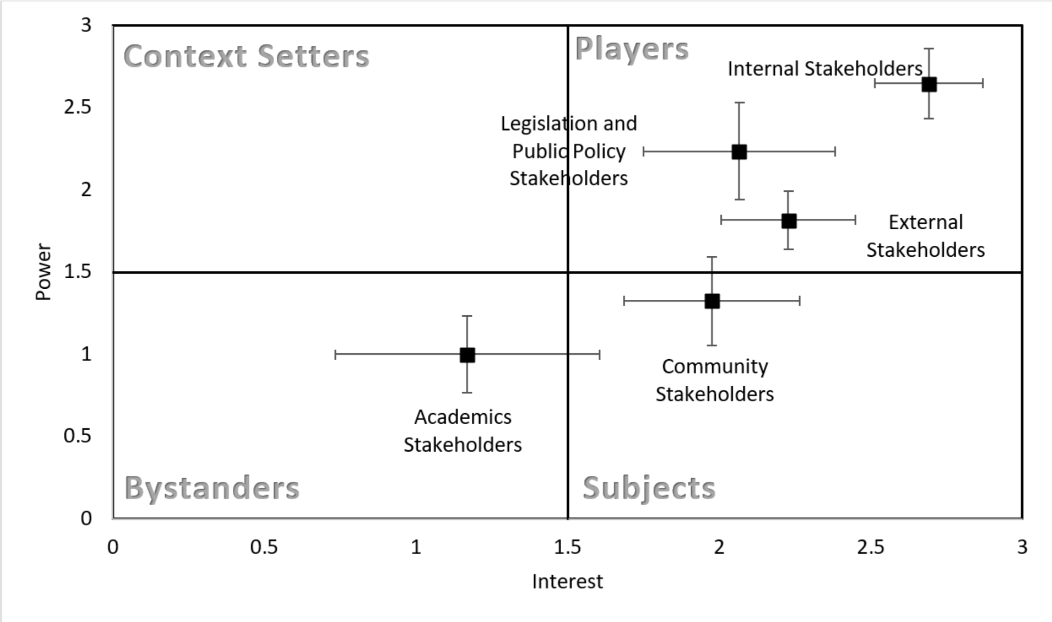

Figure 2.5 Standard deviation and stakeholder's attributes on the objectives of port planning

The relatively small error bars and the short range of data for the internal stakeholder group indicate that the weights given to the attributes of this group are densely distributed. This testimony attests to the high awareness of stakeholders about the important role of the internal stakeholder group on the objectives of port planning. The standard deviation of interest for the internal stakeholder group was larger in comparison to its power. The same characteristic, small error bars of power in comparison to the interest, was observed for the other two groups in the player quadrant. However, the interest of the external stakeholder group and both power and interest of the legislation and public policy stakeholder group had a relatively larger standard deviation, thus expressing either the diversity of ideas or lack of (limited) information among stakeholders about the attributes of these two latter groups.

The community stakeholder group was identified as a subject group in terms of the objectives of the port planning. However, the standard deviation of power for this subject group indicates that the community stakeholder group potentially can be considered as a player in the port planning process. The short standard deviation of power of this group implies high awareness of stakeholders in the influential role of the community stakeholder group. The large standard deviation of interest for the academic stakeholder group implies that this group has a high interest in the port planning process, and can be considered a subject group. It also demonstrates that this group is not well-recognized in terms of interest in the objectives of the port planning among the stakeholders.

2.6.2 Transferability of Findings Based on 2D Stakeholder Group Mapping

Players

The majority of the stakeholder groups were classified within this group. As the internal stakeholder group is the main player that endorses and executes the planning, this group has the highest power and interest in the port planning. This group should be fully engaged in decision making during the planning processes. The legislation and public policy stakeholder group is another player in the port planning. This group includes authorities and organizations which are recognized with a high level of power and interest to make the final decisions and approval of the port plan. The external stakeholder group was identified as the third player in the port planning. This group has close co-operation with the internal and legislation and public policy stakeholder groups. The external stakeholder group has less power but more interest in the port planning in comparison to the legislation and public policy stakeholder group. This implies the significant effect of the port planning on the external stakeholder group or vice versa. The external stakeholder group should be kept constantly engaged in decision making in the port planning because they are considered as allies with beneficial input. In fact, the external stakeholder group relies on the development of the port, because this group is the direct port user. The significant influence of this group indicates the high demand for port development.

As these three groups are major drivers of any changes in the port planning process, close collaboration and effective engagement with them in decision making are crucial. These three groups should be directly involved as their insight and knowledge leverage the planning process toward achieving the objectives of the stakeholders. The greatest efforts should be made to satisfy them. As discussed, these three groups have slightly different levels of power and interests in the objectives of the port planning. However, based on the 2D stakeholder mapping, since these groups are in the player quadrant, they should be classified in the same category and equal level of engagement in the decision-making process.

Subjects

The community stakeholder group was identified as a subject group. This group had relatively low influence on decisions in the port planning process. With high interest in the port planning, the community stakeholder group should be partly engaged in the decision making during the planning process. Although this group is labelled as exercising only moderate engagement, the lack of influence might be overcome in the future. For instance, growing the population increases the demand on the importation of goods or demand on the land around the port. Thus, the community stakeholder group can highly influence the decision making in the planning. As a subject group, the community stakeholder group should be kept regularly informed about the port planning process.

Bystanders

The academic stakeholder group is placed in the bystander quadrant as they are recognized as having a low level of interest and power in the port planning process; nevertheless, the academic stakeholder group should be informed with limited effort about the planning process. As a multidisciplinary task, the port planning requires engineering, management, and science. The academic stakeholder group can report from different fields of studies and offers the best possible solutions to challenges in the planning. This group, undoubtedly, has a high interest in the process of planning, as proven by the literature. As a bystander, the academic stakeholder group does not have as high a level of interest as the community stakeholder group. However, the large standard deviation in terms of the subject quadrant discloses the high potential interest of this group in the planning. The level of interest of this group might increase in the future, for instance, by being involved in the planning. Thus, the academic stakeholder group should be informed about the planning process.

Context Setter

None of the stakeholder groups is placed in this quadrant. It indicates that all stakeholder groups with a high level of power are highly interested in the port planning, and thus stand as a player.

The results indicate that the identified players are well-placed in the context of this study. Direct and indirect port activities have a significant influence on Iceland's economy as well as the society as a whole. High interest and demand for the development of the ports by external stakeholders require the internal stakeholders to develop the layers of the ports. In fact, the interests of the external and internal stakeholder groups are correlated. However, final approval of any plan is given by the legislation and public policy stakeholders. This triangle of stakeholder group connections is observed in terms of power and interest in Figure 2.5. Also, a high level of interest in the port planning is observed from the community stakeholder group. In the port cities, port activities are a part of the surrounding communities' affairs. Although community stakeholders have been identified as a subject group with high interest, a higher influence on (or being influenced by) the port planning was expected in order for them to stand as players. Indeed, as can be seen from the standard deviation, this group has been identified as a player by some stakeholders. The port planning has always been an interesting topic in academia. In this study, the academic stakeholder group is identified as a bystander; albeit a large standard deviation connects this group to the subject quadrant.

2.6.3 Salience and Prioritization of the Players

In the final stage, the stakeholder groups were prioritized based on their salience in the objectives of the port planning using fuzzy logic. In this study, the stakeholders who were assigned to the player quadrant, including legislation and public policy, and internal and external groups, were considered for prioritization. These initial categorizations before prioritization overcome the Poplawska et al. (2015) frameworks' limitation, which did not classify the stakeholders before the prioritization process (Elsaid, Salem, and Abdul-Kade 2017). Table 2.2 shows the attribute profile of the stakeholders on the objectives of the port planning.

Table 2.2 The attribute profile of the stakeholders

Stakeholder group	Attribute	Profile (X_{min}, X_{avg}, X_{max})
Internal	Power	(2.18, 2.65, 2.82)
	Interest	(2.47, 2.69, 3.00)
External	Power	(1.53, 1.82, 2.06)
	Interest	(1.88, 2.23, 2.47)
Legislation and public	Power	(1.88, 2.24, 2.65)
policy	Interest	(1.71, 2.07, 2.53)
Academic	Power	(0.65, 1.00, 1.47)
	Interest	(0.59, 1.17, 1.88)
Community	Power	(0.94, 1.32, 1.76)
	Interest	(1.59, 1.98, 2.41)

Table 2.3 presents the salience fuzzy logic of the stakeholders, which was calculated by averaging the attribute profiles of each stakeholder group.

Table 2.3 Stakeholders' salience

Stakeholder group	Profile (Avg_{min}, Avg_{avg}, Avg_{max})
Internal	(2.32, 2.67, 2.91)
External	(1.70, 2.02, 2.26)
Legislation and public policy	(1.79, 2.15, 2.59)
Academic	(0.62, 1.08, 1.67)
Community	(1.26, 1.65, 2.80)

Using the fuzzy logic approach, the stakeholders receive a degree of membership instead of a discrete class. All possible degrees of membership of the stakeholders in terms of the attributes were obtained by a trapezoidal type membership curve. The membership functions for stakeholders' attributes were formed from the values. Two input trapezoidal membership functions of low and high were defined to categorize power and interest attributes, as depicted in Figures 2.6 and 2.7, respectively.

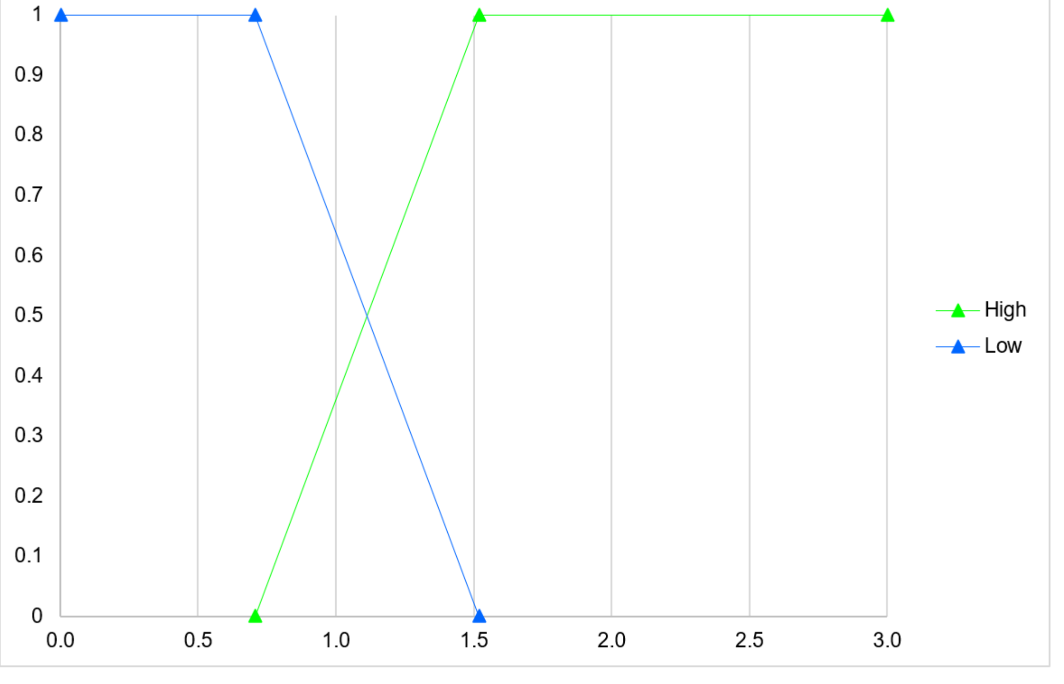

Figure 2.6 Membership functions of stakeholders' power

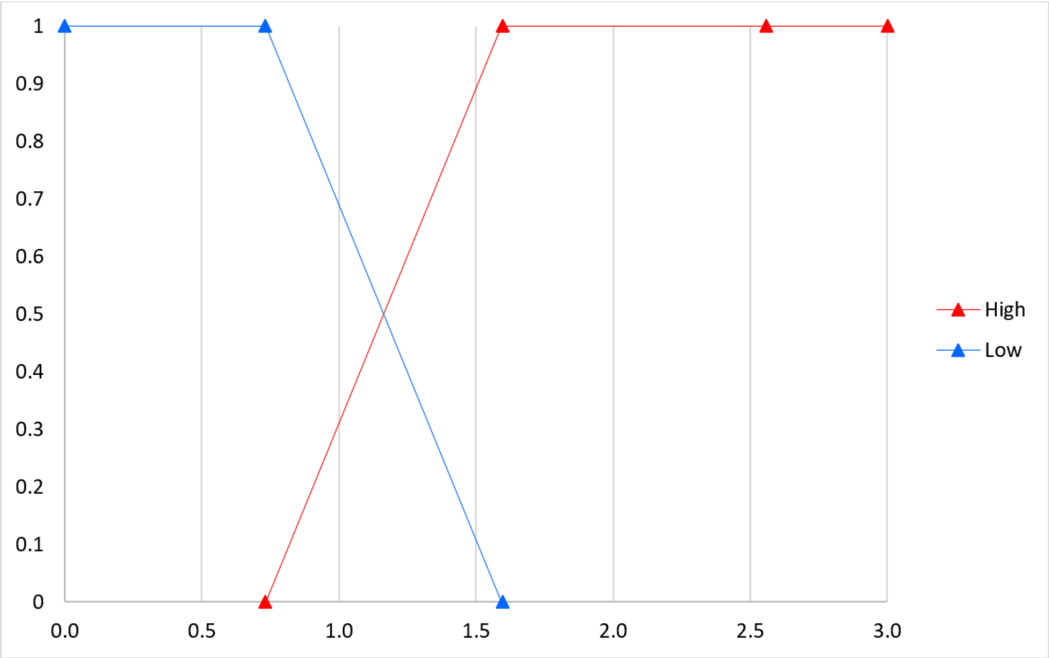

Figure 2.7 Membership functions of stakeholders' interest

Figure 2.8 shows the linguistic importance of stakeholders' salience with the three output membership functions of low, medium and high salience levels of the stakeholder groups.

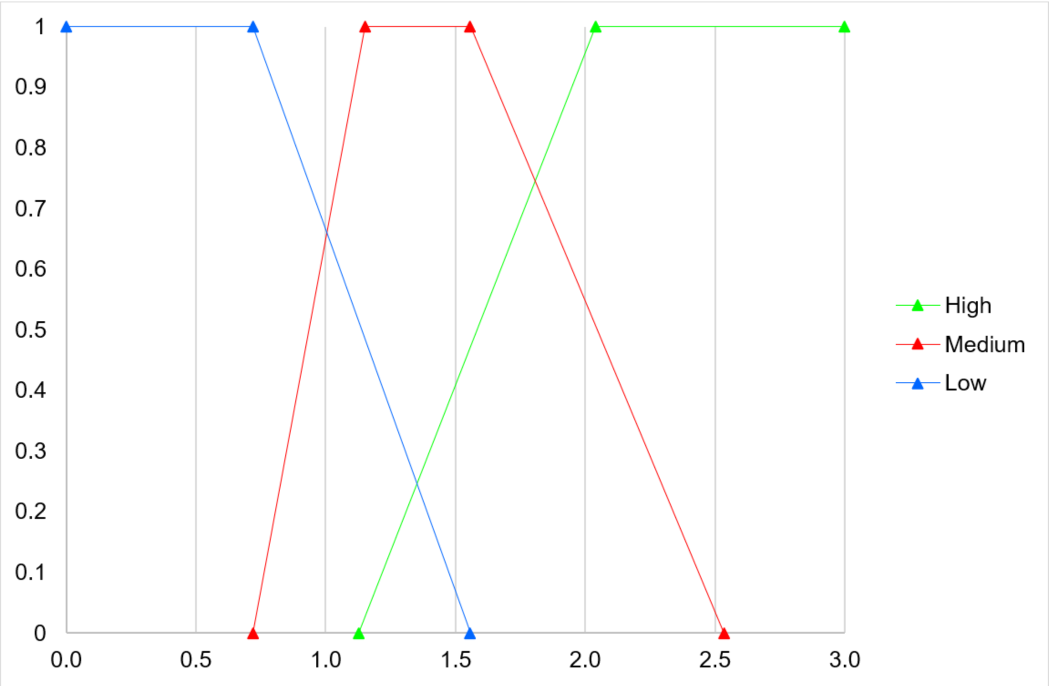

Figure 2.8 Membership functions of the importance of stakeholders' salience

Point one indicates a full degree of membership for an attribute and the lower and upper limits signify the point without membership. The values in Figures 2.6 to 2.8 represent the degree of membership of the attributes based on the result of the survey conducted in this study.

The decision surface was plotted by multiplying the membership functions of power, interest and salience. The decision surface was generated by a fuzzy interface system using the stakeholders' power and interest as input and the stakeholders' salience as output. The if-then rule was programmed to construct the behavior of the system and plot a 3D surface by generating the points and using a fuzzy logic approach to determine the values on the axes. The 3D decision surface provided a unique relation between the stakeholders' attribute, power or interest, and the stakeholders' salience.

To position the stakeholder on the decision surface, the coordinate of the central point for each stakeholder group was calculated. The coordinate contained the average values of power, interest and salience as detailed in Table 2.4. The stakeholders were positioned on the decision surface based on their coordinates.

Table 2.4 The position of the stakeholder groups on the decision surface

Stakeholder group	Profile (Avg_{power}, $Avg_{interest}$, $Avg_{salience}$)
Internal	(2.65, 2.69, 2.67)
External	(1.82, 2.23, 2.02)
Legislation and public policy	(2.24, 2.07, 2.15)
Community	(1.32, 1.98, 1.65)
Academic	(1.00, 1.17, 1.08)

Figure 2.9 illustrates the position of the legislation and public policy, internal and external stakeholder groups on the decision surface. The relationship between the players and the range, shadow circle, of salience, power, and interest are depicted on the decision surface.

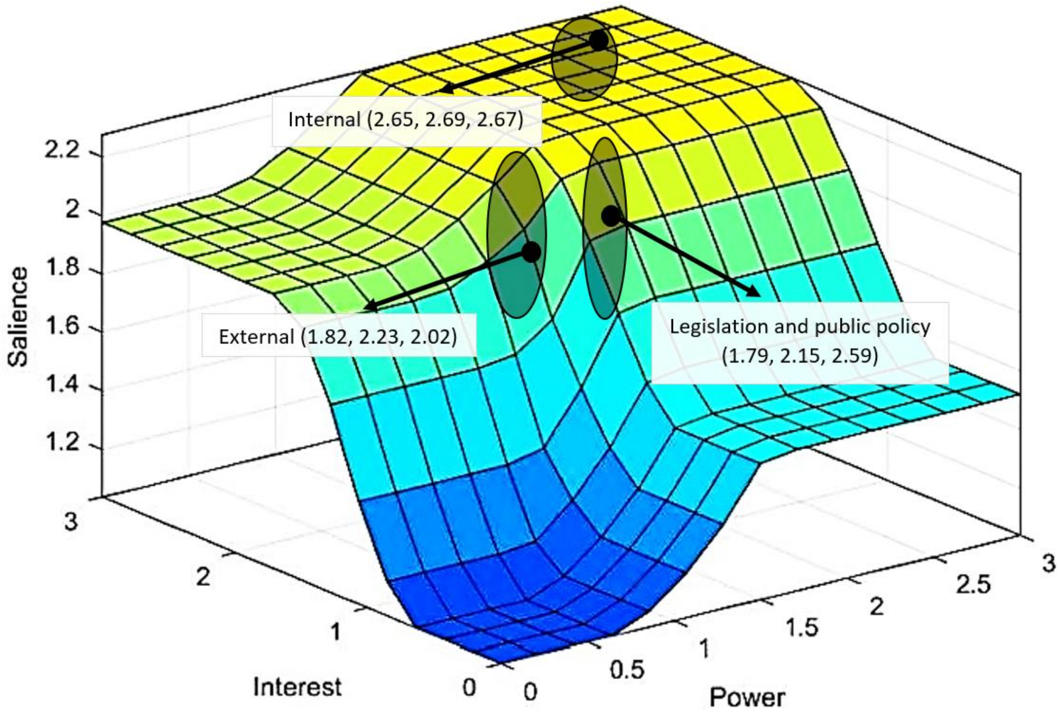

Figure 2.9 3D decision surface for the relationship between power and interests of the stakeholder groups

Figure 2.9 shows a dynamic stakeholder mapping which describes the interrelationship, evaluation, and prioritizing of players is dynamic rather than static and that it might cover a range of attributes. The dynamic mapping depicts the possible interaction with and influence of the stakeholders on each other. As illustrated, although the legislation and public policy, internal and external stakeholder groups were identified as players, the levels of their salience were not the same. The decision surface indicates the internal stakeholder group possesses a high degree of attributes and consequently salience in the port planning process. This group is placed in the flat area of the decision surface with a distinct salience. This indicates a stable role by this group in the port planning process. The acute slope of the decision surface indicates a rapid changing of the degree of membership in the attributes. The steepest slope on the decision surface is the fuzzy area. Placement of a stakeholder group in this area means that small changes in their attributes, including interest and or power lead to a rapid change in their salience. As can be seen in Figure 2.9, the legislation and public policy and in particular the external stakeholder groups are placed on the steep slope of the surface. Thus, these groups can rapidly change their salience during the port planning process.

2.7 Limitations of the Study

It should be noted that this study has its limitations. The boundary of the project was defined at the national level. However, international stakeholders such as international companies or authorities and organizations might play important roles in the decision making in the port planning process. Another concern applies whether the interviewees are representative of their departments. Moreover, the identification of the values of port planning is limited to the opinions or knowledge of the interviewees. Thus, the interviews should be accomplished with the broadest range of stakeholders to identify all possible values, as was done in this study. It should be highlighted that conducting such comprehensive interviews is both laborious and time-consuming.

Another limitation might arise in relation to the accuracy of the responses to the survey by the stakeholders, which could not be guaranteed. Although in this study the average of the 17 responses was taken into account, engaging a greater number of stakeholders can further reduce the potential of bias and strengthen the results. As stakeholders may be continuously changing their attributes, the stakeholder analysis might not be durable and should be updated prior to any major decision making.

The model contributes toward a timely and effective engagement of the key stakeholders in the port planning process. However, this is the first step toward arriving at a decision and does not necessarily mean that the final decision can be made only with respect to the key stakeholders' demands. Moreover, it should be noted that the stakeholder prioritization can be challenging when putting theory into practice.

2.8 Conclusions

Stakeholder analysis enhances decision making by rational prioritization of stakeholders to be engaged in the port planning process. This chapter presents a structured framework by synthesizing qualitative and quantitative methods to measure the salience of stakeholders in the port planning. The framework provided an analysis of stakeholders by monitoring their salience with respect to the level of their power and interest.

The result showed that 3D-decision-surface stakeholder mapping overcame the restriction of the 2D stakeholder mapping and offered a richer view for stakeholder prioritization. It not only revealed who should be engaged from the early stages and during the whole process, but who has more salience and entitlements to a role now and or possibly in the future. The 3D decision surface manifested the dynamic attributes of stakeholder and latent salience that may be absent now. It facilitated decision making to foresee the coalition of different stakeholders by assessing their salience. Therefore, for timely and effective engagement of stakeholders during the port planning process, accurate prioritization based on the 3D salience mapping, indeed, contributes to the success of the plan. Having constructed such a steppingstone of multiple stakeholder analysis in the port planning, reaching a consensus among them on a definition of success in terms of desired outcomes of the plan is acknowledged for future research.

The decision surface disclosed the absolute salience of internal stakeholder group among players. This group played a leading role in the planning of the port network. The legislation and public policy stakeholder group had high power and interest in the port planning. The position of the external stakeholder group at the steep slope indicated the critical roles of this group in the planning process. This group should be closely engaged and monitored, as small changes in this group's attributes could turn to a definitive one and highly affected the decision-making process.

The external stakeholder group was identified as a highly influential group with great concern about the port network planning. Maximum effort should be given to ensure that the concerns of this player were incorporated. These groups should be directly engaged in the whole planning process. The high interest of the community stakeholder group in the port planning indicated the importance of this group, as a subject group, in the planning process. The community stakeholder group should be kept informed throughout the planning process. The results also stressed the important role of the academic stakeholder group in the port planning. This group has high potential to be considered as a subject group with a large interest in the port planning.

Acknowledgments

The time and expertise contributed by the people in the interviews and other formal and informal groups who were involved in this project are gratefully acknowledged. This research was supported by the Doctoral Grants of the University of Iceland Research Fund (Rannsoknarsjodur Haskola Islands), Municipality of Isafjordur (Isafjardarbaer), and the Icelandic Road and Coastal Administration Research Fund (Rannsoknarsjodur Vegagerdarinnar).

3 A Value-Based Definition of Success in Adaptive Port Planning: a Case Study of the Port of Isafjordur in Iceland

This chapter contains the peer-reviewed journal article:

Eskafi, M., R. Fazeli, A. Dastgheib, P. Taneja, G. F. Ulfarsson, R. I. Thorarinsdottir, and G. Stefansson. 2020. "A Value-Based Definition of Success in Adaptive Port Planning: A Case Study of the Port of Isafjordur in Iceland", *Maritime Economics and Logistics*, 22 (3), pp. 403-431. https://doi.org/10.1057/s41278-019-00134-6

3.1 Abstract

Multiple stakeholders with a wide range of objectives are engaged in a port system. Ports themselves are faced with many uncertainties in this volatile world. To meet stakeholder objectives and deal with uncertainties, adaptive port planning is increasingly being acknowledged. This method offers robust planning, and thereby, a sustainable and flexible port may be developed. The planning process starts with defining success in terms of the specific objectives of stakeholders during the projected lifetime of the port. In the present work, an integrated framework to reach a consensus on the definition of success, involving stakeholders with different influences, stakes and objectives, is presented. The framework synthesizes the problem structuring method with stakeholder analysis and combines these with fuzzy logic to support decision makers in formulating a definition of success in the planning process. Our framework is applied to the Ports of Isafjordur Network, the third busiest port of call for cruise ships in Iceland. Values of stakeholders about port planning were structured around the value-focused thinking method to identify stakeholder objectives. The highest level of agreement on the objectives, which is viewed here as success in port planning, was revealed by the fuzzy multi-attribute group decision-making method. Success was defined, prioritizing an increase in competitiveness among other planning objectives, such as effective and deficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, better environmental implications, flexibility creation and increasing positive economic and social impacts.

Keywords: Decision-making process, Adaptive port planning, Definition of success, Value-focused thinking, Iceland.

3.2 Introduction

Ongoing globalization, constant technological improvements and environmental and economic changes, among others, have led to the continuous development of ports to satisfy new traffic demand (Bendall and Stent 2005; Taneja, Ligteringen, and Walker 2012; Woo, Moon, and Lam 2017). The dynamic nature of a port system in this volatile world develops under a high degree of uncertainty, including opportunities and vulnerabilities in port development projects. In addition, non-financial criteria are being increasingly added to financial decision-making processes (Clintworth, Boulougouris, and Lee 2018) whereby various stakeholders or decision makers with diverse interests and power emphasize their own objectives in port planning. Adaptive port planning (APP) has attracted attention in recent years as a method to deal with the uncertainties ports face and to fulfil the objectives of port stakeholders (Eskafi et al. 2020c). APP delivers robust solutions by integrating uncertainty and flexibility into the planning process (Taneja, Ligteringen, and Van Schuylenburg 2010).

APP has been presented as a method of planning while considering the uncertainties involved in the process (Taneja 2013). Planning starts with the definition of success to satisfy the objectives of port stakeholders going forward. Stakeholder engagement and cooperation in the port planning process has been acknowledged in literature (e.g., (Wiegmans et al. 2018)). Moglia and Sanguineri (2003) point to the challenges involved in achieving the primary objectives in port planning. However, the question remains: How can consensus be reached among a large number of stakeholders on the definition of success in the port planning process? The answer to this research question is still being sought.

Belton and Stewart (2010) noted that, in the first step of any decision-making among multiple stakeholders, problems should be identified, understood and structured. Further, Pidd (2009) defined the problem as its formulation is agreed by stakeholders but its solution is arguable (by them). Problem structuring methods (PSMs) facilitate decision-making processes by identifying and structuring a problem to reach a consensus on a solution among decision makers (Ackermann 2012; Rosenhead 1996).

To the best of the authors' knowledge, the benefit of PSMs has not been fully recognized in the field of port planning. Hence, this research identifies the most suitable PSM to address the research question. A systematic decision-support framework to formulate a definition of success in APP is presented herein. Success is achieved if the outcome of APP fulfils the needs and desired objectives of stakeholders.

The proposed framework provides valuable insights to support the decision-making process, to reach a consensus among multiple stakeholders on a definition of success in APP using a systematic approach. The approach is based on the integration of three methods: 1- stakeholder analysis to identify the port stakeholders and measure their influence and interests during the planning process, 2- Value-Focused Thinking (VFT) method in order to reveal values of port planning[1] for all (relevant) stakeholders and,

[1] For instance, 1- environmental value: balanced port (infra)structures to relieve pressure on the coastal area, positive environmental impacts, respect to the ecosystem, including bird and marine life, 2- social value:

subsequently, set the means objectives for further analysis, and 3- fuzzy logic to reveal the highest level of agreement on the means objective among the key stakeholders to define a fundamental objective. Although focusing on one case, the research has been carried out in such a way that the framework is applicable to other similar cases.

The remainder of this chapter is structured, as follows: subchapter 3.3 outlines a literature review by characterizing the relevance of several problem structuring methods and the VFT method in the port planning process. Subchapter 3.4 addresses data collection and methods, subchapter 3.5 states the area of study, subchapter 3.6 discusses the findings, and subchapter 3.7 draws conclusions on the definition of success in APP for the Ports of Isafjordur Network in Iceland.

3.3 Literature Review

A literature review was carried out to create a platform for introducing the multiple methods that structure a problem in a decision-making situation to address the research question as defined in the introduction: How can consensus be reached among a large number of stakeholders on the definition of success in the port planning process?

PSM is considered as qualitative Operational Research (OR) modelling (Smith and Shaw 2018), soft OR or a soft systems methodology (Marttunen, Lienert, and Belton 2017). An appropriate PSM enriches a decision-making situation by diminishing errors when solving a wrong problem, minimizing the ill-defined decision problems, generating models that yield new understanding of the situation and introducing efficient ways to acquire well-recognized objectives. For the last 20 years, PSM has been increasingly applied to address uncertainty (Mardani, Jusoh, and Zavadskas 2015) and cover conceptual and practical aspects (Marttunen, Lienert, and Belton 2017). In a complex decision-making situation where there are a variety of goals from different stakeholders, PSM can facilitate the decision-making process.

Smith and Shaw (2018) introduced four frameworks to analyze the characteristics of PSM, namely systems characteristics, knowledge and involvement of stakeholders, values of model building and structured analysis. Identifying stakeholders and obtaining knowledge from them may lead to growing consensus in structuring the problem (Checkland 1985). By means of facilitation, participation, dialogue and analysis of the elements of a problem, PSM structures the issues across stakeholders (Ackermann 2012; Rosenhead 1996).

Different problem structuring methods have been applied in literature, including Strategic Options Development and Analysis (SODA) (Eden and Ackermann 2001), Soft Systems Methodology (SSM) (Checkland and Scholes 1999; P Checkland and Winter 2006), Strategic Choice Approach (SCA) (Friend 2011), robustness analysis (Rosenhead and

ositive effect on the quality of life, job creation, safe and secure environment in the port area and quick response to emergencies, 3- Economic value: attraction of international and national port users, enough service and utility for different types of vessels, ability to operate in bad weather conditions and aesthetic port area to attract tourists. The values from these three categories are first examined as sub-objectives, and then the sub-objectives are clustered into different means objectives as discussed in this chapter.

Mingers 1989), drama theory and confrontation analysis (Bennett, Bryant, and Howard 2001) and problem structuring group workshops (Shaw 2006).

Regarding the purpose of the present study, which is to formulate a definition of success in APP, the VFT method was selected as an appropriate PSM. The main reason is that proper decisions are usually taken when decision processes are structured and modelled based on values (Keeney 1996). Stakeholders care about the values of port planning, which are the primary driving forces in the decision-making process. The main stakeholder values of port planning should be identified, evaluated, harmonized and then prioritized (Arecco et al. 2016; Slinger et al. 2017; Eskafi et al. 2018). Güner (2018) noted that value judgements are the logical structures that shape opinions of decision makers, and applied value judgement to assess the efficiency of Turkish ports. Thus, VFT was adopted in herein to tackle the problem and analyze different stakeholder values to define success in APP.

Using the VFT method, all possible ideas, proposals and opinions are garnered for a decision situation, and the decision's objectives are identified in accordance with specified values. Values can be purposes, desires, concerns and important inputs that matter the most to stakeholders (Keeney 1996; Keeney 1992) and may be taken into account by decision makers. Then, means objectives are characterized as actions (or ways) that need to be implemented to achieve a fundamental objective. Finally, the fundamental objective[2] of port stakeholders is defined as the end that decision makers want to accomplish in a specific decision situation (Keeney and McDaniels 1999).

Thinking about decision situations should therefore begin with elicitation of values (Alencar, Priori Jr., and Alencar 2017). The VFT method provides a systematic approach for identification and specification of the values of actors, structuring and categorizing these values, converting them to the means objectives, recognizing the relationships among objectives, prioritizing the means objectives to achieve the fundamental objective and enhancing the validity and reliability of the outcome (Keeney 1996; Keeney 1992; Sheng, Nah, and Siau 2005). In this problem structuring method, the fundamental objective was considered as the driving forces in final decision making (Marttunen, Lienert, and Belton 2017). Value-focused thinking is a proven method that is being widely applied in various disciplines, as listed by (Sheng, Nah, and Siau 2005), as well as in the literature, such as strategic management (Kunz, Siebert, and Mütterlein 2016), quality management practice (AlMaian et al. 2016), environmental management and wall structures (Hassan 2004).

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[2] For instance, in the context of port planning and design, a fundamental objective could be to reduce port congestion. To achieve this objective, different means objectives include increasing cargo (handling) distribution to neighboring ports, improving port connectivity to the hinterland with different types of modalities and upgrading port and terminal facilities.

3.4 Methods and Materials

3.4.1 Stakeholder Analysis

As the power and interests of port stakeholders could be very different regarding the values of port planning (Ferretti 2016), VFT does not directly provide a definition of success (the fundamental objective) in the APP. To enhance the validity and reliability of this PSM, stakeholder analysis should be taken into account. To determine the definition of success, the power and interests of key stakeholders on the means objectives (described in subchapter 3.4.2) play a critical role in the planning process, as their means objectives should be prioritized in framing the fundamental objective. Without considering the power and interest of the stakeholders, attempts to reach the fundamental objective are thwarted.

The work presented herein focusses on the key stakeholders who are either decision makers (on concluding the definition of success in APP) or the main influencers for port development. An extensive stakeholder analysis for Icelandic ports was conducted (Eskafi et al. 2019a). Although the purpose of this chapter is not to delve too deeply into stakeholder analysis, the process of analyzing the stakeholders is briefly described.

Among other methods of stakeholder identification such as literature reviews, expert interviews and focus groups, the snowball sampling approach is an acceptable and quick way to identify a comprehensive list of stakeholders (Lienert, Schnetzer, and Ingold 2013). Following this technique, a preliminary list of stakeholders based on similar and previous studies was developed. Then, the stakeholders in the initial list were asked to add possible missing stakeholders to the list. Newly added stakeholders were analyzed by a group of experts. Those considered as stakeholders were kept on the list and contacted to add any missing stakeholders to the list. The process continued until no further stakeholders could be added. Then, the identified stakeholders were categorized/grouped by their level of influence and stake in the decisions (Frooman 1999).

Next, the power-interest matrix (Eden and Ackermann 1998) and fuzzy logic decision surface (Poplawska et al. 2015; Ross 2004) were developed to map the stakeholder groups based on the collected inputs from the interviews with representatives from all stakeholder groups. The assessment of stakeholders was based on their affiliation in the short- and long-term planning processes and the subsequent port development. The stakeholders were asked to weight the groups in terms of their power and interest in different objective of port planning. The objectives were identified during the meetings with the stakeholders and expert group.

3.4.2 Identification of Values, Sub-Objectives and Means Objectives

Stakeholder identification and their engagement in the planning process lead to the disclosure of values, and consequently, to the construction of means objectives of APP. Interviews are an essential source of data gathering (Yin 1994). Face-to-face semi-structured open-ended interviews were conducted with all those who had a stake in the planning of the Ports of Isafjordur Network to ensure that a wide range of values would be captured. The engagement of representatives from all stakeholder groups created authentic contexts that covered the dynamic view of the socio-economic significance of the port

(Santos, Salvador, and Guedes Soares 2018). The interviews were audio-recorded to process the information based on the VFT method carefully and for further documentation.

The interviewees were informed about the project by email and phone before the interviews. During the interviews, an introduction was also given to the interviewees. Then interviews carried on asking the port stakeholders "What are the values of port planning from your standpoint?" All concerns and points of view raised by them were collected and carefully analyzed to provide a comprehensive list of values regardless of their priorities. It is important to point out that no attempt to differentiate the stakeholders based on their skills and experience was made. Any quantitative values and qualitative statements of values, for instance, X% increase in financial performance of the port, were systematically probed and counted. The aim was to capture different perspectives of stakeholders with different interests and power that could affect the port planning decisions. Stakeholders were encouraged to use lateral thinking to glean as many values as possible, and to specify a comprehensive set of values that would result in a comprehensive and diverse list.

The following steps were taken to remove redundant values and consolidate similar ones: Through an in-depth content analysis, common sub-objectives of port planning were obtained from the values. Note that the values could be an idea, thought, need, concern etc. of the stakeholders (Alencar, Priori Jr., and Alencar 2017) about port planning, whereas the sub-objectives were what the stakeholders would wish to achieve, and they should be addressed in the planning. Then, the sub-objectives were clustered in terms of their relation to port planning. The sub-objectives were categorized in an initial list of independent, well-defined, complete and concise means objectives.

Several interviews among a group of multidisciplinary experts and authors were held to analyze and define specific means objectives. A literature review in the field of port planning, from peer-reviewed scientific publications (e.g., (Arecco et al. 2016; Slinger et al. 2017; Taneja 2013)), as well as international laws and regulations such as PIANC and European directives were used to dive deep into the topic to complement the procedure of reaching a unique terminology for the means objectives and adjust them in line with prominent literature.

To take into account the priority of different stakeholder groups on the means objectives and visualize potential conflict among stakeholder groups, radar plots were used. Using radar plots also helped to pinpoint strong means objectives as well as to identify the weak ones held by minorities in terms of the number of stakeholders in groups to achieve a conclusive fundamental objective.

3.4.3 Framing the Fundamental Objective

The means objectives were considered as the main drivers in achieving the fundamental objective. The stakeholders with the highest power and interest in the means objectives in the port planning process were targeted for framing the fundamental objective. It should be emphasized that the contribution of other stakeholder groups, which were not considered key stakeholders, were clustered in the form of means objectives.

Once the key stakeholders were identified, a focus group meeting was held to select one representative from each key stakeholder group. The selection of the representatives was based on their power and interests, as well as on their short- and long-term roles in the planning process and the subsequent port development. Then, the list of clustered sub-objectives was sent to the representatives to 1- identify any possible new values and provide feedback on the list of sub-objectives and 2- review the identified sub-objectives of port planning and obtain an overview of other stakeholders' attributes.

To discover the importance of the means objectives from the perspective of key stakeholders, separate meetings were held with the representatives. In these meetings, representatives were asked to priorities the means objectives and explain their reasoning. Materials and ordering lists of the means objectives from the meetings then formed the basis toward achieving the fundamental objective.

3.4.4 Fuzzy Logic and Final Level of Agreement on the Means Objectives

The fuzzy multi-attribute group decision-making method was applied to define the final level of agreement among the preferences of representatives regarding the fundamental objective. The method is widely advocated in literature (e.g., (Bender and Simonovic 2000; Blin 2008; Sun et al. 2018; Wan, Wang, and Dong 2018)). By using this method, the relationship among the key stakeholders' preferences on the means objective was revealed. The fuzzy model of a group decision, as proposed by Blin (2008), was adopted in the context of port planning. The model provides a common acceptable decision from different individual stakeholders with a multiplicity of objectives. In the model, n stakeholders have a preference ordering of P_k, where $k \in n$ and a set of means objectives, X, are ordered. Klir and Folger (1988) stated that preference S is defined as a fuzzy binary in terms of membership grade function as follows:

$$\mu s: X \times X \rightarrow [0,1] \qquad (3.1)$$

where the membership grade $\mu s(x_i, x_j)$ is the degree of preference of the means objective x_i over x_j. Individual preferences were aggregated by the relative popularity method (Kahraman, Ruan, and Doğan 2003). The relative popularity of means objective x_i over x_j was calculated by dividing the number of individuals who preferred means objective x_i to x_j, shown as $N(x_i, x_j)$, by the total number of individuals, n:

$$\mu s(x_i, x_j) = N(x_i, x_j)n \qquad (3.2)$$

Based on the relative popularities of the means objectives, two clusters of high and low importance were defined. Clustering of the means objectives is an approximate method that dismisses extra unnecessary mathematics to find out all possible orders. After defining the fuzzy relationship S, the non-fuzzy preference is obtained from the component of S as follows:

$$S = U_\alpha \alpha S_\alpha \qquad (3.3)$$

where α-cuts of the fuzzy relation S form the crisp relations S_α, and $\alpha \in A_S$ is measured by α where α is the level of agreement among the individual key stakeholders on a crisp ordering S_α.

To maximize the final level of agreement among the key stakeholders' preferences for the means objectives, the classes of crisp total orderings were intersected with the pairs in the α-cuts S_α with smaller values of α. This process was continued until a single crisp total ordering was obtained. The pairs (x_i, x_j) that lead to an intransitivity should be eliminated. In this process, the maximum level of agreement among key stakeholders for the preference, which is potentially considered as the fundamental objective, is obtained from the largest value α for a specific ordering (Kahraman, Ruan, and Doğan 2003; Klir and Folger 1988).

As the definition of success in APP specifies the desired objectives of the port stakeholders, a qualitative approach to find the means objectives and a quantitative method to achieve the highest level of agreement among the objectives might not be enough. Therefore, to reach a consensus on the fundamental objective, the final level of agreement on the means objectives was discussed individually with the representative of each key stakeholder group. The definition of success was achieved when the highest level of agreement was approved by the key stakeholders. Otherwise, a common meeting with the representatives of key stakeholders was held to reach a consensus.

3.5 Study Area

The Isafjordur Port Authority manages four ports of different sizes and capacity, including the Port of Isafjordur, the Port of Sudureyri, the Port of Flateyri and the Port of Thingeyri, located in the northwest of Iceland (Figure 3.1) The Port of Isafjordur is the biggest port and distribution center in the region. The main functions of the port comprise fishing activities, cargo handling and cruise ships servicing. The Ports of Isafjordur Network is the third busiest port of call for cruise ships in the country. The other three ports provide services mostly to fishing and sailing boats.

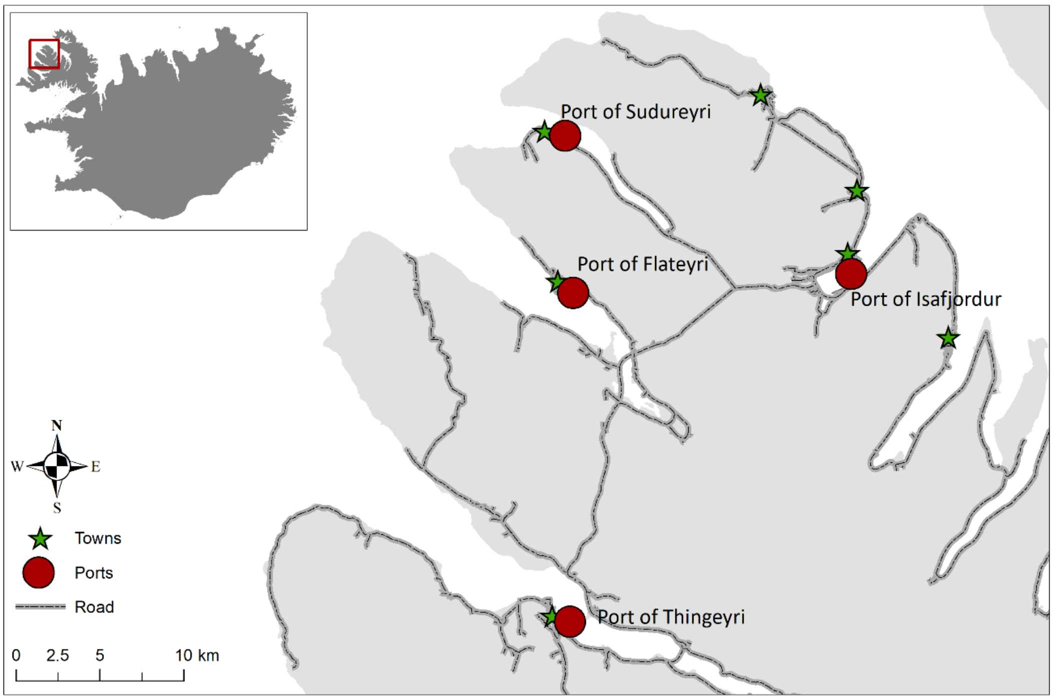

Figure 3.1 Location of ports (the study area is shown on the map of Iceland)

The Port of Isafjordur is the destination of cargo ships on a regular basis, the so-called coastal shipment of the country. The hinterland of the port comprises the whole country. The port network is faced with a rapid increase in demand by cruise liners, marine recreational activities, fishing and aquaculture industries and transport companies (Isafjordur Port Authority 2020). However, restrictions in infrastructure, operations and services of the port network limit its potential capacity for the optimum throughput. The inability to meet demand is a loss of opportunity that might affect the competitive position of the port among the other ports in the country as well as among Nordic countries in Europe. In this regard, the Port Authority has expressed its decision to further develop port areas to meet both today's and future demands. The Port Authority has decided to implement APP for the planning of the Ports of Isafjordur Network.

3.6 Results and Discussion

3.6.1 Means Objectives of Port Planning

Based on the results from the stakeholder analysis, the Icelandic port stakeholders have been classified into five groups: 1- internal stakeholders, 2- external stakeholders, 3- legislation and public policy stakeholders and 4- community stakeholders. The terminology of classification was based on the method presented by Gul Denktas and Cimen Karatas (2012)[3]. As a result of the stakeholder analysis, described in subchapter

[3] An academic stakeholder group was added as it plays an important role in the port planning by generating new ideas and developing knowledge through their research (Slinger et al. 2017).

3.4.1, the internal, external and legislation and public policy stakeholder groups were identified as the key stakeholder groups.

In the present study, 51 face-to-face semi-structured and open-ended interviews were conducted. The position of the interviewees in their companies/organizations and their stakeholder group are presented in Appendix C. This exhaustive effort to interview all (relevant) stakeholders was carried out for the first time in Iceland. In total, 314 values were elucidated from the 51 interviews. From these values, 61 specific sub-objectives were identified. Collectively, a set of eight means objectives were determined, namely: increasing competitiveness, increasing effective and deficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, better environmental implications, creating flexibility and increasing positive economic and social impacts. The sub-objectives, clustered in the form of means objectives, are presented in Table D.2 in Appendix D. The objective tree is shown in Figure 3.2.

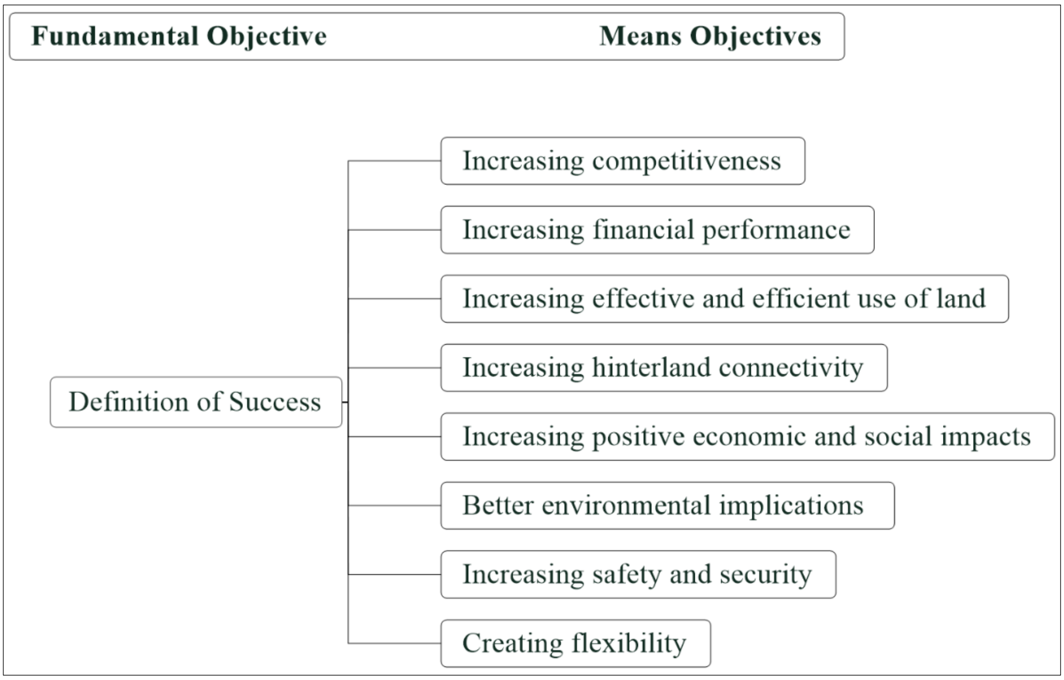

Figure 3.2 Overall objective tree of port planning

3.6.2 Attributes of Stakeholder Groups

The preferences of stakeholder groups for the means objectives clarified their concerns in the decision-making process. Hence, this helped the problem structuring process toward achieving the fundamental objective. The numbers in the radar plots indicate the aggregate number of stakeholders in a group that pointed out a sub-objective (and consequently a means objective) in the interviews.

Internal Stakeholder Group

Increasing competitiveness was a prioritized means objective for the internal stakeholder group. Cruise calls to the Port of Isafjordur have been increasing exponentially during the last few years (Isafjordur Port Authority 2020). Fish farming and aquaculture are thriving in the region (Icelandic Directorate of Fisheries 2021). This increases the volume of (un)loading cargoes and containers in the port. Although the port has a strong competitive position in the region, the growing port activity encourages the internal stakeholder group to emphasize the competitiveness and the importance of expanding its market share. In this regard, the internal stakeholder group showed preference to increasing hinterland connectivity as well. Moreover, effective and efficient use of port land has become important for the competitive position of the port, as land is limited in the port area. As shown in Figure 3.3, the internal group strongly expressed a focus on the means objectives of effective and efficient use of land. There was also a preference to increase safety and security and financial performance and to improve environmental implications. These means objectives were not strong, however. Considered as a small port, Isafjordur operates without any major issue with respect to these means objectives. However, they may carry more weight and require more attention in the future with increased port activities. The preference for increasing positive economic and social impacts was quite limited compared with other means objectives. The reason might be that this group expects that port planning per se enhances positive economic and social impacts. The extra cost of creating flexibility and its long payback period on investment (Taneja, Ligteringen, and Walker 2012) might hamper the attribute of the internal stakeholder group on this means objective.

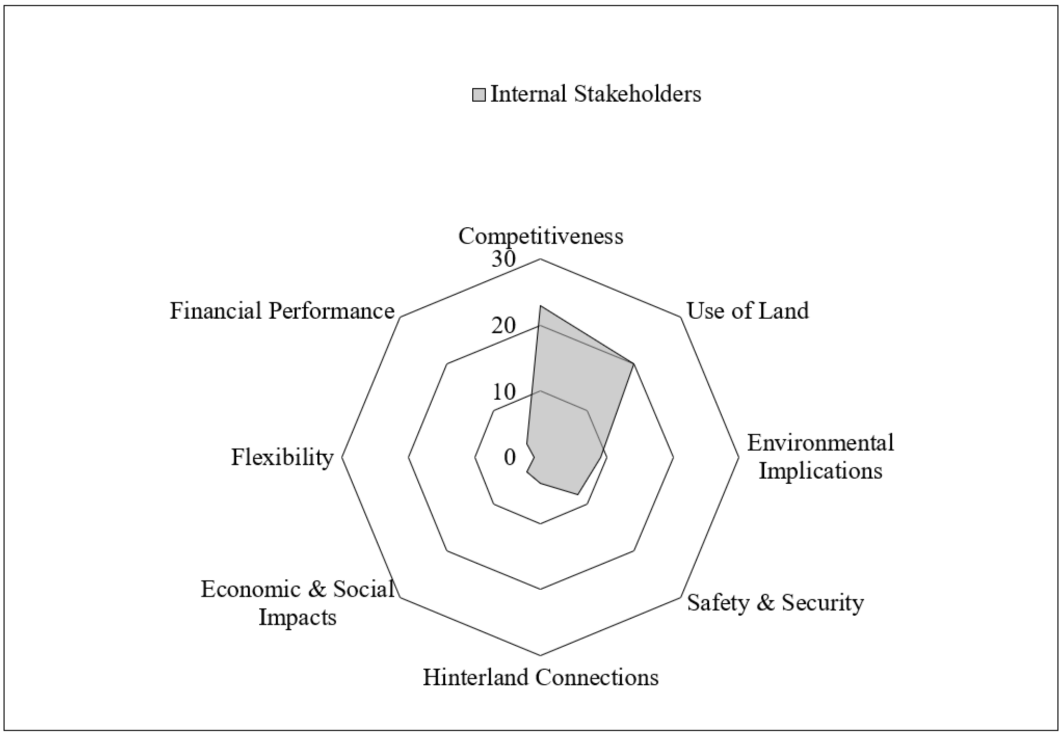

Figure 3.3 Distribution of means objectives for the internal stakeholder group

External Stakeholder Group

Increasing effective and efficient use of land was extremely important for the external stakeholder group (Figure 3.4). The limited land in the port area coupled with the increasing number of port activities, such as tourism, recreational services, fish farming, aquaculture and transportation, as the main ones, have increased the concerns of the external stakeholder group regarding effective and efficient use of land. Furthermore, this group placed emphasis on increasing competitiveness, as this means objective may bring higher quality of service with cost advantage for port users. Preference for the means objectives of increasing safety and security, better environmental implications and increasing hinterland connectivity was observed in this group. In fact, the group relies subjectively on these means objectives, for instance, fish processing factories requiring better environmental implications, and tourist agencies asking for improved safety and security. Moreover, port-hinterland interaction plays a crucial role in shaping supply-chain solutions of transport companies and logistics service providers. This group showed a preference for creating flexibility and increasing safety and security. These means objectives are required to supply the changing demand of port users and the seasonality of port activities[4]. The preference of this group for increasing positive economic and social impact and increasing financial performance was limited, as these means objectives might not imply a significant effect on their activities and commerce.

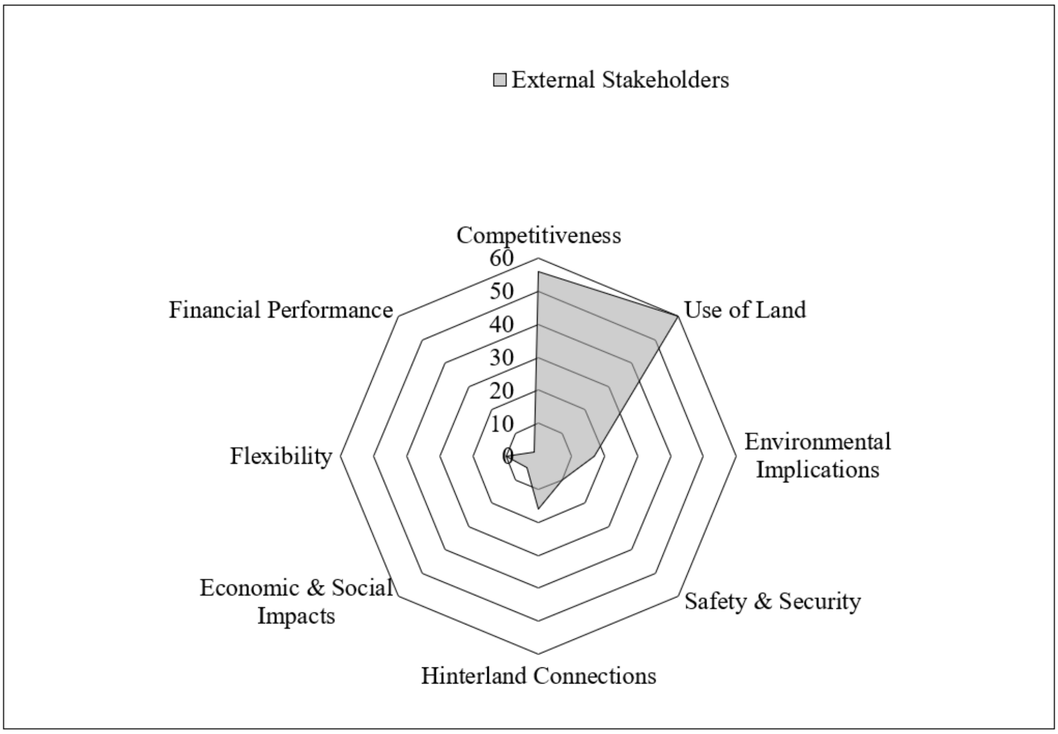

Figure 3.4 Distribution of means objectives for the external stakeholder group

Legislation and Public Policy Stakeholder Group

As shown in Figure 3.5, the legislation and public policy stakeholder group showed significant association with increasing competitiveness in the port planning process.

[4] High in the summer season because of the high number of cruise calls and low in the winter season because of the frequently harsh weather.

Increasing international and national trade through the port influences the regional economy and national supply chain. As the performance of the supply chain in terms of price, service quality and reliability might be influenced by increasing competitiveness, this group, including authorities and organizations, stressed the increase of competitiveness. The second priority in this group was to increase effective and efficient use of land. Long-term lease and land-use policies in Iceland, sustainable development and scarcity of land around the port area might be the main reasons why this group emphasized this means objective. Final decision-making for approval of port planning rests with the central Icelandic government rather than local levels. Thus, this group mostly takes into account whether the plan fulfils national and international regulations and laws, including improving safety and security. Such preference might curb the means objectives of increasing positive economic and social impacts and financial performance in this group. The legislation and public policy stakeholder group did not show a strong preference for creating flexibility. One of the reasons might be the increase in the marginal initial cost of port development by this means objective.

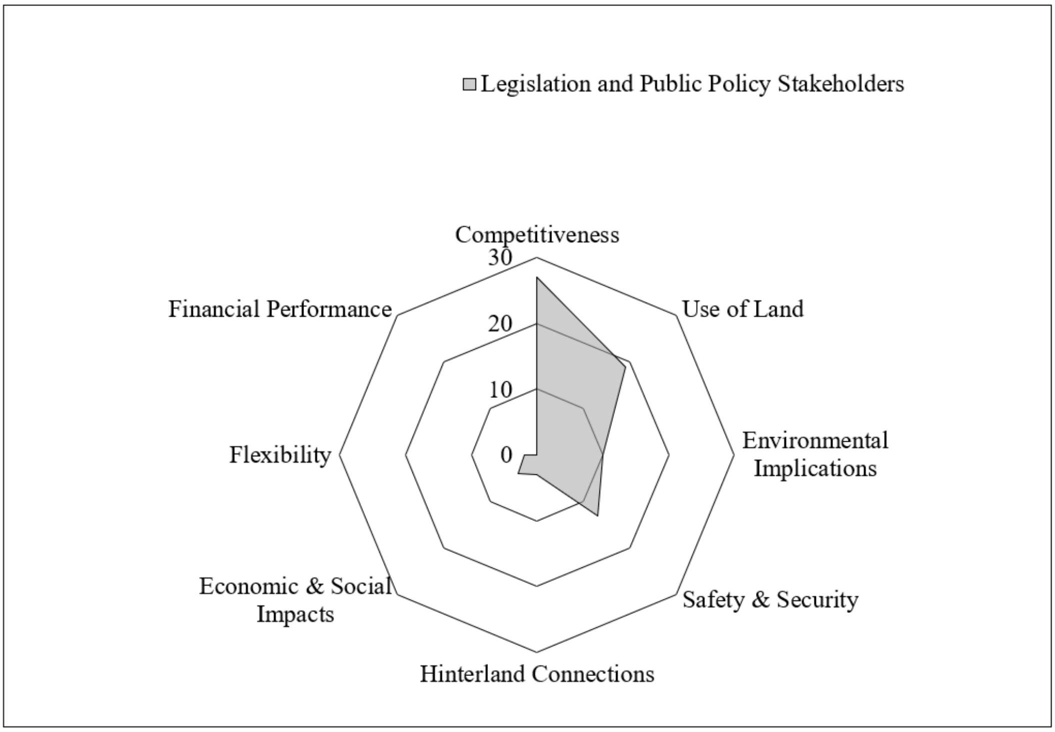

Figure 3.5 Distribution of means objectives for the legislation and public policy stakeholder group

Academic Stakeholder Group

The academic stakeholder group had a considerable preference for increasing competitiveness and increasing effective and efficient use of land. Port related research, such as ascertaining the competitive position of a port vis-a-vis its primary and secondary hinterland and land use in port planning, has been abundant (Notteboom 2009). Increasing port activities raises environmental concerns about air, noise, water and soil pollution in the port and surrounding areas. The academic stakeholder group offered possible solutions to these challenges in the port planning process. Emphasis on increasing positive economic and social impacts was stressed by this group, as this means objective plays an important role in port (city) planning in remote areas with a small surrounding community (Eskafi et al. 2019b). The academic stakeholder group showed preference for increasing flexibility, as can be seen in Figure 3.6. Adaptive port planning (APP) results in a flexible port (Taneja 2013).

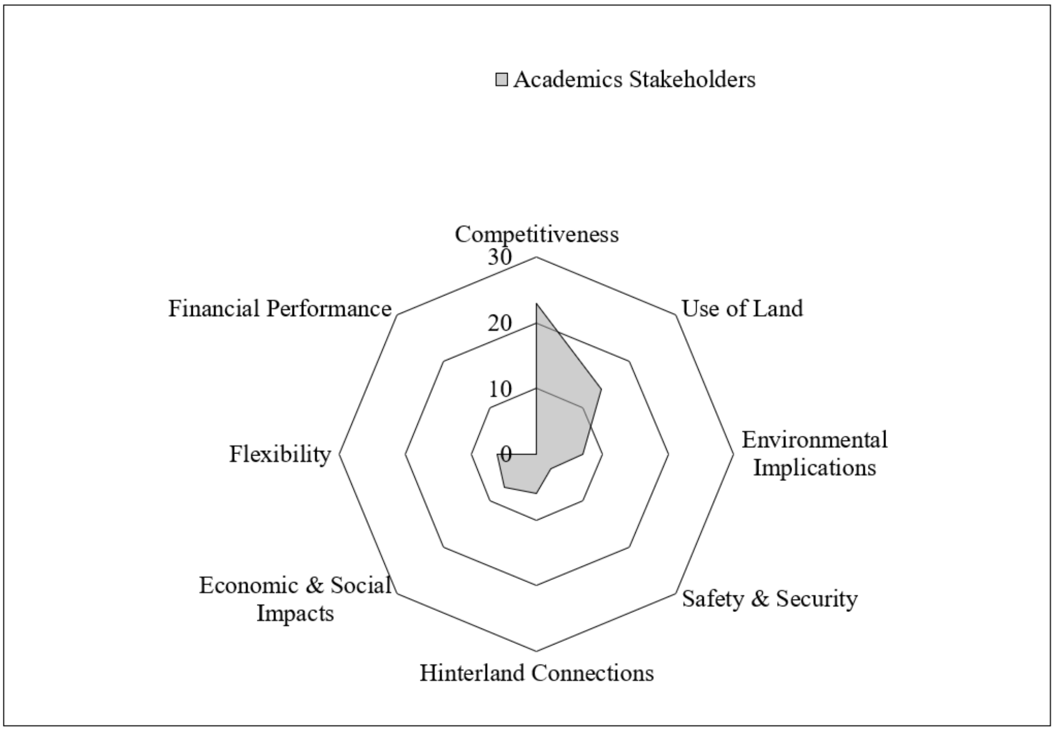

Figure 3.6 Distribution of means objectives for the academic stakeholder group

Community Stakeholder Group

In port cities, port activities directly and indirectly affect the surrounding communities in many ways; For instance, increasing cargo handling and transportation or a growing number of cruise calls, and consequently, cruise passengers, increasing environmental concerns such as local pollution and congestion. In addition to increasing port activities, growing populations heighten the demand on the land around the port. Thus, the main preference of the community stakeholder group was an increase in effective and efficient use of land. The emphasis of this group on increasing competitiveness might be the positive influence of a competitive port in terms of economic and social impacts on the surrounding community. However, improving environmental implications and increasing safety and security were stressed, as increasing port activities might have negative environmental impacts. This group also placed lesser emphasis on creating flexibility, as future generations will be able to modify and upgrade ports so as to better meet port demand. The preference of this group for increasing hinterland connectivity and financial performance was limited as depicted in Figure 3.7. The reason might be limited awareness of community stakeholders on these means objectives.

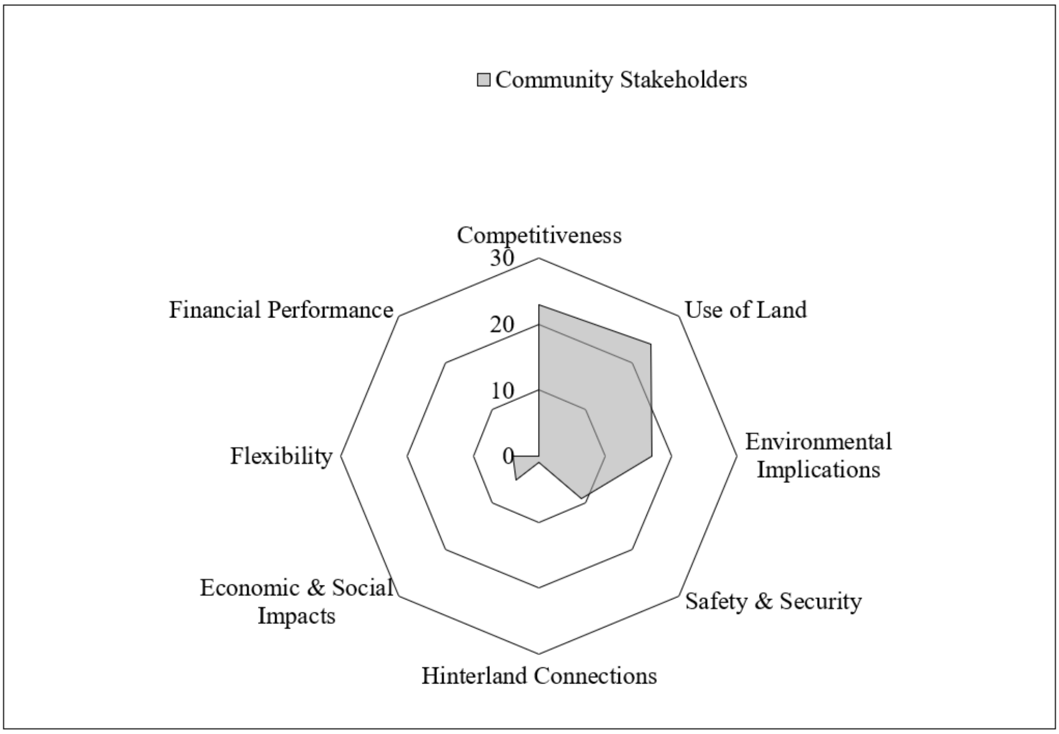

Figure 3.7 Distribution of means objectives for the community stakeholder group

3.6.3 Transferability of Findings Based on the Preferences of Stakeholder Groups on the Means Objectives

A high degree of commonality was evident among the groups, especially in terms of increasing competitiveness and effective and efficient use of land. This type of emphasis on these means objectives by the stakeholders leads to extra attention in deciding on the fundamental objective by decision makers. This finding is in line with prior research where port competitiveness is discussed (Cabral and Ramos 2014; Yuen, Zhang, and Cheung 2012).

The means objectives are also echoed by Arecco et al. (2016), who recognized a comprehensive list of 17 criteria for port success, based on a literature review and using a European Foundation for Quality Management (EFQM) model. Arecco et al. (2016) concluded that 1- safety, 2- competitiveness and 3- hinterland connections played an important role in assessing port success. However, in the present study, increasing competitiveness, increasing effective and efficient use of land and better environmental implications were the major concerns of port stakeholder groups. The main reasons for the discrepancy were: 1- Arecco et al. (2016) mainly considered internal stakeholder group in their work whereas, in the present work, all groups have been involved to deliver a comprehensive outcome; 2- different method: in the present study, complex decision making was facilitated by integration of the VFT, the stakeholder analysis and the fuzzy multi-attribute group decision-making method; however, Arecco et al. (2016) carried out literature review and desk research; and 3- discrepancy in size, capacity and activities of the ports under study.

3.6.4 Toward a Fundamental Objective and Formulating a Definition of Success

In three separate meetings, the representative of each key stakeholder group was asked to indicate their group's preference on the eight means objectives in port planning. Formulating the fundamental objective from the outcome of these three separate meetings instead of one meeting with all three representatives together provided an effective, efficient and comprehensive result. The separate meetings not only increased engagement of the representatives individually but also eliminated 1- domination of one representative's power and interest over the others, 2- time consuming debate about the means objectives by representatives because of their different perspectives about the objectives in port planning, 3- political influences, 4- deviation of the discussion from the goal of the meeting, 5- potential conflict and 6- interference from any potential biasing tendency.

The total preference ordering of the three representatives, $P_i(i \in N_3)$, on a set, X, of means objective was as follows:

X= (means objective 1, …, means objective 8)

Internal stakeholders:

P_i = (increasing financial performance, increasing competitiveness, increasing effective and efficient use of land, increasing safety and security, increasing hinterland connectivity, increasing positive economic and social impacts, creating flexibility, better environmental implications)

Legislation and public policy stakeholders:

P_l = (increasing safety and security, increasing hinterland connectivity, better environmental implications, increasing financial performance, increasing competitiveness, creating flexibility, increasing effective and efficient use of land, increasing positive economic and social impact)

External stakeholders:

P_e = (increasing effective and efficient use of land, increasing competitiveness, increasing hinterland connectivity, creating flexibility, better environmental implications, increasing safety and security, increasing positive economic and social impacts, increasing financial performance)

The outcomes of the meetings were three different preference orderings of the means objectives. Table 3.1 summarizes the relative popularities of the means objectives based on the ordering preferences; For instance, the relative popularities of increasing competitiveness to increase hinterland connectivity was calculated as follows:

μs (increasing competitiveness, increasing hinterland connectivity) = 2÷3 = 0.67

Table 3.1 Summary of fuzzy preference relations

	CO	UL	EI	SS	HC	ES	FL	FP
CO	*	0.67	0.67	0.67	0.67	1	1	0.33
UL	0.33	*	0.67	0.67	0.67	1	0.67	0.33
EI	0.33	0.33	*	0.33	0	0.67	0.33	0.67
SS	0.33	0.33	0.67	*	0.67	1	0.67	0.67
HC	0.33	0.33	1	0.33	*	1	1	0.67
ES	0	0	0.33	0	0	*	0.33	0.33
FL	0	0.33	0.67	0.33	0	0.67	*	0.33
FP	0.67	0.67	0.33	0.33	0.33	0.67	0.67	*

The abbreviations in Table 3.1 are CO: competitiveness, UL: use of land, EI: environmental implications, SS: safety and security, HC: hinterland connectivity, ES: economic and social impact, FL: flexibility, FP: financial performance.

Based on the average relative popularity of a means objective, two clusters of high and low importance were defined to avoid unnecessary mathematical complexity of discovering all possible orders (40,320 orders for eight means objectives). The average relative popularity of every means objective indicated different preferences of the representative on a means objective, in comparison with others. Thus, the contribution of the means objective in achieving the fundamental objective could be estimated.

The means objectives of increasing competitiveness (0.63), increasing hinterland connectivity (0.58), increasing effective and efficient use of land (0.54) and increasing safety and security (0.54) played prominent roles in port planning, as they had high average relative popularities. These means objectives were followed by increasing financial performance (0.46), better environmental implications (0.33), creating flexibility (0.29) and increasing positive economic and social impacts (0.12). To achieve the possible final level of agreement on the means objectives, the high and low importance clusters were defined as:

Cluster_H: (increasing competitiveness, increasing hinterland connectivity, increasing effective and efficient use of land and increasing safety and security)

Cluster_L: (increasing financial performance, better environmental implications, creating flexibility and increasing positive economic and social impacts)

Based on Equation 3, the α-cuts for fuzzy relations were:

Cluster_H ($S_{0.67}$) = (increasing competitiveness, increasing effective and efficient use of land), (increasing competitiveness, increasing safety and security), (increasing competitiveness, increasing hinterland connectivity), (increasing effective and efficient use of land, increasing safety and security), (increasing effective and efficient use of land, increasing hinterland connectivity), (increasing safety and security, increasing hinterland connectivity)

Cluster_H ($S_{0.33}$) = (increasing effective and efficient use of land, increasing competitiveness), (increasing safety and security, increasing competitiveness), (increasing safety and security, increasing effective and efficient use of land), (increasing hinterland connectivity, increasing competitiveness), (increasing hinterland connectivity, increasing effective and efficient use of land), (increasing hinterland connectivity, increasing safety and security)

Cluster$_L$ ($S_{0.67}$) = (better environmental implications, increasing positive economic and social impacts), (creating flexibility, better environmental implications), (creating flexibility, increasing positive economic and social impacts), (increasing financial performance, increasing positive economic and social impacts), (increasing financial performance, creating flexibility)

Cluster$_L$ ($S_{0.33}$) = (better environmental implications, creating flexibility), (increasing positive economic and social impacts, better environmental implications), (increasing positive economic and social impacts, creating flexibility), (increasing financial performance, better environmental implications)

The unique crisp of ordered means objectives O_α in the fuzzy relation S_α were seen to be:

Cluster$_H$ ($O_{0.67}$) = (increasing competitiveness, increasing effective and efficient use of land, increasing safety and security, increasing hinterland connectivity)

Cluster$_H$ ($O_{0.33}$) = (increasing hinterland connectivity, increasing safety and security, increasing effective and efficient use of land, increasing competitiveness)

Cluster$_L$ ($O_{0.67}$) = (increasing financial performance, creating flexibility, better environmental implications, increasing positive economic and social impacts)

Cluster$_L$ ($O_{0.33}$) = [(increasing financial performance, increasing positive economic and social impacts, better environmental implications, creating flexibility), (increasing positive economic and social impacts, increasing financial performance, better environmental implications, creating flexibility)]

As can be seen in both clusters, for the value 0.67, only one order was obtained. Thus, finding the orders of value 0.33 was not required since they should be of a compatible order with the orders of the higher value (0.67).

Cluster$_H$ ($O_{0.67}$) ∩ Cluster$_\mathrm{H}$ ($O_{0.33}$) = Cluster$_\mathrm{H}$ ($O_{0.67}$)

Cluster$_L$ ($O_{0.67}$) ∩ Cluster$_\mathrm{L}$ ($O_{0.33}$) = Cluster$_\mathrm{L}$ ($O_{0.67}$)

Hence, the value 0.67 represents the group level of agreement on the means objectives.

The combination of Cluster$_H$ ($O_{0.67}$) and Cluster$_L$ ($O_{0.67}$) denotes the total orderings of: (increasing competitiveness, increasing effective and efficient of use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, creating flexibility, better environmental implications, increasing positive economic and social impacts).

This ordering of the means objectives has the highest level of agreement among the representatives of key stakeholder groups and can be considered as the fundamental objective. The final level of agreement and the orders were discussed with the representatives of key stakeholders, separately. They were asked if the defined fundamental objective fulfilled their desired objective in the planning process. Considering the highest level of agreement (value 0.67), the order was confirmed by the representatives of the internal, external and legislation and public policy stakeholder groups to be considered as the definition of success in APP.

3.7 Conclusions

The complexity of a port system and the concomitant uncertainties call for a new port development approach. Adaptive port planning deals with such uncertainties and meets the desired objectives of port stakeholders during the projected lifetime of the port, because it starts with a definition of success. Reaching a consensus on the definition of success is not an easy task when multiple stakeholders, with different interests and power, highlight a wide range of objectives.

An integrated qualitative and quantitative approach was conducted to effectively capture stakeholders' objectives, account for conflicting interests and, at the same time, ensure consistency in the whole process. The approach comprised stakeholder analysis, the value-focused thinking method, existing literature in the area of port planning and fuzzy logic. The results show that VFT is a capable problem structuring method in port planning, mainly because it facilitates the identification of values of a large group of often 'diverging' stakeholders. VFT enhanced the decision-making process to articulate the means objectives. The fuzzy multi-attribute group decision-making method was applied to identify the highest level of agreement on the objectives and, eventually, formulate the definition of success in the APP.

Conflict of interest among stakeholders in a group, over the sub-objectives, was revealed, extensively. Eight means objectives of port planning were identified by harmonizing and clustering the sub-objectives obtained from the interviews with all relevant stakeholders. The means objectives were increasing competitiveness, increasing effective and efficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, creating flexibility, better environmental implications and increasing positive economic and social impacts.

Although the means objectives of increasing competitiveness and increasing effective and efficient use of land were pivotal among stakeholders, financial performance seemed to be a formidable challenge, as a conflicting interest. The results indicated that increasing financial performance was prioritized by the internal stakeholder group, the one having the greatest salience. Thus, consideration should be given to this means objective in formulating the definition of success by a port planner. A consensus was reached among the key stakeholders on the definition of success, by prioritizing increasing competitiveness among identified means objectives in the APP.

The present framework supports decision making in port planning, including the APP, to answer the research question. It offers the highest level of agreement on the definition of success among the various stakeholders. The proposed framework provides an easy process for turning the highest level of agreement into a consensus in the follow-up meetings and negotiation with the (key) stakeholders. The scope of the framework is rather flexible and can be applied to large ports with numerous stakeholders, or smaller ones, such as in the present case study. The transparency of the approach allows the active engagement of key stakeholders to monitor each step of the analysis, review the findings and provide feedback.

Acknowledgments

The time and expertise contributed by the people listed in Appendix C and other formal and informal groups who were involved in this project are acknowledged. The authors are grateful to anonymous referees for their careful review of this article, corrections and fruitful remarks. This work was supported in part by the University of Iceland Research Fund (Rannsoknarsjodur Haskola Islands), the Municipality of Isafjordur (Isajardarbaer) and the Icelandic Road and Coastal Administration Research Fund (Rannsoknarsjodur Vegagerdarinnar).

4 Mutual Information Analysis of the Factors Influencing Port Throughput

This chapter contains the peer-reviewed journal article:

Eskafi, M., M. Kowsari, A. Dastgheib, G. F. Ulfarsson, P. Taneja, and R. I. Thorarinsdottir. 2021. “Mutual Information Analysis of the Factors Influencing Port Throughput”, *Maritime Business Review*, 6 (2), pp. 129-146.
https://doi.org/10.1108/MABR-05-2020-0030

4.1 Abstract

Port throughput analysis is a challenging task as it consists of intertwined interactions between a variety of cargos and numerous influencing factors. This study aims to purpose a quantitative method to facilitate port throughput analysis by identification of important cargos and key macroeconomic variables. Mutual information is applied to measure the linear and nonlinear correlation among variables. The method gives a unique measure of dependence between two variables by quantifying the amount of information held in one variable through another variable. This study uses the mutual information to the Port of Isafjordur in Iceland to facilitate the port throughput analysis. The results show that marine products are the main export cargo, whereas most imports are fuel oil, industrial materials, and marine product. The aggregation of these cargos, handled in the port, meaningfully determines the non-containerized port throughput. The relation between non-containerized export and the national gross domestic product (GDP) is relatively high. However, non-containerized import is mostly related to the world GDP. The non-containerized throughput shows a strong relation to the national GDP. Furthermore, the results reveal that the volume of national export trade is the key influencing macroeconomic variable to the containerized throughput. Application of the mutual information in port throughput analysis effectively reduces epistemic uncertainty in the identification of important cargos and key influencing macroeconomic variables. Thus, it increases the reliability of the port throughput forecast.

Keywords: Iceland, Macroeconomics, Mutual information, Port throughput.

4.2 Introduction

Demand projection and selection of promising markets play an important role in the port planning process (Geweke and Whiteman 2006). Identification of the key cargo for a port characterizes the strategy and direction of port planning projects and aids the preliminary design of basic infrastructure (Chen, Chen, and Li 2016). Financial viability and infrastructure-based investments should be supported by potential (cargo) demands (De Langen, Van Meijeren, and Tavasszy 2012). Appropriate investment in port capacity, based on the promising cargos, helps to win market share and strengthen the competitive position of the port (Taneja, Ligteringen, and Van Schuylenburg 2010). On the other hand, inaccurate statements about the likely course of demand lead to an improper development plan (Peng and Chu 2009).

Port throughput analysis prior to resource allocation decisions in port capacity planning and development is critical. The information about the flow will have a substantial impact on port operations and planning, and the utilization of assets (Milenković et al. 2019). Port throughput analysis depends on the flow of different types of cargo and numerous macroeconomic variables. However, in the dynamic and complex nature of a port system, identification of the demand has remained with multiple uncertainties including epistemic uncertainty (Taneja 2013).

Epistemic uncertainties in demand analysis depend upon the degree to which the information pertaining to the system is available. Ping and Fei (2013) expressed that port throughput is affected by numerous variables including macroeconomic variables. Owing to complex nonlinear relations between port throughput and macroeconomic variables, a single linear model (Chen, Chen, and Li 2016), or application of traditional regression methods may result in inaccurate analysis performance (Gökkuş, Yıldırım, and Aydin 2017). Hui, Seabrooke, and Wong (2004) stated that the classical regression methods are valid if the data series are stationary and without a time trend. Chou, Chu, and Liang (2008) emphasized the nonstationary relation between the cargo flow and macroeconomic variables.

Therefore, a comprehensive study on the identification of main cargos and macroeconomic variables, in port throughput analysis is important. For this purpose, the correlation coefficient, as the most known measure of dependence between two random variables, can be used. However, its application has been criticized, as it is only able to detect linear dependencies (e.g., (Sagar and Guevara 2005)). To overcome this problem, mutual information can be used to capture nonlinear dependency between variables.

In this study, mutual information is applied to evaluate the dependencies among different types of cargo and port throughput and identifies the prominent cargos that would heuristically describe the port throughput. In information theory, mutual information measures the amount of information that one variable contains about the other. Mutual information quantifies the statistical dependence between two random variables. Thus, it provides a better criterion than the autocorrelation function, which only measures linear dependence (Fraser and Swinney 1986). In contrast to the linear correlation coefficient, it is also sensitive to dependencies that do not manifest themselves in the covariance (Kraskov, Stögbauer, and Grassberger 2004).

Mutual information has been used in previous maritime research, albeit not in the context of port throughput. For instance, Wu et al. (2020) used mutual information to reduce needs for expert judgment in the identification of input variables for the Bayesian network for consequence estimation of navigational accidents. Yang, Yang, and Yin (2018) applied mutual information to facilitate the recognition of insignificant variables that should be excluded from a Bayesian network. Hänninen and Kujala (2014) used mutual information to reduce uncertainty by identification of influential variables in a Bayesian model for ship accident involvement. Furthermore, Hänninen (2014) discussed the advantage of applying mutual information for determining the uncertainty of variables' dependency in a maritime safety model.

Hence, this study applied mutual information in the analysis of port throughput influencing factors. The explanatory power of mutual information delivers a more systematic way of analysis for identification of the most and least important cargos and influencing macroeconomic variables based on an analysis-oriented approach of data, rather than arbitrary judgment (that may have biases), which is an advancement over present practice. This is especially the case where historic data of the port are not sufficiently indicative. Therefore, it contributes to improving the port throughput analysis and consequent forecast as it reduces the epistemic uncertainties associated with the identification of main cargos and key macroeconomic variables. It also offers a more transparent, simpler, and easier way to interpret the result of analysis. Mutual information is applied to the multipurpose Port of Isafjordur in Iceland. The presented method can be used for other cases. Although focusing on one case, the presented method in this chapter could be used for other similar cases.

The remainder of this chapter is structured, as follows: subchapter 4.3 outlines the literature review by discussing the influencing factors on the port throughput, subchapter 4.4 addresses the method, subchapter 4.5 describes the study area and presents data collection, subchapter 4.6 discusses the results and the findings, and subchapter 4.7 draws conclusions on the throughput analysis for the Port of Isafjordur in Iceland.

4.3 Influencing Factors on Port Throughput

The long technical lifetime of port infrastructure, huge capital investments and a long payback period make port planning a challenging task (Taneja, Ligteringen, and Van Schuylenburg 2010). Port capacity should satisfy the demand of multiple stakeholders with various objectives (Eskafi et al. 2020b). Overcapacity leads to the lack of cost-effectiveness in port planning, and capacity shortage results in loss of competitive position of ports (Jugovic, Hess, and Jugović 2011). Before port capacity planning, port throughput analysis needs to be conducted and for that, identification of the main cargos and influencing factors is essential.

Luo and Grigalunas (2003) pointed out that (cargo) demand analysis is challenging, as it is influenced by many factors. Demand analysis may have an uncertain outcome, because of difficulties in identification of the main cargo, determination of exogenous and endogenous variables and their complex causal relations with cargos (Taneja 2013). Cargo flow is volatile over time and affected by the temporal demand of salient stakeholders in the projected lifetime of a port (Eskafi et al. 2019a). Van Dorsser, Wolters, and Wee (2012) put forward that demand projection is sensitive to trend breaches and attaching much investment to one single cargo over a projected lifetime is not advocated.

As economic development is an important driver of maritime trade, there should be an interrelation between port throughput and macroeconomic variables (De Langen, Van Meijeren, and Tavasszy 2012). Jugovic, Hess, and Jugović (2011) recognized Gross Domestic Product (GDP) as a known macroeconomic variable that is the main reference of the elasticity factor for cargo flow in a port. Ping and Fei (2013) pointed out that the regional economy (i.e., regional GDP) considerably affects the port throughput. Van Dorsser, Wolters, and Wee (2012) presented the correlation between GDP and port throughput by using a macroeconomic model. Moreover, Gökkuş, Yıldırım, and Aydin (2017) expressed that there is a strong correlation between GDP and the trade volume of a country.

Cargo flow is increasingly intertwined with the population, trade, global economic activity (e.g., (Taneja, Ligteringen, and Walker 2012)), fuel and energy prices (Van Dorsser, Wolters, and Wee 2012), competitive position, market share (Meersman, Van de Voorde, and Janssens 2003), and country logistics system and supply chain, technology evolution, and government policies (Günther and Kim 2005). Frankel (1987) pointed out that, before port throughput analysis, deep knowledge of the hinterland is fundamental. Jugovic, Hess, and Jugović (2011) echoed that cargo flow analysis should begin with the characterization of hinterland that gravitates to the port under study.

According to the cited literature, many factors should be considered when port throughput is analyzed. However, it is neither necessary nor possible (due to limited data) to take all variables into account. When the number of exogenous inputs is huge, numerous problems can occur related to high dimensionality and multicollinearity (Fuentes, Poncela, and Rodríguez 2015), or the analysis is sensitive to false reduction (Bankes 1993).

JICA (1994) used population and GDP variables to analyze and forecast a container port’s throughput using a regression model. However, Gosasang, Chandraprakaikul, and Kiattisin (2011) criticized them because of their use of inadequate variables in the analysis. Later, De Langen, Van Meijeren, and Tavasszy (2012) and Van Dorsser, Wolters, and Wee (2012) discussed using only GDP for port throughput analysis and forecast. Chou, Chu, and Liang (2008) used several macroeconomic variables to forecast port throughput but did not discuss the reason for the selection of macroeconomic variables. Gosasang, Yip, and Chandraprakaikul (2018) used multiple macroeconomic variables for developing a container throughput forecast. However, their work neither discussed the relation of the macroeconomic variables with port throughput nor showed which variables may have a higher influence on port throughput. Moreover, Dragan et al. (2020) used macroeconomic variables that presumably influence cargo throughput to forecast the throughput of different types of cargo. However, they did not discuss reasons for the selection of certain macroeconomic variables. Milenković et al. (2019) stressed the importance of determining an optimal set of input variables for developing a container throughput forecast model.

The complexity of port throughput analysis calls for a method to screen the main cargos and influencing macroeconomic variables. Mutual information analysis has been a useful method for data analysis. However, the application of mutual information has not been used in analysis of the factors influencing port throughput which is the novelty of the present study.

4.4 Mutual Information Analysis

Mutual information is an important concept in information theory to handle uncertainties and abstraction of the notion of information. It measures the level of correlation among variables and then determines their dependency on each other by quantifying the amount of information held in a variable through another variable. In general, information refers to the ease of predictability of unknown outcomes provided by one probability distribution relative to another probability distribution (Soofi, Zhao, and Nazareth 2010). Mutual information gives a unique measure of dependence between the two variables, which is also connected to the concept of entropy and Kullback-Leibler divergence.

The advantages of mutual information in variable selection problems compared to the other criteria such as coefficient-based methods (Hall 1999), RELIEF and RELIEF-F (Robnik-Šikonja and Kononenko 2003), have been shown in previous studies (Zeng et al. 2014). Kwak and Choi (2002) pointed out that in variable selection, mutual information can effectively eliminate redundant variables with relatively low computational effort. Mutual information has advantages to Pearson correlation in variable selection, as the former identifies the linear and nonlinear dependence and independence of variables, but the latter only recognizes the linear dependence of variables (Li 1990; Steuer et al. 2002). Peng, Long, and Ding (2005) expressed mutual information as an appropriate variable selection method compared to the max-dependency method, as the latter method requires much data and has relatively slow computational speed. Pethel and Hahs (2014) stated that chi-squared tests for variable selection are valid in the asymptotic limit of infinite data whereas mutual information does not have the limitation of chi-squared tests. Zuur et al. (2003) pointed out the advantage of mutual information to a Markov Chain Monte Carlo method for parameter selection as the latter method requires a large data set that imposes restrictions in its application. Li, Xie, and Goh (2009) stated that mutual information achieves better test performance and faster computation efficiency than Wrapper methods. Furthermore, Wrapper methods are faced with over-fitting problems. Also, they showed that mutual information outperforms Wrapper methods in variable selection when the number of variables is large. The merit of mutual information is to avoid unnecessary work and reduce the need for expert judgment, provide a straightforward, fast, with relatively low computational complexity, and cost-effective approach to recognize the influencing macroeconomic variables on port throughput (Wu et al. 2020; Yang, Yang, and Yin 2018). Mutual information also offers a useful visual tool for a better understanding of the dependencies among variables (Li, Xie, and Goh 2009).

For a pair of random variables (X, Y) with marginal probability distributions of $\mu_x(x)$ and $\mu_y(y)$, mutual information uses the Kullback-Leibler measure to determine the distance between the joint probability distribution, $\mu(x, y)$, and the distribution associated with the case of complete independence (i.e., $\mu_x(x)\mu_y(y)$) and is expressed as (Kraskov, Stögbauer, and Grassberger 2004):

$$(X, Y) = \iint \mu(x, y) \log \frac{\mu(x,y)}{\mu_x(x)\mu_y(y)} dxdy \tag{4.1}$$

Furthermore, mutual information is related to the concept of information entropy that was introduced by Shannon (1948) and quantifies how informative a random variable (X) with possible outcomes (x_i), each with probability $p(x)$, could be:

$$H(X) = -\int_{x \in X} p(x) \log_2 p(x) dx \tag{4.2}$$

where the base 2 logarithm is corresponding to the unit of information measured in "bits" (Shannon 1948). Thus, mutual information can be obtained by:

$$\begin{aligned} I(X,Y) &= H(X) + H(Y) - H(X,Y) \\ &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X) \end{aligned} \tag{4.3}$$

where $H(X)$ and $H(Y)$ are the entropy of random variables X and Y, respectively, $H(X,Y)$ is their joint entropy and $H(X|Y)$ and $H(Y|X)$ are their conditional entropy and calculated as:

$$H(X|Y) = -\iint \mu(x,y) \log \mu(x|y)\, dxdy \tag{4.4}$$

where $\mu(x,y)$ is the joint probability distribution. The conditional entropy $H(X|Y)$ is the amount of uncertainty left in X when knowing Y. Thus, from these equations, the $I(X,Y)$ is interpreted as the reduction in the uncertainty of the random variable X by the knowledge of another random Y (Maes et al. 1997). Mutual information illustrates the distributions of the information measures in terms of interdependency between variables. Mutual information takes the value of zero if and only if the two random variables are statistically independent, and when the two variables are identical their mutual information reaches the maximum. To calculate mutual information among variables, the equations can be coded in a computer programming language. In this study, MATLAB is used to code the equations and calculate mutual information for further analysis.

To evaluate the correlation between the port throughput and macroeconomic variables, at first, the dependency of the port throughput on different cargos is investigated. It helps to recognize the main cargo and eliminate cargos that are occasionally handled in (especially multipurpose) ports. The recognition of the main cargo reduces biases (e.g., a large amount of a specific cargo that is handled only a few times for a particular purpose) in the collection of data. On the other hand, including many cargos increases the complexity of the analysis and (epistemic) uncertainty in the results (Van Dorsser, Wolters, and Wee 2012).

4.5 Study Area and Data Used

The multipurpose Port of Isafjordur is the leading cargo port and hub in the Westfjords region of Iceland (Figure 4.1). This port plays a significant role in the logistic chain of the country. It is well connected to the hinterland in terms of coastal shipping and road transportation. It has a strategic location with short sailing time to the open sea and enough services for different types of vessels. Fisheries and industrial aquaculture are the core businesses of the region, where these activities are thriving (Icelandic Directorate of Fisheries 2021), which increases cargo and container handling at the port. The port provides services to industries all over the country, and thus, its hinterland is the whole country.

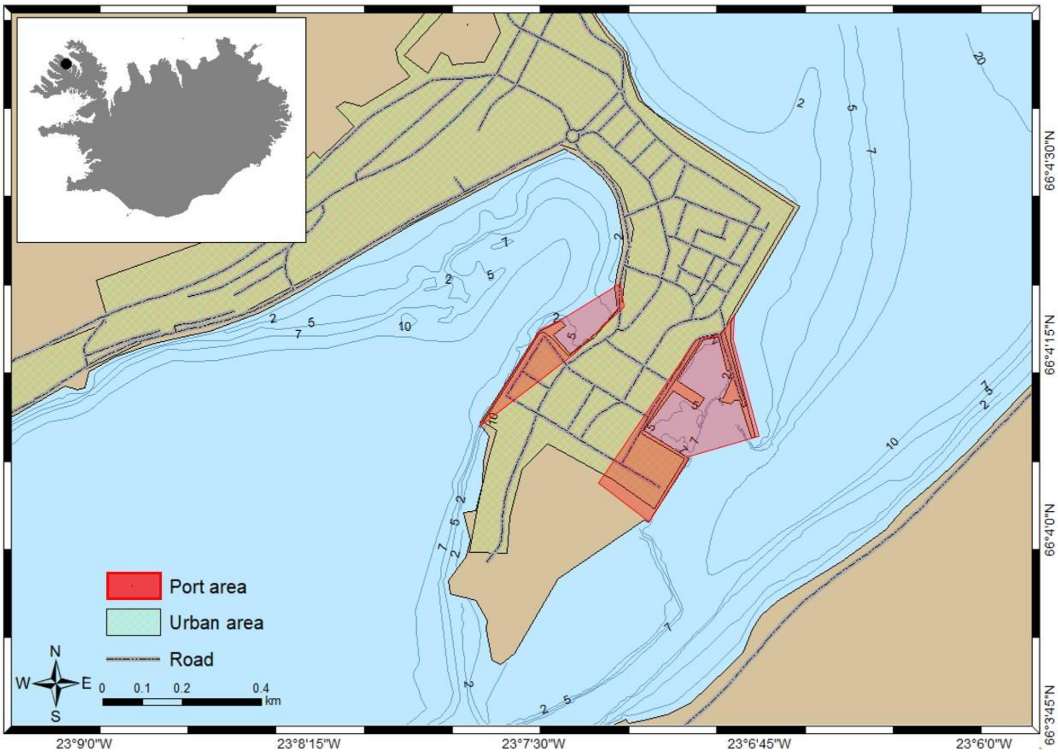

Figure 4.1 The multipurpose Port of Isafjordur. The location of the study is marked with a black dot on the inset map of Iceland at the top left.

The main functions of the port are:

- Transfer and storage of containerized and non-containerized cargo;
- Industrial value-added activities, including marine productions;
- Recreational activities, including servicing expedition and cruise ships, sailing boats and water sport activities.

Among the aforementioned factors (in subchapter 4.3) that influence port throughput, this study excludes those that are unavailable, cannot be accurately predicted (e.g., new technologies), and those that their influence cannot be quantified from observation of the past (e.g., growth in the hinterland) (Taneja, Ligteringen, and Van Schuylenburg 2010). Thus, six macroeconomic variables that are available and published by the relevant authorities are used for analysis. These are the national GDP, the average yearly Consumer Price Index (CPI), the world GDP, the volume of national export trade, the volume of national import trade, and the national population. These variables were also used in previous studies (e.g., (Gökkuş, Yıldırım, and Aydin 2017)). Table 4.1 describes the variables used in this study.

In case of the availability of more macroeconomic variables, these can be added. One of the scientific contributions of the present study is to identify which macroeconomic variable among the variables would have the highest influence on the port throughput. The identification of the most influential macroeconomic variables increases the accuracy of the port throughput forecast. Figure 4.2 shows the schematic application of mutual information in port throughput analysis.

Yet, there are many unknown variables that can affect the port throughput. These unknown unknowns (Walker, Lempert, and Kwakkel 2013), and black-swan events (Smil 2012), can considerably influence port throughput as their intensity and frequency cannot be meaningfully addressed. In testimony of this, the Coronavirus disease (COVID-19) pandemic in 2020 is significantly affecting maritime sectors, as cruise ship calls have slumped, and there is a decline in port throughput. The effects of these events can be detected on macroeconomic developments. Thus, considering these events in port throughput analysis is out of the scope of this study.

In this study, non-containerized cargos are categorized as fuel oil, road construction and maintenance materials, fertilizer and fish feed, marine products, and industrial materials. Small (in terms of quantity) cargos are considered as other general cargo. These cargos are measured in tonnes. The non-containerized port throughput data are garnered between 1990 and 2016. Containerized cargo (cargo that is transported in a [refrigerated] container) used in this study is based on a Twenty-foot Equivalent Unit (TEU). The annual containerized port throughput and the macroeconomic variables are collected between 1990 and 2019.

In this study, the mutual information value between containerized port throughput and the macroeconomic variables is measured separately. The main reason is that containers have been attractive and promising to transport cargo. Determining the relation between containerized port throughput and the macroeconomic variables facilitates decision making for strategic capacity development by the Port Authority.

The port throughput analysis does not include the recreational activities. Limited data, differing data sources, and inconsistencies in terms of the accuracy and uniformity of recording variables and cargos could affect the results of this study. Thus, uniform collection and management of statistical data is recommended.

4.6 Results and Discussion

To evaluate the correlation of (non-)containerized port throughput and macroeconomic variables, mutual information was conducted using equations 1-4.

Table 4.1 List of variables for analysis of port throughput

Acronym	Variable	Unit	Mean	Standard deviation	Minimum	Maximum
FOL	Fuel oil (gasoline, [marine] diesel oil)	Tonnes (T)	95.4	38.9	42.4	169.5
RCM	Road construction and maintenance materials (asphalt, salt, cement, etc.)	Tonnes (T)	45.2	103.9	0	540.5
FFF	Fertilizer and fish feed	Tonnes (T)	34290.7	78719.6	0	378900.0
MAP	Marine products (fresh, frozen, (un)processed, wild and farmed fish, shrimp, etc.)	Tonnes (T)	167.0	93.7	19.7	346.0
INM	Industrial materials (fishing and maritime equipment, scrap, etc.)	Tonnes (T)	108.9	129.3	0	371.4
SGC	Small general cargo (construction material, etc.)	Tonnes (T)	211.2	409.8	0	1357.8
-	Non-container port throughput	Tonnes (T)	117.8	63.8	30.2	279.5
-	Container and refrigerated container port throughput	Twenty-foot Equivalent Unit (TEU)	122.8	65.6	65.3	331.2
NGDP	National gross domestic product	Icelandic Krona (ISK)	95.4	25.8	60.8	141.7
ACPI	Average yearly consumer price index	No unit	115.2	45.3	59.6	191.9
WGDP	World gross domestic product	Billion USD	107.1	45.5	47.6	186.2
VNET	Volume of national export trade	Tonnes (T)	109.8	48.1	51.6	203.1
VNIT	Volume of national import trade	Tonnes (T)	74.5	26.9	36.4	124.9
NPOP	National population	Number	101.3	10.1	86.4	121.6

In Table 4.1, the values for the cargos (i.e., FOL, RCM, FFF, MAP, INM, and SGC) are based on the summation of their export and import. The variables are indexed to their value in the year 2005.

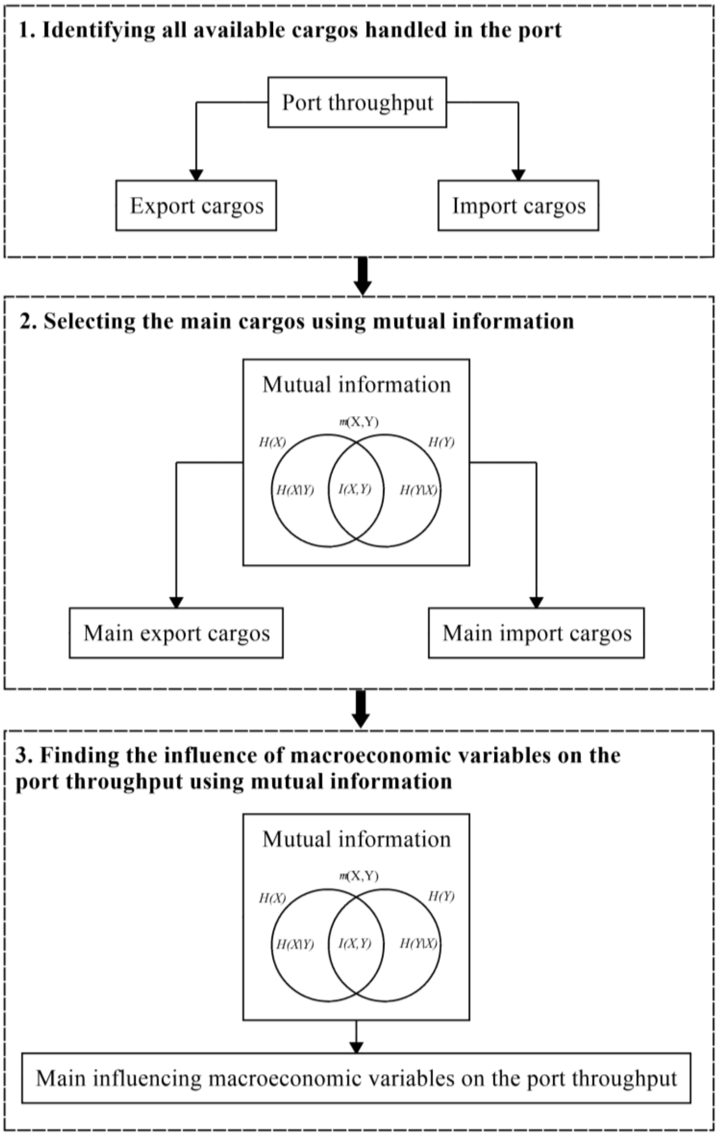

Figure 4.2 A schematic representation of the application of the mutual information in port throughput analysis

4.6.1 Identification of the Main Cargos

The results of the mutual information values of the handled non-containerized cargos at the port with export and import are depicted in Figure 4.3. The values of mutual information of non-containerized cargos with export and import are shown in Table 4.2.

From Figure 4.3, marine products cargo is the main pillar of export. This is because the core businesses in the region are fisheries and aquaculture. Therefore, these activities can significantly influence the export. As seen in Figure 4.3, the mutual information values of the other cargos in export are considerably lower than the marine products. Fertilizer and fish feed and general cargo have relatively low mutual information values. These cargos with low mutual information values are mainly fisheries-related activities, for instance, processed products, industrial equipment, etc. The industrial materials cargo and fuel oil have the lowest mutual information values in the export.

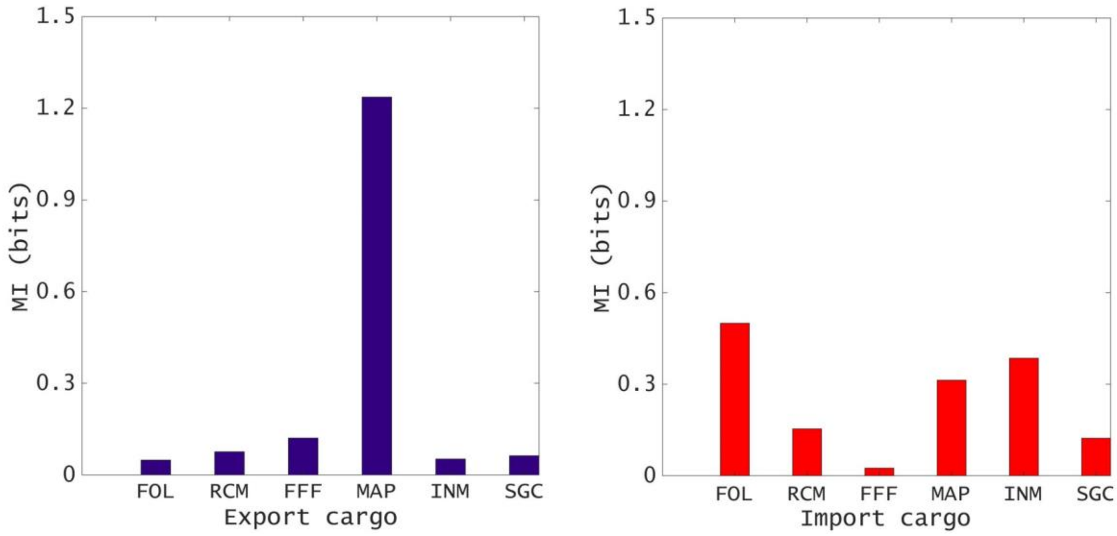

Figure 4.3 The mutual information (MI) values of the non-containerized cargos for export (left) and import at the port (right).

In Figure 4.3, the cargos are fuel oil (FOL), road construction and maintenance materials (RCM), fertilizer and fish feed (FFF), marine products (MAP), industrial materials (INM), and small general cargo (SGC).

Table 4.2 Mutual information values of non-containerized cargos with export and import

Acronym	Cargo flow	Mutual information	
		Export	Import
FOL	Fuel oil	0.044	0.499
RCM	Road construction and maintenance materials	0.085	0.156
FFF	Fertilizer and fish feed	0.141	0.018
MAP	Marine products	1.240	0.317
INM	Industrial materials	0.047	0.342
SGC	Small general cargo	0.051	0.134

For the import cargos, the mutual information values for several cargos are relatively large. These cargos, however, have small differences in their mutual information values. The results show that fuel oil has the largest mutual information value. The industrial materials cargo has a relatively lower value but higher than the marine products. These cargos could be considered as the raw materials and the main needs of the industries for their activities. The contribution of other cargos to the import is relatively weak.

As is shown in Figure 4.3, the main export cargo is marine products, whereas the aggregation of fuel oil, marine products, and industrial materials can be indicated as credible import cargos. Therefore, it can be inferred that the non-containerized port throughput has a considerable dependency on marine products, fuel oil, and industrial materials. This result is used to calculate the correlation between the non-containerized port throughput and macroeconomic variables.

4.6.2 Port Throughput and Macroeconomic Variables Data

Figure 4.4 gives the development of the port throughput and macroeconomic variables. To keep the confidentiality of (non-)containerized data and allow for comparison between the port throughput and the macroeconomic variables, the historical data are indexed to the year 2005.

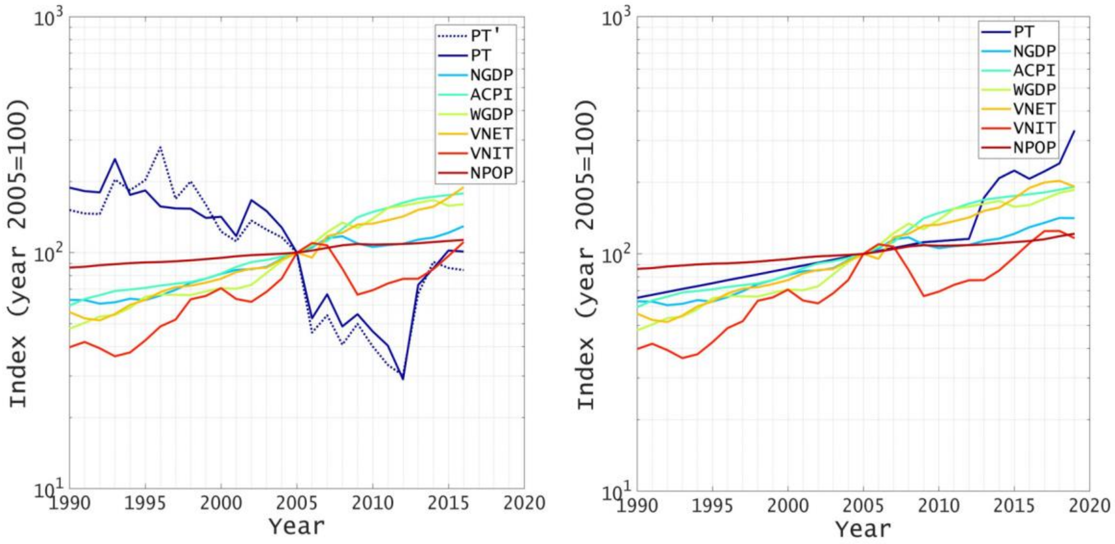

Figure 4.4 Historical development of the port throughput (left: non-containerized cargo, right: containerized cargo) and the macroeconomic variables

In Figure 4.4, the variables are the port throughput (PT' before and PT after application of mutual information), and macroeconomic variables including the national GDP (NGDP), the average yearly CPI (ACPI), the world GDP (WGDP), the volume of national export trade (VNET), the volume of national import trade (VNIT), and the national population (NPOP).

As illustrated in Figure 4.4, the macroeconomic variables have been generally growing, though a trend breach can be observed at the world economic downturn in 2008. Afterward, containerized port throughput growth slowed until 2012, whereas non-containerized port throughput dropped in the same period. Then, the containerized port throughput increased again. Over the period, fluctuations are attributed to economic activity and trade. The containerized port throughput and macroeconomic variables indicate increasing trends. However, non-containerized port throughput shows a decreasing trend until 2012. The main reason is continuous growth in the use of containers for transporting goods. The significant jump in the port throughput after 2012 could be due to rapid growth in aquaculture, especially the salmon industry in Iceland. The fast-growing aquaculture drives the growth of relevant activities including marine production and industrial equipment manufacturing. Furthermore, another shipping company (additional to the first one) started calling the port from 2013.

4.6.3 Identification of the Relation Between Port Throughput and Macroeconomic Variables

Based on the identified main cargos, Figure 4.5 shows the results of the mutual information values between non-containerized export, import, port throughput and macroeconomic variables. This means that export includes marine products cargo, import consists of fuel oil, marine products, and industrial materials cargos, and port throughput represents the aggregation of export and import.

The results indicate that the non-containerized export is mostly related to the national GDP. As identified, marine products cargo is the major export, and this cargo has a high impact on the GDP of the country (Statistics Iceland Office 2019). GDP has been determined as one of the main influencing variables on port throughput (e.g., (Van Dorsser, Wolters, and Wee 2012)). On the other hand, the relation between the non-containerized import and world GDP is the strongest. This result indicates the influence of the economy (or GDP) of the country (the hinterland) and the world on the port activities (Jugovic, Hess, and Jugović 2011). There is a relatively high relation between the non-containerized port throughput and the national GDP. The non-containerized port throughput and the national GDP are intercorrelated, as they are affected by import (national consumption) and the export (productivity) of goods (Van Dorsser, Wolters, and Wee 2012). The result further shows the relation of the volume of national export trade with the non-containerized port throughput, as also mentioned by Gökkuş, Yıldırım, and Aydin (2017). The volume of national import trade has the lowest correlation with the non-containerized port throughput.

The results of mutual information among containerized export, import, port throughput and macroeconomic variables are shown in Figure 4.6. The results show similar patterns for the containerized export, import and throughput concerning the macroeconomic variables. The relation between the containerized port throughput and the volume of national export trade is the highest. This is because containerized cargo can be transported efficiently over long distances and easily transferred between modes of transport.

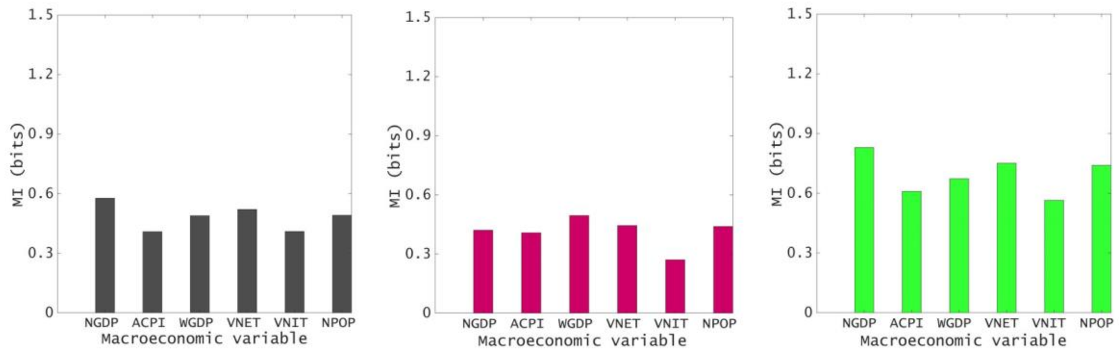

Figure 4.5 The mutual information (MI) values between non-containerized export, import, port throughput and macroeconomic variables (left to right, respectively)

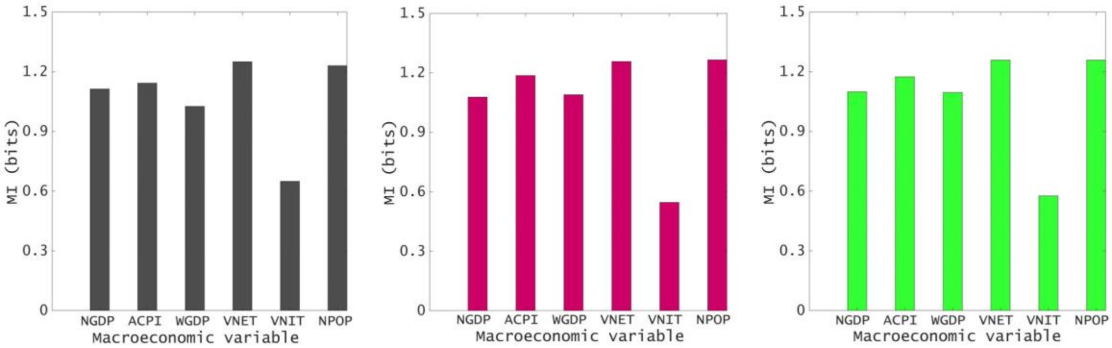

Figure 4.6 The mutual information (MI) values between containerized export, import, port throughput and macroeconomic variables (left to right, respectively)

In Figures 4.5 and 4.6, the macroeconomic variables are the national GDP (NGDP), the average yearly CPI (ACPI), the world GDP (WGDP), the volume of national export trade (VNET), the volume of national import trade (VNIT), and the national population (NPOP).

The variables with slightly lower mutual information values are the national population, the average yearly CPI and the national GDP. This is in line with literature where population, national GDP, and inflation rate were used as the key influencing variables in container throughput forecast (Gökkuş, Yıldırım, and Aydin 2017). The average yearly CPI partly determines the annual value of the national GDP (Gosasang, Chandraprakaikul, and Kiattisin 2011), and national GDP is a good indicator of container port throughput (Van Dorsser, Wolters, and Wee 2012). Population growth stimulates trade flow because of increased labor force and economic improvements (Hanushek and Kimko 2000). Table 4.3 gives the values of mutual information of macroeconomic variables with (non-)containerized export, import and port throughput.

As depicted in Figures 4.5 and 4.6, the volume of national import trade (VNIT) has the lowest mutual information with the port throughput. One of the main reasons for this low value is that the majority of import to the country is to the Port in Reykjavik, the capital of Iceland, not to the Port of Isafjordur.

Fuentes, Poncela, and Rodríguez (2014) stressed that including more inputs to the forecast models does not necessarily lead to better results with lower uncertainty. Hence, in the case of the throughput forecast for the port in this study, the VNIT can be excluded from the input to forecast models. Nevertheless, the volume of import trade (Ping and Fei 2013) and the value of import trade (Hui, Seabrooke, and Wong 2004; Gökkuş, Yıldırım, and Aydin 2017; Gosasang, Yip, and Chandraprakaikul 2018) have been included in port throughput forecast in previous studies. The discussion on the selection of this macroeconomic variable (i.e., VNIT) in these studies was not rigorous, and the focuses on describing the relation are qualitative relations based on expert judgment and literature review. Therefore, the present study proposes that selection of influencing macroeconomic variables for forecast models only based on expert judgment and literature review may not be sufficient.

Qualitative (or expert-judgment-based) evaluation of influencing factors on port throughput may be time consuming, laborious, include biases (Wu et al. 2020), and rely on incomplete and subjective knowledge which is conditional on the background and experience of experts (Hänninen 2014). Furthermore, experts are not always available to determine the influencing variables (Montewka et al. 2014). Application of mutual information in port throughput analysis reduced the need for expert judgment and provided informative diagrams to recognize the influencing macroeconomic variables on port throughput (Li, Xie, and Goh 2009; Wu et al. 2020).

Selection of relevant variables from a large feasible set of input data improves forecast efficiency (Fuentes, Poncela, and Rodríguez 2014). Thus, the application of mutual information for (macroeconomic) variable selection in port throughput forecast models increases the accuracy of models and reduces the uncertainty of the results (Hänninen 2014; Hänninen and Kujala 2014; Yang, Yang, and Yin 2018). The premise of mutual information is to deliver a unique measure of dependence of factors influencing port throughput.

Table 4.3 Mutual information values of macroeconomic variables with export, import and port throughput.

Macroeconomic variable	Mutual information					
	Non-containerized			Containerized		
	Export	Import	Port throughput	Export	Import	Port throughput
National GDP (NGDP)	0.596	0.405	0.804	1.123	1.088	1.099
Average yearly CPI (ACPI)	0.426	0.398	0.609	1.159	1.196	1.174
World GDP (WGDP)	0.496	0.486	0.684	1.070	1.089	1.096
Volume of national export trade (VNET)	0.537	0.440	0.759	1.265	1.257	1.258
Volume of national import trade (VNIT)	0.430	0.273	0.582	0.642	0.546	0.576
National population (NPOP)	0.491	0.437	0.746	1.238	1.258	1.258

The theoretical contribution of the application of mutual information in port throughput is to reduce the epistemic uncertainty in port throughput forecast. The managerial contribution of the application of mutual information in port throughput analysis is to provide a better insight into the major cargos handled in a port and a robust estimation of macroeconomic variables' influence on the port throughput.

4.7 Conclusions

Port throughput analysis provides valuable and fundamental inputs for port capacity planning and development. However, port throughput analysis is a complex task as it is interwoven with a variety of cargos handled in the port, which are in turn influenced by numerous factors including macroeconomic variables. The analysis requires the selection of prominent cargos that meaningfully contribute to the port throughput. Furthermore, the analysis necessitates investigating the relation of port throughput with macroeconomic variables.

This study used mutual information analysis as a quantitative method to measure the linear and nonlinear correlation among variables. The presented method was able to indicate the important cargos handled in the port. Moreover, the method determined the relation between port throughput and macroeconomic variables.

The results showed that marine products cargo is the main non-containerized export, whereas the non-containerized import is mainly constituted by fuel oil, industrial materials, and marine products. The aggregation of these cargos handled in the port would make up the non-containerized port throughput. Among the available macroeconomic variables in the present study, the national GDP has a relatively high relation with the non-containerized export. However, the non-containerized import is mainly related to the world GDP. The non-containerized port throughput showed relatively high correlations with the national GDP. The results unveiled that the relation between containerized port throughput and the volume of national export trade is more than other macroeconomic variables.

The new finding of this study is that the application of mutual information offers a solution for reducing epistemic uncertainty in port throughput analysis as it: 1- determines the main cargos that significantly contribute to port throughput, and 2- effectively identifies the relation between port throughput and macroeconomic variables. Thus, this approach can improve the reliability of port throughput forecast, which is recommended for future study.

Acknowledgments

The authors are grateful to Professor Gunnar Stefansson in the Faculty of Industrial Engineering, Mechanical Engineering, and Computer Science at the University of Iceland for his valuable remarks on this study. The authors thank the Icelandic Road and Coastal Administration, Statistics Iceland, Eimskip hf. and Samskip hf. companies for providing data. The authors thank the two anonymous referees for their review and fruitful comments. This research was supported in part by the University of Iceland Research Fund (Rannsoknarsjodur Haskola Islands), the Municipality of Isafjordur (Isafjardarbaer), and the Icelandic Road and Coastal Administration Research Fund (Rannsoknarsjodur Vegagerdarinnar)

5 A Model for Port Throughput Forecasting Using Bayesian Estimation

This chapter contains the peer-reviewed journal article:

Eskafi, M., M. Kowsari, A. Dastgheib, G. F. Ulfarsson, G. Stefansson, P. Taneja, and R. I. Thorarinsdottir. 2021. "A Model for Port Throughput Forecasting Using Bayesian Estimation", *Maritime Economics and Logistics*, 23 (2), pp. 348-368.
https://doi.org/10.1057/s41278-021-00190-x

5.1 Abstract

Capacity plays a crucial role in a port's competitive position and growth of market share. An investment decision to provide new port capacity should be supported by a growing demand for port services. However, port demand is volatile and uncertain in an increasingly competitive market environment. Also, forecasting models themselves are associated with epistemic uncertainty due to model and parameter uncertainties. This chapter applies a Bayesian statistical method to forecast the annual port throughput of the multipurpose Port of Isafjordur in Iceland. Model uncertainties are thus taken into account, while parameter uncertainties are handled by selecting influencing macroeconomic variables based on mutual information analysis. The presented model has an adaptive capability as new information becomes available. Our method results in a range of port throughput forecasts, in addition to a point estimate, and it also accounts for epistemic uncertainty, thus increasing the reliability of forecasts. Our results provide support for informed decision making in capacity planning and management. Our forecasts show a constant linear growth of containerized throughput the period 2020-2025. Non-containerized throughput declines rapidly over the same period.

Keywords: Port throughput, Epistemic uncertainty, Bayesian estimation, Mutual information, Forecasting, Iceland.

5.2 Introduction

Port throughput forecasting plays an important role in port capacity planning and management. This is due to the long technical life of indivisible and the irreversible nature port infrastructure investments (Taneja, Ligteringen, and Van Schuylenburg 2010). Once the infrastructure is in place, the characteristics of the port are determined for a long period (Van Dorsser, Wolters, and Wee 2012). Furthermore, port planning processes may take 5-15 years, from the initiation of the plan to its final approval (Notteboom 2006). Moreover, port projects require capital and fixed investments having long payback periods. This necessitates the financial viability of investments based on projections of port throughput and commodity flows (De Langen, Van Meijeren, and Tavasszy 2012).

A capacity shortage affects port performance and consequently the competitive position of the port due to congestion and increases in waiting time (Jarrett 2015). On the other hand, structural overcapacity signifies a failure in port planning, but excess port capacity is often created and offered to port users to satisfy their potential growth (Haralambides 2017). Eskafi et al. (2019a) pointed out that demand is temporally and spatially affected by salient stakeholders during the projected lifetime of a port. Furthermore, demand levels are volatile over time (Novaes et al. 2012) and the assumption of system stability leads to uncertain and inaccurate forecasts (Flyvbjerg, Bruzelius, and Rothengatter 2003). In testimony of volatile circumstances, the current outbreak of COVID-19 has created uncertainty in cargo flows, signaling increasing challenges in decision making in port development projects (Notteboom and Haralambides 2020).

Forecasting models provide insights to the development of port demand. Soft computing models have received increasing attention as they capture linear and nonlinear causal relations between input data and port throughput (Munim and Schramm 2020). For instance, port throughput forecasting models based on back-propagation (BP) neural network algorithms (Ping and Fei 2013) have been presented in the literature. However, a lack of input data restricts the performance of these models, increases uncertainty, and reduces the reliability of the forecasts result (Parola et al. 2020).

The multiplicity of disciplines with uncertain or missing information (quantitative and qualitative) and data in engineering and management systems entail various uncertainties associated with model outputs (Yang and Xu 2002). Rasouli and Timmermans (2014) stressed the existence of uncertainty associated with input data and forecast models. Liu and Duru (2020) emphasized that to increase the reliability of forecasts, the epistemic uncertainty of the forecast should be taken into account. Epistemic uncertainties are divided into model uncertainties (due to the choice of variables, assumptions, and the processes) and parameter uncertainties (related to the quantity and quality of the data used) (Kowsari et al. 2019).

However, as far as epistemic uncertainty in port throughput forecasts is concerned, and as overviewed in subchapter 5.3, forecasting models generally suffer from the following: 1- limited handling of uncertainties in the models, 2- subjectively selecting explanatory variables, and 3- insufficient/sparse input data to properly build a forecasting model. These limitations hamper the reliability and performance of a port throughput forecasting model.

Therefore, this chapter presents a rigorous Bayesian model that accounts for epistemic uncertainties in a port throughput forecast. The model meaningfully increases the reliability of forecast results and facilitates informed decision making in port capacity planning and management.

To select our influencing macroeconomic variables, a variable selection method based on mutual information is applied. The method estimates the level of linear and nonlinear correlations between variables. It also determines the statistical dependency of the variables by quantifying the amount of information held in a variable through another variable (Soofi, Zhao, and Nazareth 2010).

The uncertainty of parameters is accounted for in the Bayesian method by treating the regression coefficients as random variables and considering their distributions conditional on the data (Kowsari et al. 2020). One of the advantages of the Bayesian method in port throughput forecasting, moreover, is that it can be used with sparse or relatively small number of input observations, providing acceptable results[5]. Taneja (2013, p. 199) states that demand forecasts in port planning should take into account a certain degree of uncertainty, providing interval forecasts rather than point estimates. The model presented in this chapter not only gives a point forecast which has the highest probability, but also offers a range of port throughput forecasts with confidence intervals. Consequently, the outcome of the model provides useful information to decision makers and port planners, enabling them to better meet changing and uncertain future demand. Another strength of our model lies in the fact that it has an adaptive learning capability to be updated over time based on new information. Hence, it can provide a continuously or regularly updated port throughput forecast.

Our methodology is applied to forecast the annual port throughput of the multipurpose Port of Isafjordur in Iceland. The approach presented here can be tailored to other ports to forecast their throughput.

The remainder of the chapter is structured, as follows: subchapter 5.3 outlines the literature review by discussing different port throughput forecasting methods. Subchapter 5.4 addresses the mutual information and Bayesian method. Subchapter 5.5 describes the study area and the data used. Subchapter 5.6 presents and discusses the results. Subchapter 5.7 concludes with further remarks.

5.3 Different Port Throughput Forecasting Methods

Given the importance of port throughput forecasting, this subchapter provides a literature overview of the state-of-the-art in port throughput forecasting research, while also pointing out the present knowledge gap.

Different time series models have been used earlier to forecast port throughput. The moving average is a simple time series model that uses past internal patterns of data to forecast future values (Sepúlveda-Rojas et al. 2015). However, Van Dorsser, Wolters, and Wee (2012) criticized the model as it assumes a static environment without insights from

[5] This said, however, an increase in the number of input data would improve the accuracy of the results.

external influencing factors, which is an inappropriate simplification for (long-term) port throughput forecasts.

Hui, Seabrooke, and Wong (2004) used regression models to forecast container throughput. The authors seized the opportunity to reiterate the obvious need for stationarity in regressor variables. In a port throughput forecasting context, they also point out that, if a non-stationary time series follows a random walk, the capability of the model to include the effects of a temporary macroeconomic shock is limited (Gosasang, Chandraprakaikul, and Kiattisin 2011) and/or the shock is not dissipated with the time series (Van Dorsser, Wolters, and Wee 2012).

A vector error correction model without a theoretical basis has been criticized as a purely mathematical model (Bonham, Gangnes, and Zhou 2009). The vector error correction and its alternative error correction (Hui, Seabrooke, and Wong 2004) are suitable for multivariate forecasting models where macroeconomic variables are characterized by stationary time series (Munim and Schramm 2020) and have a true relation in the long-term with port throughput (Van Dorsser, Wolters, and Wee 2012). Jarrett (2015) pointed out that, to forecast port throughput, time series decomposition models can be used if observed data show a seasonal pattern, and the seasonal component has a multiplicative or additive trend. This model is mainly suitable for intermediate or long-range port throughput forecasts.

Due to the limitations of time series models, recent studies have used soft computing models including artificial neural networks (Gosasang, Chandraprakaikul, and Kiattisin 2011); transfer forecasting models (Xiao et al. 2014); fuzzy logic; genetic algorithms (Chen and Chen 2010); artificial bee colony (Gökkuş, Yıldırım, and Aydin 2017); and ant colony algorithms (Nie and Zhao 2019). These models are used to simulate complex processes where a mathematical description is not performable due to random behavior and non-linear characteristics of the process (Peng and Chu 2009). These models postulate the relation between port throughput and one or more independent variables.

Gosasang, Yip, and Chandraprakaikul (2018) pointed out that an artificial neural network is suitable for non-stationary data. This method provides better forecasting results than traditional methods (Gosasang, Chandraprakaikul, and Kiattisin 2011) as the artificial neural network effectively captures complex (linear and nonlinear) relations between macroeconomic variables and port throughput (Ping and Fei 2013). However, artificial neural network models require a substantial amount of input data during the training and learning process, otherwise they are not able to generate accurate and reliable results (Ping and Fei 2013). The models are prone to be over fitted by a wide variety of variables due to their black-box nature and complexity (Gosasang, Yip, and Chandraprakaikul 2018).

Qualitative methods mainly rely on expert judgment (De Langen, Van Meijeren, and Tavasszy 2012). These methods apply different techniques including rating scale, analog, Delphi, leading indicator, diffusion, performance evaluation review technique, survey, interviews, direct observation, and written documents (Jain 2005; Kesh and Raja 2005; Patton 2001). Qualitative models are used when data are unavailable, scarce, and ambiguous. However, the results of these models are based on the opinion, knowledge, and experience of experts, and thus are subjective and prone to (cognitive) biases (Patton 2001).

Chen, Chen, and Li (2016) pointed out that, due to the diversity of many influencing factors, a single model is often insufficient and may result in inaccurate forecasts. Hybrid (or joint) models, made up of two or more models to synthesize their information (Chen, Chen, and Li 2016), take advantage of each model for more stable results (Van Dorsser, Wolters, and Wee 2012; Tian et al. 2010) and improved forecast precision (Huang et al. 2015; Li, Chen, and Cui 2008). Hybrid models are useful when it is uncertain which single model provides the most accurate forecast (Armstrong 2001). However, Chen, Chen, and Li (2016) warned that in hybrid models, individual models should be carefully selected as each model has its own influence and thus increases the uncertainty of the result. On the other hand, using several models may increase the redundancy, complexity, and computation load of hybrid models.

Moreover, despite the advances made in forecasting methods, the correct interpretation of results and their effective communication to stakeholders present challenges to port authorities, with regard to choosing and applying the right forecasting methods (Parola et al. 2020). Parola et al. (2020) stressed that the time horizon can further influence the selection of forecasting method and that, in strategic planning, port authorities should deal with uncertainties including opportunities and vulnerabilities. In this vein, Eskafi et al. (2021b) presented a framework to deal with uncertainties in port planning process aimed at seizing opportunities and managing vulnerabilities in different time horizons of a port plan. They point out that the time horizon can affect the level of uncertainty and, consequently, the forecasting method.

Port throughput forecasting models have always contained epistemic uncertainty due to incomplete knowledge of model components, and complex and causal (with partly known) relations, with a large number of macroeconomic variables that often include limited data in them, the chosen modeling technique, the applied modeling assumptions, and the necessary simplifications. To increase the reliability of the forecast results, the inevitable epistemic uncertainty should be taken into consideration.

Eskafi et al. (2021c) presented the advantages of mutual information in the selection of influencing macroeconomic variables as input for port throughput forecasting models. They stated that the application of mutual information increases the reliability of the models. The mutual information method identifies the important variables that should be used in Bayesian models, and thus it improves the accuracy of model results (Yang, Yang, and Yin 2018) as it accounts for model uncertainties. The Bayesian method has been used in the literature in different fields including ship emissions (Liu and Duru 2020), shipping accidents (Zhang and Thai 2016), resilience of inland waterways ports (Hosseini and Barker 2016), deep-water port infrastructure resilience (Hossain et al. 2019), and classification of port variables (Molina-Serrano et al. 2018). However, the application of a Bayesian method to forecast port throughput is scant in the scientific literature.

5.4 Methods

5.4.1 Mutual Information

Economic development is an important driver of maritime trade, and there is an interrelation between port throughput and macroeconomic variables (e.g., (Parola et al.

2020)). We use mutual information to identify key macroeconomic variables that influence port throughput, and thus reduce the need to subjectively select macroeconomic input variables. Application of mutual information reduces uncertainty in port throughput forecasts, as it effectively identifies the influencing macroeconomic variables on port throughput (Eskafi et al. 2021c). In other words, mutual information can be used as an approach to recognize insignificant variables that should be excluded from a model (Yang, Yang, and Yin 2018).

Mutual information is an important concept in information theory and a widely used measure to define the dependency of variables, especially in nonlinear systems. It is rooted in the concept of entropy (Shannon 1948) and Kullback-Leibler divergence (Kullback and Leibler 1951) and is suitable for assessing uncertainties and the information content between variables. The mutual information method measures the linear and nonlinear correlation between random variables and illustrates the distributions of the information measures in terms of interdependency between variables. It takes a zero value iff the two random variables (e.g., macroeconomic variables and port throughput in this study) are statistically independent. However, when the two variables are similar their mutual information is maximized.

For a pair of random variables (X, Y) with marginal probability distributions of $\mu_x(x)$ and $\mu_y(y)$, mutual information uses the Kullback-Leibler measure to determine the distance between the joint probability distribution, $\mu(x, y)$, and the distribution associated with the case of complete independence (i.e., $\mu_x(x)\,\mu_y(y)$) and according to Kraskov, Stögbauer, and Grassberger (2004) is expressed:

$$I(X, Y) = \iint \mu(x, y) \log \frac{\mu(x,y)}{\mu_x(x)\mu_y(y)} dxdy \tag{5.1}$$

Mutual information quantifies how informative a random variable (X) with possible outcomes (x_i), each with probability $p(x)$, could be:

$$H(X) = -\int_{x \in X} p(x) \log_2 p(x) dx \tag{5.2}$$

where the 2-base logarithm[6] corresponds to the unit of information measured in "bits" (Shannon 1948). Thus, mutual information can be obtained by:

$$\begin{aligned} I(X, Y) &= H(X) + H(Y) - H(X, Y) \\ &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X) \end{aligned} \tag{5.3}$$

where $H(X)$ and $H(Y)$ are the entropy of random variables X and Y, respectively; $H(X, Y)$ is their joint entropy; and $H(X|Y)$ and $H(Y|X)$ are their conditional entropy and can be calculated as:

[6] The base of the logarithm determines the units in which information is measured. For example, the base 2 logarithm is corresponding to information measured in "bits". If the natural logarithm (ln) is used, it produces a measurement of entropy in "nats" and if 10-based logarithm (log) is used it gives "dits".

$$H(X|Y) = -\iint \mu(x,y)\log\mu(x|y)\,dxdy \tag{5.4}$$

where $\mu(x,y)$ is the joint probability distribution. The conditional entropy $H(X|Y)$ is the amount of uncertainty left in X when knowing Y. Thus, from these equations, the $I(X,Y)$ can be interpreted as the reduction in the uncertainty of the random variable X by the knowledge of another random Y (Maes et al. 1997).

5.4.2 Bayesian Method

The Bayesian statistical method is an effective approach that allows the combination of knowledge about parameters, in a synthesis of prior knowledge with the available data. In the Bayesian method, a posterior probability density is proportional to the likelihood function on the data, multiplied by the prior probability density. In classical approaches, instead, such as maximum likelihood, the inference is based on the likelihood of the coefficients, conditional on the data alone (Congdon 2014). To utilize the Bayesian method, the prediction models can be linearized by a simple expression of the following form:

$$\log y_i = C_0 + C_1x_1 + C_2x_2 + C_3x_3 + C_4x_4 + C_5x_5 + C_6x_6 \tag{5.5}$$

where the dependent variable (y_i) is the annual port throughput; the independent variables (x_i) are the macroeconomic variables; and the coefficients C_0–C_6 can be estimated by Bayesian regression. In other words, the relationship between a dependent variable (y_i) and the explanatory variables (x_i) can be obtained by a linear regression model. Let $y_i = (y_i, \dots, y_n)$ be a vector of historic data, with n number of available observations. The matrix of explanatory variables (X) can be expressed as:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix} \tag{5.6}$$

Assuming a conditional normal distribution of the dependent variable (y_i), given the explanatory variables (X), the mean of the normal distribution has a linear function as:

$$\mathrm{E}(y_i|\theta, X) = \theta_1x_{i1} + \cdots + \theta_kx_{ik} \tag{5.7}$$

where $\theta = (\theta_i, \dots, \theta_k)$ is a vector of unknown parameters. In other words, the dependent variable follows a normal distribution, $y_i \sim N(X\theta, \sigma^2 I)$, with a mean of $X\theta$ and variance of $\sigma^2 I$ where I is the $n \times n$ identity matrix.

In Bayesian statistics, the posterior distribution describes updated information about the unknown parameter (θ) and can be obtained by multiplying a prior distribution by a likelihood function as follows:

$$p(\theta|y) \propto p(\theta)p(y|\theta) \tag{5.8}$$

where $p(\theta)$ is the prior distribution and $p(y|\theta)$ is the likelihood function; i.e., a probability distribution that expresses the information contained in the historic data.

In this chapter, the logarithm of the port throughput is assumed to follow a normal distribution, so that (Ding and Teo 2010):

$$p(y|\sigma^2, \theta, X) = \prod_{i=1}^{N} \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{(y_i - (X\theta)_i)^2}{2\sigma^2}) \qquad (5.9)$$

where N is the number of available historical observations, y is the vector of the logarithm of the port throughput data, $(X\theta)_i$ is the i-th element of the vector $X\theta$ representing the mean value of the prediction model, and σ is the standard deviation. On the other hand, we assume a non-informative prior for the unknown parameters, i.e., $p(\theta, \sigma^2|X) \propto \sigma^2$. Thus, the joint posterior distribution of θ and σ^2 is given by:

$$p(\theta, \sigma^2|y, X) \propto p(\theta, \sigma^2|X) p(y|\sigma^2, y, X) \propto \sigma^2 \prod_{i=1}^{n} N(y_i|(X\theta)_i, \sigma^2) \qquad (5.10)$$

The posterior distribution of the unknown parameters θ is obtained by using Equation 10. Therefore, the Bayesian posterior inference is used to simulate port throughput from the posterior macroeconomic variables.

The Bayesian model can take into account the statistical uncertainty associated with the limited number of input observations. The macroeconomic variables are considered as random variables and their associated uncertainties are quantified by the posterior distribution. This makes the Bayesian method preferable over classical regression because more information can be extracted from the probability distribution of each parameter. The capability of accounting for causal and uncertain relations of macroeconomic variables with port throughput makes the Bayesian model a useful tool for port throughput forecast.

In this chapter, the MATLAB programming language is used to code the equations: 1- to calculate the mutual information between macroeconomic variables and port throughput, to identify the macroeconomic variables that influence port throughput; and 2- to develop a Bayesian model to forecast port throughput based on the selected macroeconomic variables.

5.5 Study Area and Data Used

The multipurpose Port of Isafjordur is a hub port in northwest Iceland, in the so-called Westfjords (Figure 5.1). The port has a competitive advantage, due to its infrastructure and services, among the other ports in the region. Coastal shipping and road transportation are the only two transport modes that connect the port to its hinterland, which is the whole country. Industrial fisheries, aquaculture, and further fish processing (i.e., packing, freezing, storage) are the main businesses of the region. These activities are increasing in the region, which increases the volume of cargo and container handling in the port. A reliable port throughput forecast supports the Port Authority in decision making for capacity planning and management to position the port for sustained growth.

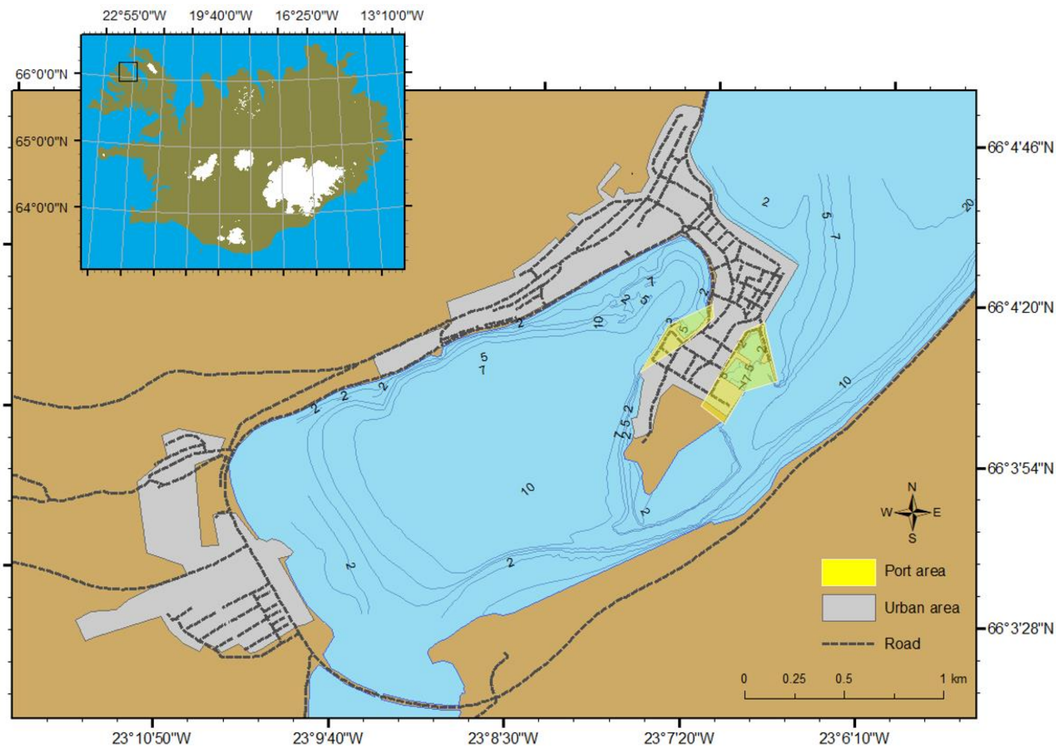

Figure 5.1 The multipurpose Port of Isafjordur. The location of the study area is shown on the map of Iceland at the top left.

The main functions of the Port of Isafjordur include:

- Transfer and storage of containerized and non-containerized cargo;
- Industrial value-added activities related to fisheries and aquaculture;
- Recreational activities, such as rendering services to expedition vessels, cruise ships, and small private and sailing boats.

In this study, two types of port throughput data are collected: containerized throughput in Twenty-foot Equivalent Unit (TEU), and non-containerized throughput in tonnes. The latter includes fuel oil, marine products, and industrial materials. Table 5.1 presents all cargoes that are handled in the port in question. Small cargoes (in terms of quantity) are considered as other general cargo. There is no information about the nature of the cargo inside containers. Port throughput related to recreational activities has not been considered in our study.

Table 5.1 List of cargoes handled at the Port of Isafjordur

Non-containerized cargo (T)	Containerized cargo (TEU)
Fuel oil (gasoline, [marine] diesel oil)	Containers and reefer containers
Road construction and maintenance materials (asphalt, salt, cement, etc.)	
Fertilizer and fish feed	
Marine product (fish, shrimp, etc.)	
Industrial materials (fishing and maritime equipment, scrap, etc.)	
Small general cargo (construction material, etc.)	

The annual containerized throughput data of the port are collected for the years 1990 to 2019. The available data for non-containerized throughput are garnered between 1990 and 2016. Non-containerized data for 2017-2019 were limited and unusable for building the model. Thus, the non-containerized throughput is forecasted for 2017-2025.

To build our model, six macroeconomic variables, available at Statistics Iceland (2019), have been used. They include national Gross Domestic Product (GDP); average yearly Consumer Price Index (CPI); world GDP; the volume of national export trade; the volume of national import trade; and the national population. These variables were also used in previous studies (Gökkuş, Yıldırım, and Aydin 2017; Gosasang, Yip, and Chandraprakaikul 2018). Of course, if more macroeconomic variables are available, they could naturally be used in mutual information analysis to discover those that influence port throughput the most. In other words, the application of mutual information discovers variables that should be used and/or excluded as inputs in building a forecasting model. Historic and forecast values of these variables refer to 1990-2019 and 2020-2025 respectively (Statistics Iceland Office 2021).

The influence of factors that cannot be quantified from observation of the past (e.g., growth in the ports' captive market) or cannot be accurately predicted (e.g., innovation or breakthrough technology in cargo handling) are excluded in this study. Transshipment flows are not covered in this study either. However, the presented methodology can also be applied to forecast (non-)containerized port throughput with (high) share of transshipment flow. This is because the changes in transshipment flow are also influenced by the development of macroeconomic variables (e.g., (Parola et al. 2020)).

5.6 Results and Discussion

To increase the reliability of our model, the associated epistemic uncertainties are taken into consideration. To account for parameter uncertainty, mutual information is used to objectively select the input variables for of model. Figure 5.2 shows the results of the mutual information values between port throughput and macroeconomic variables.

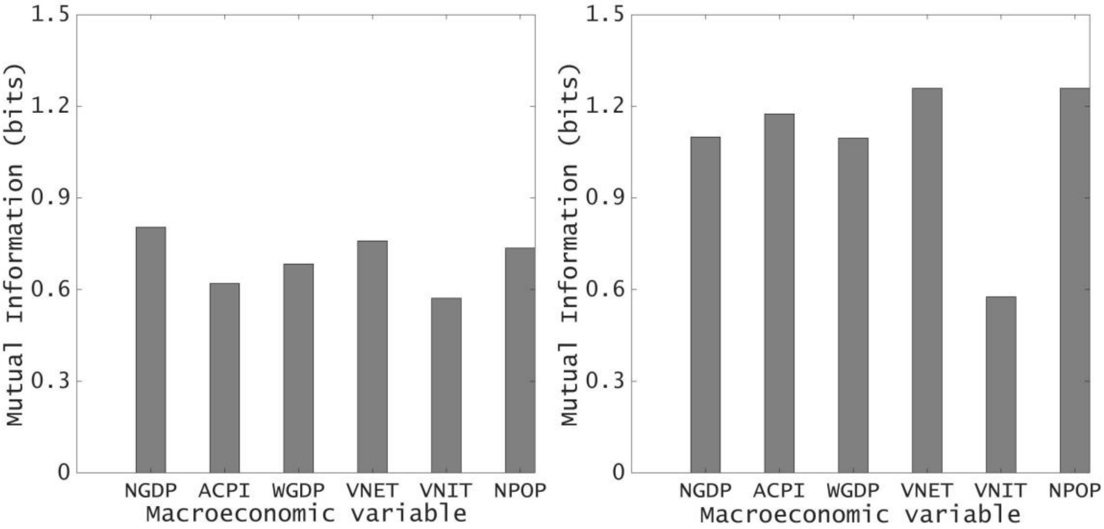

Figure 5.2 Mutual information values between port throughput (right: containerized, left: non-containerized) and macroeconomic variables.

In Figure 5.2, the acronyms are the national GDP (NGDP), the average yearly CPI (ACPI), the world GDP (WGDP), the volume of national export trade (VNET), the volume of national import trade (VNIT), and the national population (NPOP).

The results indicate that port throughput is correlated with the six macroeconomic variables of this study. In comparison with non-containerized throughput, containerized throughput has a relatively higher correlation with macroeconomic variables. This is because the majority of cargo flows in the port is containerized, and containerized cargo is the main form of transportation from/to the Port of Isafjordur.

Since the port throughput is influenced by the six macroeconomic variables, these variables are used as independent variables (input) in the port throughput forecasting model. The mean and standard deviation of the model parameters, along with the total standard deviation of the model with respect to the port throughput are shown in Table 5.2. The values are derived from the corresponding variable's posterior distribution that results from the model.

Table 5.2 Parameter estimates and 95% marginal posterior intervals of the model parameters for containerized (C) and non-containerized (NC) throughout.

Parameter	Mean (μ)		Standard deviation (σ)		95% posterior interval			
					Lower bound		Upper bound	
	C	NC	C	NC	C	NC	C	NC
C_0	0.7195	4.6782	0.7207	1.7819	-0.6931	1.1858	2.1322	8.1707
C_1	-0.0064	-0.0046	0.0043	0.0099	-0.0149	-0.0240	0.0020	0.0149
C_2	0.0030	0.0012	0.0030	0.0072	-0.0030	-0.0129	0.0089	0.0152
C_3	-0.0025	-0.0092	0.0020	0.0043	-0.0064	-0.0175	0.0015	-0.0008
C_4	0.0026	0.0114	0.0018	0.0048	-0.0009	0.0019	0.0061	0.0209
C_5	0.0029	0.0012	0.0016	0.0033	-0.0001	-0.0053	0.0060	0.0076
C_6	0.0134	-0.0269	0.0107	0.0263	-0.0076	-0.0785	0.0344	0.0076
σ	0.0570	0.0570	-	-	0.0439	0.0894	0.0815	0.1750

Figure 5.3 shows the posterior distributions of the model parameters. For the sake of space, only containerized throughput is depicted. However, almost the same behavior can be seen for non-containerized throughput. The well-defined normal-shaped posterior distribution of the regression coefficients indicates an appropriate assumption of the prior distribution.

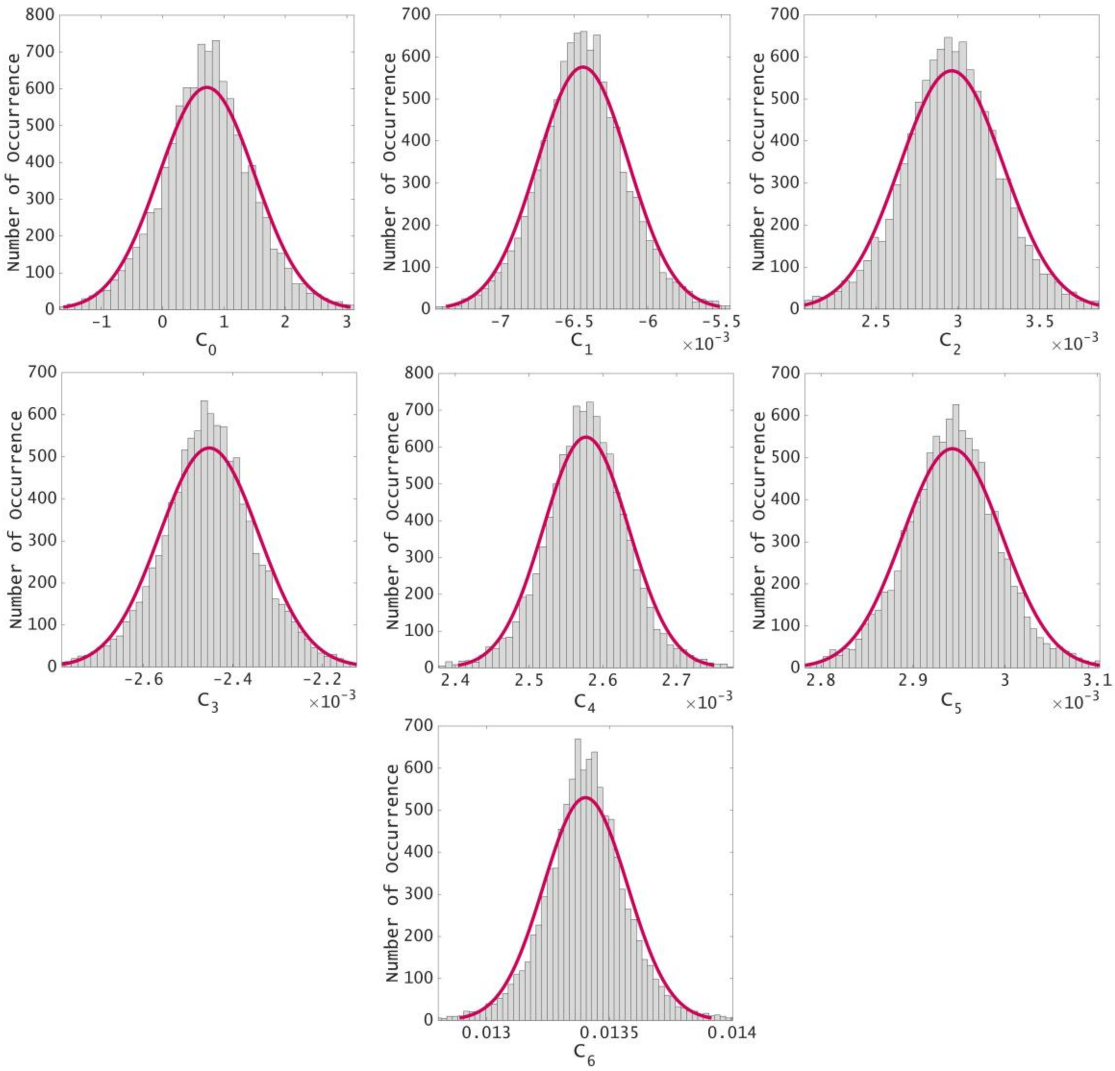

Figure 5.3 The posterior histograms of the regression coefficients. The solid lines indicate the normal distribution fitted on the posterior values for containerized throughput.

Figure 5.3 showcases one of the advantages of the Bayesian statistical method, as it determines the posterior distribution of macroeconomic variables, vis à vis classical approaches which only return point estimates.

Figure 5.4 shows the residuals as a function of data that represent the model goodness of fit. Another qualitative assessment of normality is demonstrated by the histograms of the residuals. The residuals of the model follow the Gaussian distribution and are generally assumed from the outset to be normally distributed with zero mean and a standard deviation of σ. This assumption is depicted by a normal probability plot in Figure 5.4.

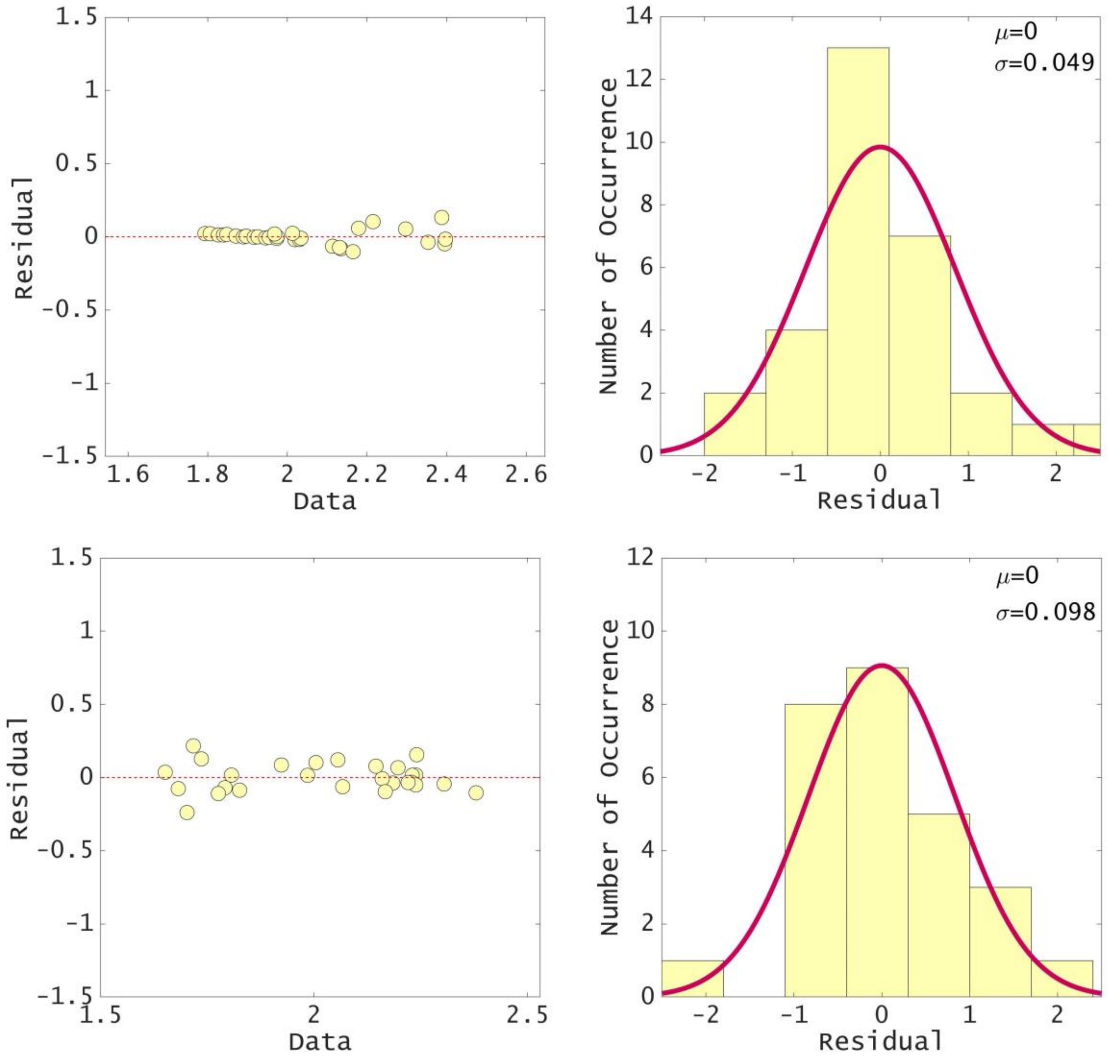

Figure 5.4 Right: the histogram of residuals along with a fitted normal distribution. The mean and standard deviation of the residuals are also shown. Left: residuals (circles) of the prediction model using the mean model parameter estimates for containerized throughput (top row) and non-containerized throughput (bottom row).

As can be seen in Figure 5.4, both in containerized and non-containerized throughput, the residuals are distributed around zero. Also, the residuals of the model are normally distributed with zero mean and small standard deviation (i.e., 0.049 σ for containerized and 0.098 σ for non-containerized throughput), indicating that there are neither significant residual outliers nor systematic trends in the overall distribution of residuals. As demonstrated, the results show the model's goodness of fit with (limited[7]) input data. Table 5.3 gives the result of the port throughput forecasts, based on the available forecasted macroeconomic variables (i.e., X_1 to X_6) and their distribution over the years.

[7] For instance, relatively short data series of 27 observations (1990-2017) of annual non-containerized- and 29 observations (1990-2019) of annual containerized port throughput are used. The small number of observations is insufficient in soft computing models (e.g., artificial neural network) but it is workable here.

Table 5.3 The prediction of the port throughput (logarithms base10) is based on the explanatory variables for throughput.

Year	PT (Log Y)		NGDP	ACPI	WGDP	VNET	VNIT	NPOP
	Non-containerized	Containerized	(X_1)	(X_2)	(X_3)	(X_4)	(X_5)	(X_6)
2017	2.03	-	135.20	181.48	170.44	199.89	124.70	115.25
2018	1.86	-	141.72	186.35	180.79	203.10	124.88	118.69
2019	1.60	-	141.43	191.94	186.22	191.93	116.51	121.60
2020	1.54	2.41	143.84	196.93	192.55	195.19	120.82	123.05
2021	1.46	2.44	147.72	201.85	199.48	200.26	124.32	125.56
2022	1.39	2.47	151.56	206.90	206.66	205.87	127.43	127.60
2023	1.35	2.48	155.50	212.07	214.10	211.43	130.87	128.78
2024	1.30	2.49	159.39	217.37	221.81	216.93	134.54	129.94
2025	1.27	2.51	163.37	222.80	228.00	222.35	138.71	131.08

In Table 5.3, the acronyms stand for port throughput (PT), the national GDP (NGDP), the average yearly CPI (ACPI), the world GDP (WGDP), the volume of national export trade (VNET), the volume of national import trade (VNIT), and the national population (NPOP). Numbers are indexed to the year 2005.

Figure 5.5 shows the development of the historical and the forecast port throughput expressed by the gray shaded area for different confidence intervals of the forecast.

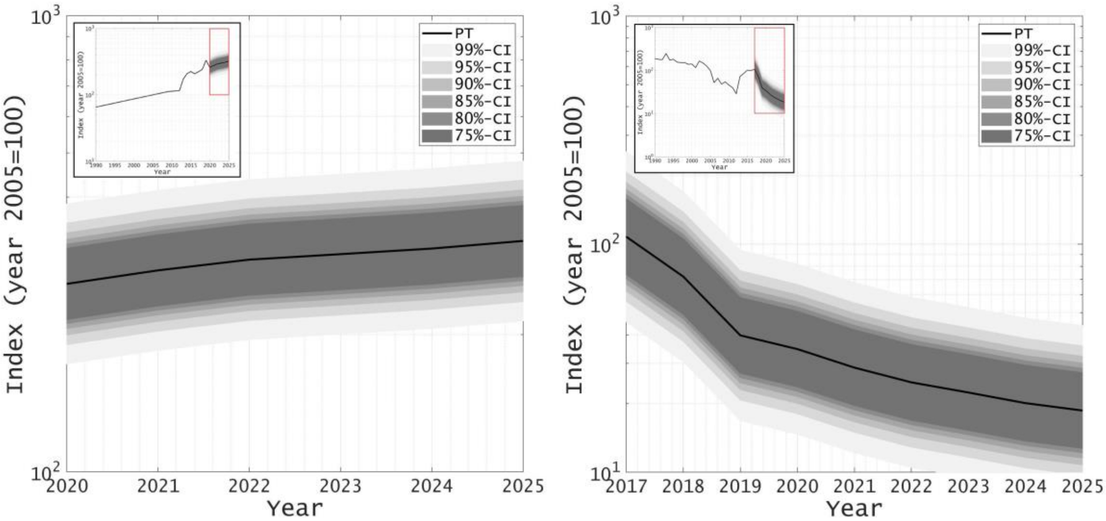

Figure 5.5 Historical and forecast containerized (left) and non-containerized (right) Port Throughput (PT) developments, and Confidence Interval (CI). The forecasted port throughput is surrounded with the red box in the inserted graph including the historical data.

The confidence limits indicate the future port throughput forecasts while associating the epistemic uncertainties, including model uncertainties and parameter uncertainties. Thus, the uncertainty bounds can be further used for decision making in port planning and management. For instance, the national GDP and the world GDP have been affected by the

COVID-19 pandemic. In this context, although updated macroeconomic variables including the national and world GDPs forecasts were not used in this study, port throughput can be expected to be within the lower uncertainty bounds.

As shown in Figure 5.5, containerized throughput shows a growing trend since 1990. However, during the world economic downturn of 2008-2009, a reduced pace of growth is observed until 2012. Non-containerized throughput generally shows a decreasing trend from 1990 to 2012. In 2013, non-containerized throughput recovered, and containerized throughput significantly increased. One of the reasons for this substantial increase is the rapid growth in aquaculture, especially the salmon industry in the region. The fast-growing aquaculture stimulates the business environment and drives the growth of relevant activities including marine production, processing, and packing, as well as industrial equipment manufacturing. In this respect, an additional shipping company started calling the port from 2013 to satisfy the increasing demand.

As depicted in Figure 5.5, the forecasted containerized throughput follows an increasing trend. The growth rate is somewhat lower between 2022 and 2025. Containerized throughput in the period from 2020 to 2025 resumes a total increase of about 26% in TEU. This is an increase of 324 TEU (324/100=3.24 times the TEU containerized throughput of the indexed year 2005). The outer bound (shaded area indicating the 99% confidence interval) surpasses the maximum values of 480 and the minimum value accounts for almost 215 TEU. Higher market uncertainty requires higher flexibility in port infrastructure, operation, and services (Taneja, Ligteringen, and Van Schuylenburg 2010; Wang, Mileski, and Zeng 2019). Thus, this range of port throughput forecasts with confidence intervals provides useful information to decision makers and port planners to develop flexibility and create a buffer in port capacity planning to satisfy changing and uncertain future demand (Notteboom and Haralambides 2020).

The continuous need for export of marine and aquaculture products (i.e., farmed and wild; frozen and fresh; processed and unprocessed), as well as imports of industrial and consumer goods are increasingly handled in containers in the multipurpose Port of Isafjordur. Also, there is an increasing need for a reliable and quick exporting of marine catch and products which are considered as time-sensitive cargo in reefer containers (Eskafi et al. 2020b). Imports of fish feed in containers has increased. The increase in containerized throughput is supported by the causal relation with the increasing macroeconomics of Iceland. In response to this increase, larger vessels are being utilized, enjoying economies of scale, which have impacted the containerized throughput of the port. This growth in containerized throughput is also aligned with the increase in scale and concentration in the world container markets (Haralambides 2019). Containerization is an important transportation system in the rapid growth of international trade. As a preferred form of transport of both exports and imports, containerization is one of the reasons for the container growth in the present study (Gharehgozli, Zaerpour, and de Koster 2019).

As depicted in Figure 5.5, non-containerized throughput follows the historical data trend and continuously decreases until 2025. The decline in non-containerized throughput reached 40 tonnes in 2019 (40/100=0.4 times tonnes of the non-containerized throughput of the indexed year 2005). Afterwards, a gradual decline in non-containerized throughput, of a lower rate, is observed until 2025. Non-containerized throughput is forecast to decrease by 82% from 2017 through 2025. This is a decrease to 19 tonnes of non-containerized throughput. The outer bound (shaded area indicating the 99% confidence interval) reaches a maximum value of about 45 tonnes and the minimum value is about 8 tonnes. The decline in non-containerized throughput may gradually stabilize in the long run. The slowdown of the decline from 2019 to 2025 can be due to an increase in Iceland's macroeconomics until 2025, thus resulting in economic growth and consequently in an increase of maritime trade (De Langen et al. 2012). The ongoing containerization is driving non-containerized throughput down, with non-containerized cargos increasingly transported by containers (Haralambides 2019).

This decreasing and stabilizing range of non-containerized throughput helps the Port Authority to determine the ultimate required capacities and facilities that can satisfy future demand. Furthermore, the Port Authority can consider phasing of new development based on the changing demand in the volatile market environment. The results of this short-term forecast facilitate the port's operational decisions (i.e., port capacity utilization, cargo handling, and facilities development plan), resources allocation (Gökkuş, Yıldırım, and Aydin 2017; Rashed et al. 2017), port logistics, and terminal and hinterland connections capacity (Brooks, Pallis, and Perkins 2014).

In comparison with existing forecasting methods, the presented method has several advantages including the following: 1- it quantifies the relationship of macroeconomic variables with port throughput and then identifies the influencing macroeconomic variables as input to the model. This meaningfully increases the accuracy of the model (Yang, Yang, and Yin 2018) and the reliability of the forecast results (Eskafi et al. 2021c). Thus, it considers model uncertainties; 2- it uses a probabilistic approach to quantify the associated parameter uncertainty of the influencing macroeconomic variables by providing their posterior distributions; 3- the Bayesian model can be updated when more data are available (Zhang et al. 2013); 4- it can deal with uncertain information characterized by scarcity and limitation of data (Kowsari et al. 2019). The method was applied to the Port of Isafjordur in Iceland just as one of the many ports that could have been used as a case.

5.7 Conclusions

Port throughput forecasts provide valuable and fundamental input to capacity planning and management, adjusting this way the direction of port development. Additionally, to uncertain demand and a volatile market environment, epistemic uncertainty associated with parameter uncertainties and model uncertainties impose challenges in decision making. In the context of uncertainty, decision makers should not rely on a single-point forecast but should assess a range of port throughput forecasts.

This chapter presented a port throughput forecasting model using the Bayesian statistical method. Our model was developed to forecast the annual containerized and non-containerized throughputs of the multipurpose Port of Isafjordur from 2020 to 2025. The mutual information approach was used to determine the influence of macroeconomic variables on port throughput and thus objectively use input variables in the forecasting model, resulting in reduced model uncertainties. The Bayesian method accounted for the uncertainty associated with the macroeconomic variables, considered to be random variables following a given probability distribution. The model also accounted for parameter uncertainties and delivered reliable results with relatively sparse input data. Furthermore, the model offered a range of port throughput forecasts that allows decision makers and port planners to develop flexibility in capacity planning to satisfy the changing and uncertain needs of port users.

Our results show a growth of containerized throughput up to 2025. That throughput increases by 26% during the period 2020-2025 and, in 2025, it reaches 324 TEU (324/100=3.24 times the TEU containerized throughput of the indexed year 2005). However, in that year, non-containerized throughput slumped to about 19 tonnes. This is about an 82% decrease over the period 2017-2025. The decline in non-containerized throughput slowed down after 2019. An increase in containerized throughput and a decline and stabilization in non-containerized throughput helps the Port Authority to consider the required port capacities and facilities and be proactive in planning to satisfy the future demands of stakeholders.

The theoretical contribution of this chapter lies in the presentation of a robust port throughput forecasting model, based on the influencing macroeconomic variables that accounts for epistemic uncertainties including model uncertainties (choice of variables, assumptions, and processes) and parameter uncertainties (quantity and quality of data used). Furthermore, the managerial contribution of the chapter is by drawing up a reliable port throughput forecasting framework that can support port authorities to rationalize their investment decisions based on future demand and thus maintain the competitive edge of their ports and growth in their market share. Various data sources, and inconsistencies in terms of data collection may have affected the results of this case study. Although the chapter has developed a short-term forecast due to a lack of forecasts of independent variables, the model can be applied for long-term forecasts too, which are useful to assess future infrastructure investment decisions. The application of the Bayesian statistical method in long-term forecasting is recommended in future research.

Acknowledgments

The authors would like to thank the Icelandic Road and Coastal Administration (Vegagerdin), Statistics Iceland Office (Hagstofa Islands), Eimskip hf. and Samskip hf. companies for providing data. The authors are grateful to Maritime Economics and Logistics (MEL) and its anonymous reviewers for their careful review of the study, their corrections, and fruitful remarks. This research was supported in part by the University of Iceland Research Fund (Rannsoknarsjodur Haskola Islands), the Municipality of Isafjordur (Isafjardarbaer), and the Icelandic Road and Coastal Administration Research Fund (Rannsoknarsjodur Vegagerdarinnar)

6 Framework for Dealing with Uncertainty in the Port Planning Process

This chapter contains the peer-reviewed journal article:

Eskafi, M., A. Dastgheib, P. Taneja, G. F. Ulfarsson, G. Stefansson, and R. I. Thorarinsdottir. 2021. "Framework for Dealing with Uncertainty in the Port Planning Process", *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 147 (3).
https://doi.org/10.1061/(ASCE)WW.1943-5460.0000636

6.1 Abstract

Ports are complex engineering systems that have always been evolving to satisfy the new or changing demands of stakeholders. However, the ever-growing complexity in port sectors in a volatile environment creates a high degree of uncertainty in port planning projects. This study presents a structured framework to deal with uncertainties in the port planning process. Stakeholder analysis, different methods of addressing uncertain developments, and SWOT analysis were jointly used to develop the framework. Effective actions were planned in response to opportunities and vulnerabilities derived from uncertainties that manifest in a projected lifetime. Face-to-face interviews with key stakeholders and literature review were conducted to identify uncertainties and planning horizons. The framework was applied to the Ports of Isafjordur Network in Iceland. The results show that demand for aquaculture and cruise activities create the main uncertainties for the port network. Uncertainties mainly present opportunities in the short-term horizon, while in the middle-term horizon the port network is confronted with multiple vulnerabilities. The nonlinearity of dealing with uncertainty by application of the framework provides a robust and better plan toward its success in a dynamic world. The framework supports decision making under uncertainty by facilitating adaptive port planning.

Keywords: Adaptive port planning; Uncertainty; Flexible port; Iceland.

6.2 Introduction

A port is recognized as a complex set of functions (Moglia and Sanguineri 2003), as it has emergent and nonlinear behavior in which multiple interactions between different components are possible (Bettis and Hitt 1995). Some of the components of a port system themselves represent complex systems (Taneja 2013). The complexity of a port system is involved in unlimited geographic boundaries and trading network, long lifetime, multiple worldwide uncertainties (e.g., technological and political), its numerous stakeholders, and its intricacy with the society, environment, and economy (Herder et al. 2008; Taneja, Ligteringen, and Van Schuylenburg 2010).

Decision makers are being faced with fast-paced, transformative, and often unexpected changes. In a volatile environment, where uncertainty is an inherent property of the future, decisions are usually made at the beginning of a project. However, under uncertainty decision making for long-lifetime projects (e.g., port projects) is challenging. In this context, Taneja, Ligteringen, and Van Schuylenburg (2010) pointed out challenges in port planning and design under relevant political, logistical, technological, and economic uncertainties.

Commensurate with the volatile circumstances at the time of writing this dissertation, the outbreak of the Coronavirus disease (COVID-19) pandemic has significantly affected maritime sectors, cruise ship calls have slumped, and there is a concomitant decline in cargo throughput (Zhang, Gong, and Yin 2020). The present uncertain situation in maritime sectors due to the COVID-19 pandemic was not anticipated, not even a few months ago. These unpredictable events have had significant impacts on the throughput of some ports that highly depend on a particular flow of cargo/container/passenger (Pallis and De Langen 2010). For instance, the throughput of the port network in this study has mainly depended on container flow and servicing cruise ships.

Under volatile circumstances, dealing with uncertainties in the planning process increases the success of long-lifetime projects (García-Morales, Baquerizo, and Losada 2015). Taneja et al. (2012) stated that the main reason for unsuccessful port development projects is inadequate consideration of uncertainty in the planning process. Unsuccessful port projects may result in a loss of investment, failure of the projects, congestion in the port area or hinterland, redundancy and obsolescence of ports, or costly regular adaptations of port infrastructure (e.g., deepening of access channel), operational facilities (e.g., using larger quay crane), and services (e.g., providing renewable energy fuel to vessels) (Taneja et al. 2012; Taneja, Ligteringen, and Walker 2012). In addition is the loss of competitive position, cargo, and revenue during the period that the port cannot be used due to the adaptation. Traditional linear planning of infrastructure projects usually beset the bad side of uncertainty, without taking advantage of their potential (Taneja 2013). Salling and Nielsen (2015) pointed out that in most transport projects there is no recommendation for doing an ex-ante-based evaluation of uncertainties.

In this context, Hoehn et al. (2017) stated that the world has entered a new era of complexity. A complex system does not have a central-control or central-processing unit (Hayek 1964). Components of a complex system are heterogeneous in terms of their function, and their interactions are driven by heterogeneity. A complex system exhibits nonlinear and dynamic behavior. Although its behavior cannot be predicted in detail, its patterns can be described, and its formation can be analyzed. Nevertheless, the future of a complex system is fundamentally uncertain (Page 2011).

The complexity of a port system and the concomitant uncertainties during its projected lifetime in the volatile environment make considerations for uncertainty inevitable in the planning process. However, the question is: How can uncertainties be dealt with in the port planning process? The answer to this research question was the motivation for the present study.

Therefore, in this study, a framework was developed based on three components to identify the uncertainties that are manifested during the projected lifetime of the plan and deal with them in the planning process. The components are: 1- stakeholder analysis to a) identify port stakeholders, b) disclose stakeholder's objectives and consequently define the success of port planning, and c) identify uncertainties around stakeholders' activities and objectives, and determine different planning horizons; 2- different methods to systematically address uncertain developments; and 3- SWOT (strengths, weaknesses, opportunities, threats) analysis to identify opportunities and vulnerabilities derived from uncertainties. To seize opportunities and manage vulnerabilities and thus deal with uncertainties, effective actions were planned. Port authorities and decision makers can strategically implement the actions in the face of uncertainty that emerges in the projected lifetime of the port.

This study provides building blocks to improve the quality of port planning under conditions of uncertainty, the first such study in Iceland. The framework described herein is applied to a case study and can be readily extended to other ports and meet practical needs.

The remainder of this chapter is structured, as follows: subchapter 6.3 sheds light on port planning under conditions of uncertainty. The method used is characterized in subchapter 6.4. Subchapter 6.5 describes the study area and presents the results for the case study of the Ports of Isafjordur Network in Iceland. Subchapter 6.6 discusses the findings, and subchapter 6.7 draws conclusions on dealing with uncertainties in port planning for the case study.

6.3 Planning Under Uncertainty

There is a growing consensus of increasing uncertainty in the world (Brynjolfsson and McAfee 2014; Leonhard et al. 2016). Engineering systems are under pressure to satisfy changing demands while ensuring functionality, capacity, and quality of service (Hansman et al. 2006).

Long-term planning of large-scale engineering projects (e.g., port planning projects) implies a high degree of uncertainty. The planning needs a long-term view to ascertain the functionality of large infrastructure units (Hansman et al. 2006); otherwise, it is ineffective and uneconomical to change their configuration (De Langen, Van Meijeren, and Tavasszy 2012) during the projected lifetime. Van Dorsser, Taneja, and Vellinga (2018) stated that an understanding of the plausible future changes is necessary for port planning. Uncertainties and the existing, prevailing, and emerging trends that directly or indirectly affect a complex port system should be examined in the planning processes (Taneja 2013). Uncertainty in port planning projects implies that decision making is based on incomplete knowledge about the projects.

For handling of uncertainties, their three dimensions including location, level, and nature should duly be taken into consideration (Walker et al. 2003). Over the years, many methods have emerged in attempts to deal with uncertainties and support decision making in the port planning process. Taneja (2013) categorized uncertainty handling methods in three categories of qualitative, quantitative, and mixed qualitative and quantitative.

Decision makers often seek predictions for informed decision choices. However, decision making based on pure prediction may be proved wrong due to the volatility and complexity of the market environment. Forecasting the demand over a long-term horizon is a strategic approach in large-scale transport models. However, forecast models may have an inherent uncertainty that increases over time and thus reduces the reliability of results (Manzo, Nielsen, and Prato 2015). Furthermore, Rasouli and Timmermans (2014) stressed that forecast models themselves have uncertainty associated with input data and models. In this line, Eskafi et al. (2021d) stated that forecasting models should account for epistemic uncertainty including parameter uncertainties and model uncertainties. Van Dorsser, Taneja, and Vellinga (2018) pointed out that forecasts do not perform well under a changing and uncertain market environment. Analytical and quantitative tools, even those that model dynamic decision making, are not able to deal with the qualitative nature of uncertainty (Alessandri et al. 2004).

On the other hand, scenario planning, as an alternative approach to predict the future, may not seize opportunities offered by transition in port planning projects (Van Dorsser, Taneja, and Vellinga 2018). Armstrong (2001) put forward the belief that scenario planning can be "wrong and convincing" for anticipating future developments. In this vein, Walker, Haasnoot, and Kwakkel (2013) emphasized that a static optimal plan using a single most likely future may fail if another future materializes.

Prediction reduces uncertainty, but it narrows uncertainty by focusing on a specific uncertain development (Lempert 2019) (e.g., predicting specific cargo/container demand), which may not be the case in a complex port system where a wide range of uncertainties exists. Herder et al. (2011) pointed out that instead of investing efforts to reduce uncertainties, different methods at different time horizons should be applied to coexist with uncertainties, just as the framework in the present study offers. De Neufville et al. (2008), and Moses and Whitney (2004) stated that planning for a long-term horizon should aim to benefit from uncertainty.

In the context of uncertainty and complexity, policy making (setting a course of action) to deal with uncertainty in projects works better than relying only on predictions (Lempert and Popper 2005). This encompasses a new paradigm of treating uncertainty in the planning process.

Representatives of this paradigm are given as robust policymaking (Lempert, Popper, and Bankes 2003), dynamic strategic planning (De Neufville 2000), adaptive policymaking (Walker, Rahman, and Cave 2001), flexible strategic planning (Burghouwt 2007), adaptive airport strategic planning (Kwakkel, Walker, and Marchau 2010a), adaptive port planning (Taneja 2013), assumption-based planning (Dewar 2002), dynamic adaptive policy pathways (Haasnoot et al. 2013) that combines adaptive policymaking with adaptation tipping points (Kwadijk et al. 2010), and adaptation pathways (Haasnoot et al. 2012).

Indeed, the capital and fixed investments for port infrastructure development with a long technical lifetime in the volatile market environment calls for an effective approach to deal with uncertainties in the port planning process. The novelty of this chapter is to deliver a structured framework aimed at dealing with uncertainties that appear during the projected lifetime of a port and thus to increase the success of the port plan.

6.4 Methods

Habegger (2010) stated that a single-issue focus of dealing with uncertainties, including opportunities and vulnerabilities, is no longer sufficient. To deal with uncertainties against projected, probable, plausible, possible futures (Van Dorsser et al. 2018), a framework must be developed and adapted to port planning. Figure 6.1 depicts the framework.

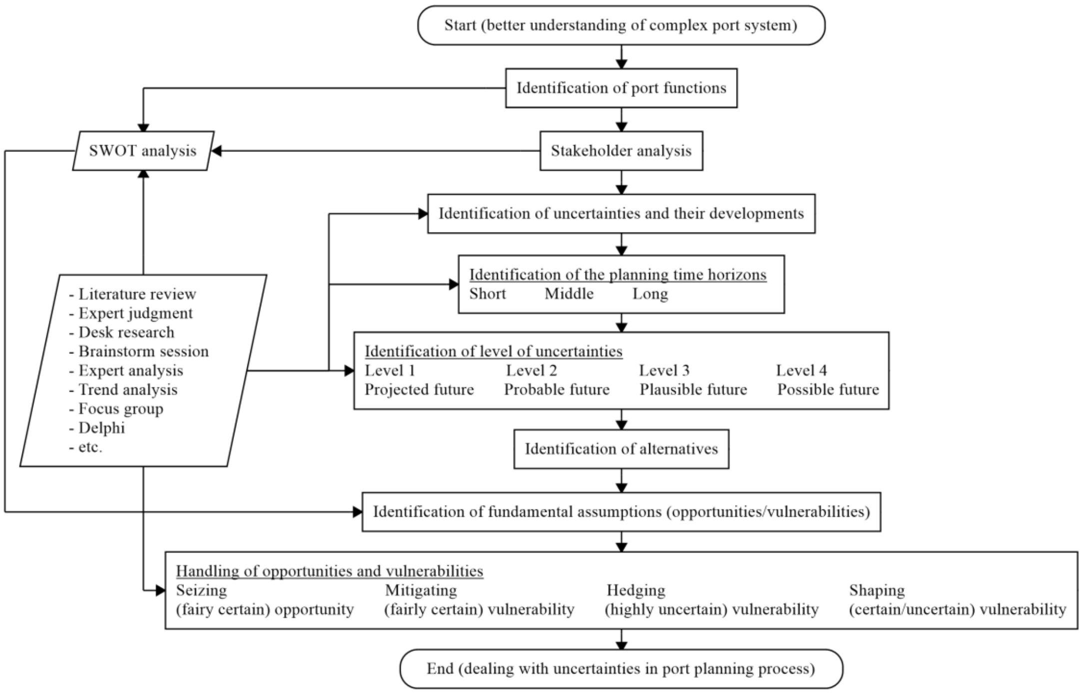

Figure 6.1 A framework of dealing with uncertainty in the port planning process.

The steps in Figure 6.1 are elaborated throughout this chapter.

6.4.1 Identification of Port Functions

The main functions of a port represent the main purposes for which the port is used. Prior to the planning and design of ports, it is necessary to determine their functions (Ligteringen

2017). The functions of a port play important roles in decision making for greenfield and brownfield port development plans. Port functions are fulfilled through various port activities. In this study, to determine the port functions and port activities, information was obtained through the literature (Ligteringen 2017), port visits, and interviews with the Port Authority.

6.4.2 Stakeholder Analysis

Stakeholder engagement develops insights into a complex decision-making process. Decision making can benefit a range of perspectives by engaging the stakeholders (Fischer et al. 2014). In this study, stakeholder analysis was used to identify 1- port stakeholders, 2- stakeholder's objectives (and ultimately define the success of the port planning), and 3- uncertainties around stakeholders' activities and objectives, and determine different planning horizons.

This study was based on the results of the port stakeholder analysis conducted by Eskafi et al. (2019a). They applied the power-interest matrix, fuzzy logic, and decision surface to measure the salience of port stakeholders and identify the key stakeholders.

Identification of stakeholders' objectives is a critical part of the port planning process. A deep understanding of the objectives is required to define the success of port planning. Based on the success of port planning, port authorities should determine the necessary decisions in the port planning process so as to anticipate legislation (PIANC 2014). Eskafi et al. (2020b) applied value-focused thinking and a fuzzy multi-attribute group decision-making method to identify the highest level of agreement on the objectives of port stakeholders that can stand as the success of port planning. The success of port planning is the driving force of decision making. Success is achieved if the outcome of planning fulfills the objectives of the stakeholders.

Furthermore, effective stakeholder engagement helps to uncover the uncertain developments that are aligned with their activities or objectives (Greenwood 2007). In this study, key stakeholders were engaged to screen uncertainties related to their activities and objectives.

6.4.3 Identification of Uncertainties and Their Developments

One of the best ways to deal with uncertainties is understanding the sources, amount and quality of information available (Uusitalo et al. 2015). Aven (2008) stated that uncertainty identification is a qualitative procedure using expert opinion, literature review, brainstorming sessions, group discussions, and interviews with stakeholders.

Port planning should include various stakeholders. However, the engagement of all port stakeholders in planning processes is not possible as ports are connected to a broad spectrum of national and international stakeholders. In addition, the engagement of a wide range of stakeholders in planning processes may not result in an increase in the quality of planning. Thus, this study focused on key stakeholders who have considerable influence and interests in the port planning and development and thus play a critical role in decision making in the planning process. It should be noted that as stakeholders continuously change their influence and interests in the planning and development (Eskafi et al. 2019a), the salient stakeholders should be identified and engaged prior to making any decisions. This increases effective stakeholder inclusion in the planning process. To identify uncertainties, separate in-depth face-to-face interviews were conducted with representatives of key stakeholders. Separate interviews allowed each key stakeholder a more comfortable and honest information sharing, leading to a relatively high possibility of participation and providing valuable input from different sources (Phuong Vu, Grant, and Menachof 2019). The selection of the representatives was based on their short-, middle-, and long-term roles in the planning process and port development. The representatives were first contacted by email, followed by a phone call where they were provided with general information about the project, and then there were follow-up interviews. In the interviews, uncertainties related to their activities and objectives were discussed. Out-of-the-box thinking was encouraged during the interviews. The interviews were audio recorded and transcribed for careful processing of information.

The results of interviews provide knowledge of the various uncertainties and their developments in the future. The characteristic of uncertainty is explained by its development. Taneja (2013) defined developments as the state of changes from a given time.

Additional to the identified uncertainties during the interviews with the key stakeholders, other endogenous and exogenous uncertainties in a port system, for instance, future market uncertainties (Pinder and Slack 2012), political and regulatory developments, social uncertainties, technological changes, uncertainties around national and international economies, environmental uncertainties, globalization and liberalization uncertainties (Taneja, Ligteringen, and Van Schuylenburg 2010) could be further elaborated by literature review, desk research and interview with relevant stakeholders.

6.4.4 Identification of the Planning Time Horizons

Brier (2005) noted that forecasting with a long-term horizon is challenging as instability and uncertainty increase with time. Manzo, Nielsen, and Prato (2015) echoed that the inherent uncertainty of complex transport models increases over time. Thus, describing uncertainty propagation over time provides more complete information about the planning processes.

Flechtheim (1971) stressed that studies about the future should always be connected in a time horizon. He, however, did not specify any number in years for different ranges of time horizons. Taneja (2013) emphasized that uncertain developments should be time bounded as they are unique within a time horizon. Without a planning time horizon, every assumption on uncertain developments can be vulnerable in the lifetime of a project. With a predefined time horizon, only uncertain developments that change during a time horizon are considered vulnerable.

A linear demarcation of time horizon from the present time to the future is a simplification and pragmatic approach (Nordlund 2012). A clear time horizon in the future cannot be expressed when the start and end of the horizon have not arrived yet. Therefore, it is better to specify a time horizon from a given timescale, for instance, starting after a few months, years, or decades. Furthermore, Brier (2005) emphasized that time horizons necessarily are not definite because the future can be seen as a moving target in which behaviors and actions are materialized. Thus, the specification of exact time horizons in the future (when the future has not yet existed) should be avoided.

Tonn, Hemrick, and Conrad (2006) stated that five to fifty years of time horizons for future studies are in good agreement. Inayatullah (1996) considered less than five years, and five to fifty years as short- and long-term horizons, respectively. Linstone (1985) specified ten to fifty years for a long-term horizon, while Martino (1993) distinguished forty years as a long-term horizon. Masini (1993) pointed out that up to five years is a short-term horizon, while five to ten (and alternatively twenty) years is a middle-term horizon, and twenty to fifty years is a long-term horizon. Slaughter (1996) concurred that less than five years is a short-term horizon, between five and twenty years a middle-term horizon, but twenty years without an upper limit is a long-term horizon. De Jouvenel (1967) indicated four to five years as a short-term horizon and fifteen years or more for a long-term horizon. However, Flechtheim (1971) emphasized that more than fifty years has to be regarded as a very extended time horizon.

As can be seen from the literature, and also stated by Nordlund (2012), there is not a generally accepted standard and explicit view for extension of time in terms of specified short-, middle-, and long-term horizons. Correspondingly, Masini (1993) asserted that time horizons vary and closely depend on the subject under consideration. The distinction of time horizons is arbitrary and determined by plausible future changes as well as the project’s duration (Taneja 2013).

In the present study, a planning time horizon is defined as the farthest time that uncertain developments are addressed. The main drivers of uncertain developments related to the stakeholders’ activities and objectives, as identified from the interviews, are examined to distinguish a time horizon. Accordingly, in a short-term horizon, things are likely to stay the same, in a middle-term horizon less so, and in a long-term horizon, there is time for actual transformational change to occur.

6.4.5 Identification of Level of Uncertainties

Walker, Haasnoot, and Kwakkel (2013) and Walker, Rahman, and Cave (2001) pointed out that handling of uncertainties based on their level is an appropriate approach. In this study to address uncertainties, their encountered level was taken into consideration. These levels express the degree or severity of uncertainties. Based on the four levels of uncertainties presented by Walker, Marchau, and Kwakkel (2013), uncertainties were systematically addressed. Van Dorsser et al. (2018) linked the four levels of uncertainties to different disciplines of the future field. In this context, level 1 uncertainty (projected futures) is addressed by deterministic forecasting. Level 2 uncertainty (probable futures) is handled by probabilistic forecasting (Armstrong 2001). Level 3 uncertainty (plausible futures) is considered by (strategic) foresight (Van Dorsser and Taneja 2020). Level 4 uncertainty (possible futures) accounts for (nonfiction) visualization of any possible future (Haasnoot et al. 2013).

In the present study, these methods of addressing uncertainties were applied based on the level of uncertain developments in different time horizons. The levels are recognized by gaining insight during the interviews with the key stakeholders as well as interviews with a group of multidisciplinary experts based on the driving forces of uncertainties. It should be noted that time horizons could meaningfully affect the choice of level of uncertain developments. Therefore, an uncertain development can have different levels over different time horizons. Using this approach avoids unnecessary ambiguity in the literature of dealing with uncertainty (Van Dorsser et al. 2018) in the port planning process.

6.4.6 Identification of Alternatives and Fundamental Assumptions

In the presence of uncertainty, a successful approach for long-term horizon planning considers a large range of solutions (generating alternatives) (Walker, Haasnoot, and Kwakkel 2013). In response to the uncertain developments, several alternatives were developed over different time horizons, and consequently, their fundamental assumptions were explored.

Dewar (2002) identified fundamental assumptions as explicit and implicit assumptions that are made in the planning process. If a fundamental assumption is in favor of the plan, it is an opportunity, and if it causes the plan to fail it is a vulnerability. Opportunities can help a plan to move toward its success, while vulnerabilities may hamper achieving success (Haasnoot et al. 2013).

To identify the opportunities and vulnerabilities, a port SWOT analysis was carried out. SWOT analysis is a straightforward method to recognize the capability and inability of a system. SWOT analysis has commonly been used in the literature, including evaluation of container development strategies in port (Lu, Lin, and Lee 2010), port logistics strategies (Kim et al. 2020), decision making in port development (Van Dorsser and Taneja 2020), and strategic port planning (Zauner 2008). The qualitative nature of SWOT analysis helps to categorize the port characteristics. Taking the strengths and weaknesses of the port into consideration, the fundamental assumptions are translated into opportunities and vulnerabilities. Strengths and weaknesses are recognized as internal factors of the port, whereas opportunities and threats (or vulnerabilities) can be from external environments (e.g., uncertainties). Strengths and weaknesses are factors relevant to the present situation. However, opportunities and vulnerabilities can be plausible in the future.

In this study, the port SWOT analysis was first developed by desk research and literature review and further improved by a group of experts with knowledge about port planning and development. To benefits from different perspectives and knowledge, the interviewed stakeholders were asked to enrich the SWOT analysis. Newly added suggestions on port SWOT analysis were examined by a group of experts again to remove redundant suggestions, consolidate similar ones, and check whether the suggestions had been correctly added to the SWOT categories. Thus, the identification of fundamental assumptions could be taken as the result of a more reliable SWOT analysis.

6.4.7 Handling of Opportunities and Vulnerabilities

To handle opportunities and vulnerabilities derived from uncertainties, effective actions are planned. The actions either seize opportunities or manage vulnerabilities to protect the plan against failures and move the plan toward success (Lempert 2019). Taneja (2013) distinguished efficacious actions to deal with opportunities and vulnerabilities. The actions, which are in line with the actions introduced by Dewar (2002) and Kwakkel, Walker, and Marchau (2010b), are mitigating, hedging, shaping, and seizing actions. Mitigating actions are in response to the fairly certain vulnerabilities and reduce their potential adverse effects. Hedging actions spread and reduce highly uncertain adverse effects of vulnerabilities. Shaping actions affect certain and uncertain vulnerabilities to change their nature, prevent their development, and direct them toward a preferred plan. Finally, seizing actions take advantage of fairly certain opportunities.

Planning of these actions is not necessarily linear for an uncertain development and different actions can be examined in various time horizons in response to fundamental assumptions, including opportunities and vulnerabilities. These actions prepare the plan for adaptation against uncertainties in the projected lifetime.

6.5 Case Study

In this section, the framework for dealing with uncertainties in the port planning process is demonstrated for the Ports of Isafjordur Network in Iceland. The application of the framework for the case study not only illustrates the potential use of the framework in practice but also gives an opportunity to transparently explore the capability of the framework in dealing with uncertainty.

The Ports of Isafjordur Network is the third busiest port of call for cruise ships in Iceland with a considerable increase in the number of cruise calls in the last few years (Isafjordur Port Authority 2020). Fishing and aquaculture activities are the mainstay of the port network. These activities are thriving in the region, and therefore increase the volume of loading and unloading of cargos and containers in the network. However, infrastructure restrictions have limited the port throughput. The inability to meet demand threatens the competitive position of the port network in the region. To satisfy the demand of port users, the Port Authority has decided to develop the port network. Nevertheless, dealing with uncertainties surrounding port development imposes challenges in the planning process. The port sectors are in the state of radical changes, and uncertainty is the biggest challenge confronting port projects (Taneja et al. 2012). For instance, at the time of writing this dissertation, the current crisis of the COVID-19 pandemic has extremely impacted port activities and dropped cruise ship calls to zero in 2020. In addition, an avalanche that was confined to the Port of Flateyri in the network under study and caused major damage to boats and port facilities implied the importance of dealing with uncertain and unpredictable future.

The Port Authority has expressed its decision to develop adaptive planning of the port network to meet demands of today and in the future. This requires dealing with uncertainties in the projected lifetime of the port network. The purposed framework addresses this concern. If the framework had been used by the Port Authority to implement adaptive port planning, then the effects of the COVID-19 pandemic or the avalanche on the port network in this study could have been reduced.

6.5.1 Identification of Port Functions

The Ports of Isafjordur Network is located in the northwest of Iceland. The port network plays a significant role in the logistic chain of the region as well as the country. The port network is well connected to the hinterland by coastal shipping and road transportation modes. It has a strategic location with short sailing times to the open sea. The spatial distribution of the ports gives a dominant and competitive position to the port network in the region. Figure 6.2 depicts the Ports of Isafjordur Network.

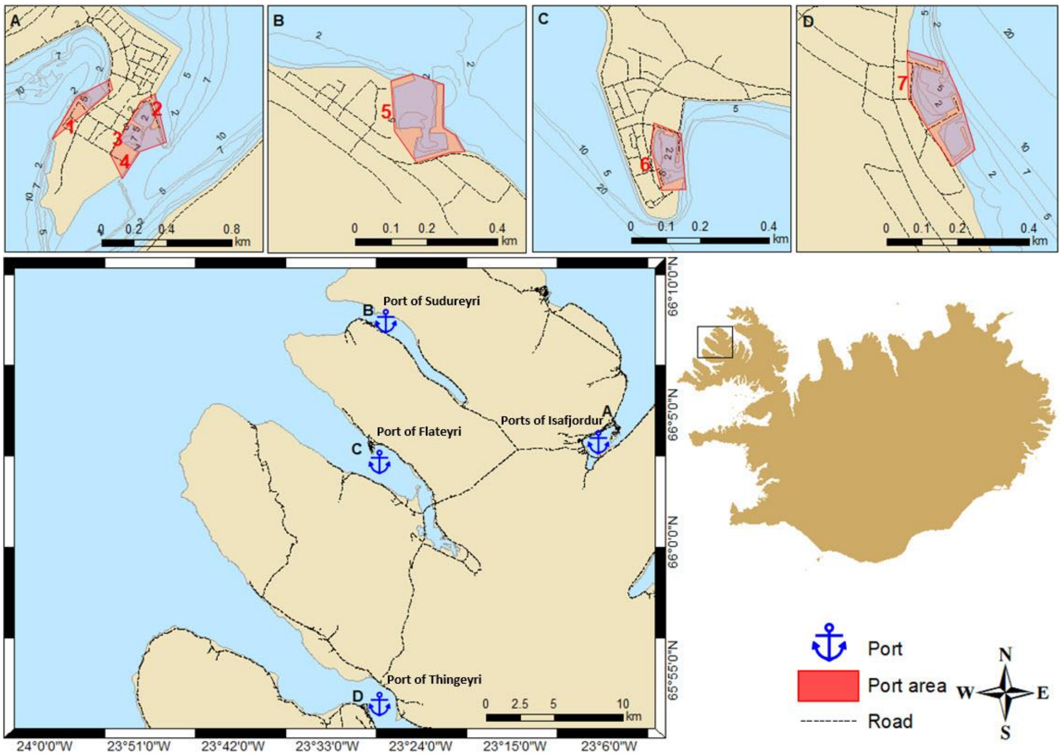

Figure 6.2 The location of the Ports of Isafjordur Network. The study area is shown on the map of Iceland. A, B, C, and D stand for the Ports of Isafjordur, Sudureyri, Flateyri, and Thingeyri, respectively. The numbers indicate the commonly used quays.

The main functions and activities of the Ports of Isafjordur Network are described Appendix E.

The fishing and aquaculture-related industries provide the greatest contribution to the cargo flow in the port network. The port network regularly services fishing vessels. The marine catch is either transported to the fishing industries in the country or shipped to the (mostly) European market. Most of the marine catch is transported by truck to the industries in the region/country for further processing and then exported to the international market. In 2019, about 28,460 tonnes of the marine catch were unloaded in the port network and then distributed to the industries and market (Icelandic Directorate of Fisheries 2021). There is no industrial cluster inside the port network. The port network is a major contributor to the economy of the municipality. In 2019, about half of the revenue (GDP) of the municipality came directly from port revenue (Isafjordur Port Authority 2020).

The Port of Isafjordur is the biggest port and the hub of the network. In the summer of 2019 from May to September the port serviced 131 cruise ships (about 100,000 passengers). In 2018, the fourth-largest cruise ship in the world, the MSC Meraviglia, called at the port three times (Isafjordur Port Authority 2020). In the same year, the port network had the highest proportion of its revenue from cruise ships and accounted for 46% of the port network's revenue. This income is also important for the Port Association of North Iceland (Hafnasamlag Nordurlands) since it amounts to 34% of the Association's income (Port Association of Iceland 2019).

The Port of Isafjordur is supported with infrastructure, operational facilities, and a variety of services to handle domestic and international container, dry and liquid bulk and general/multipurpose cargo vessels. The port is the premier container port in the region and the distribution center for the network. The port offers 24-hour unloading, repair of small vessels and ships, customs, expert servicing of the fishing fleet, and accommodates different vessel types, including recreational and sailing boats. This port has a competitive advantage due to economies of scale in the region. The other three ports (Sudureyri, Flateyri, and Thingeyri) mainly render services to fishing boats and occasionally to smaller cruise ships, recreational boats, and cargo vessels. These ports accommodate national and international sailing boats and yachts.

6.5.2 Stakeholder Analysis

Eskafi et al. (2019a) conducted a stakeholder analysis for port planning in Iceland. They identified a broad range of port stakeholders and concluded that internal, external, and legislation and public policy stakeholder groups are the key stakeholder groups that should be engaged throughout the planning process. Thus, in this study, separate interviews were held with representatives of these three groups to deliberate uncertainties associated with each stakeholder's activities and objectives (Eskafi et al. 2020b) as well as their corresponding level of uncertainties in the planning horizons.

In a bid to reduce possible bias and cover a wider range of information that could be accounted for in the analysis, five representatives from the external stakeholder group were interviewed based on the activities in the port network, including 1- fishing, 2- aquaculture, 3- cargo handling and transportation, 4- expedition and cruise, and 5- the Port Association of Iceland. The representatives of the internal, and the legislation and public policy stakeholder groups were the Port Authority, and the Icelandic Road and Coastal Administration, respectively. In total, seven stakeholder representatives from the three key stakeholder groups were interviewed to ensure consideration of views from different perspectives.

Eskafi et al. (2020b) defined the success of planning of the Ports of Isafjordur Network by prioritizing an increase in competitiveness among other planning objectives, such as effective and efficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, better environmental implications, flexibility creation, and increasing positive economic and social impacts. To achieve success, the outcome of planning under uncertainty should fulfill these objectives in the projected lifetime.

6.5.3 Identification of Uncertainties and Their Developments

The outcome of interviews with the key stakeholders and literature review shows that the development of the port network is confronted by diverse uncertain developments that present a variety of opportunities and vulnerabilities. The results indicate that fishing and aquaculture, as well as expedition and cruise activities, create the main uncertainties. The relevant market sectors, including operation and services, have a high potential for growth and earnings.

Fishing and aquaculture activities are growing quickly, with rapid changes to win national and international markets. Export of farmed and wild, frozen and fresh, and processed and unprocessed fish are expected to be the most sustainable business and cargo in the future.

Containers will continue to be attractive and promising to transport cargo. Vessel size is being increased to utilize economies of scale. Larger vessels demand better handling performance and container handling management. This development affects container throughput and consequently port capacity planning and management.

Another fast-growing segment is the expedition and cruise market. Expedition and cruise vessel calls are expected to increase, not only in the summer season but also during the winter. The increase in expedition and cruise vessel calls will grow coastal excursions and tourism activities.

6.5.4 Identification of the Planning Time Horizons

Five years (2020-2025) and 25 years (2025-2050) were considered as the short- and middle-term horizons, respectively. A 5-year period was chosen as the short-term horizon because the Port Authority wants to develop the Port of Isafjordur in the next five years to meet the expected rapid and changing demands of fishing, aquaculture, and cruise activities. Also, this time horizon covers the Icelandic Road and Coastal Administration's policy from 2020 to 2025 (Icelandic Road and Coastal Administration 2019). This time horizon is treated as a low- to medium-uncertainty planning problem, where the management objective is clear, but alternatives may need to be examined to benefit from opportunities and manage vulnerabilities. Furthermore, this five-year time horizon is in line with the short-term horizon indicated in the literature (Inayatullah 1996; De Jouvenel 1967; Masini 1993; Slaughter 1996).

The ports users, including fishing, aquaculture, and transportation companies, are developing their commerce, for instance processing and packing of marine products, in the port network. A 25-year middle-term horizon would capture their development projects and activities. This demarcation of the middle-term horizon up to 2050 is in line with the result of Van Dorsser, Taneja, and Vellinga (2018) that concluded that the next 30 years are expected to be dominated by innovation and new development. A 25-year time horizon fulfills the middle-term horizon cited in the literature (Masini 1993; Slaughter 1996).

Although a long-term horizon was not taken into consideration (for the planning horizon of the Port Authority), this study was structured in a way that readers can extend their own plan for a long-term horizon.

6.5.5 Identification of Level of Uncertainties

The corresponding level of uncertain development was recognized from the interviews with the key stakeholders as well as a group of multidisciplinary experts. The level of uncertain development expresses the degree of knowledge and information about the development of uncertainty. The results showed that in most cases the levels of identified uncertain developments increase over time.

The uncertain developments around the industrial value-added activities including marine production and renewable energy usage are faced with multiple driving forces. In the short-term these uncertain developments can adequately be described and thus have level 1 uncertainty. The materialization of these developments can reasonably be explained by expert judgment. However, in the middle-term horizon, the size and probability of these uncertain developments cannot be estimated as they are faced with multiple influencing (political, societal, environmental, and financial) factors. In the middle-term horizon, these developments become less certain and less detailed. Therefore, these uncertain developments have level 3 uncertainty in the middle-term horizon. At this level of uncertainty, the actual probability of these developments cannot be measured, and foresight should be used to cover a range of plausible futures.

The uncertain developments around the cargo flow and relevant activities can be projected in the short-term horizon of the plan. This is because containerization has become a preferred form of transport and most of the cargo flow in the port network is containerized. The ongoing containerization is driving non-containerized flow down and reduces the port's non-containerized throughput. These uncertain developments can have level 1 uncertainty. Thus, a reliable forecast can meaningfully provide the future state of the cargo flow and relevant activities in the port network. However, in the middle-term horizon, the level of uncertain developments around the cargo flow increases as there is less information about the flow. These uncertain developments therefore have level 2 uncertainty. To provide insight into the possible future cargo flow, a probabilistic forecast can be used.

Expedition and cruise vessel calls to the port network have been increasing during the last two decades. Although an increase in expedition and cruise markets reasonably used to be clear in the short-term horizon, cruise operators have been announcing plans to defer or cancel their schedules due to the COVID-19 pandemic. These uncertain developments have level 2 uncertainty as there is a probability of the resumption of cruise calls under certain conditions and monitoring protocols, for instance, passengers get a COVID-19 test before departing from the home port and before arrival to the port of call in Iceland, or certain days of quarantine for passengers in Iceland. At this level of uncertainty, the probabilistic forecast can be used. However, this market is expected to remain growing during the middle-term horizon of the plan. Thus, the uncertain developments around servicing expedition and cruise vessels as well as leisure boats and water sport activities have level 1 uncertainty. To provide insight into these uncertain developments, expert judgment and reliable forecasts can be conducted, accompanied by a sensitivity analysis that indicates the sensitivity of the developments to changes by their drivers.

6.5.6 Identification of Alternatives and Fundamental Assumptions

To respond to the uncertain developments, different alternatives were generated in the context of planning objectives in the short- and middle-term horizons. To identify fundamental assumptions from the alternative a port SWOT analysis was conducted. Based on the results of the SWOT analysis, in conjunction with the uncertain developments, opportunities and vulnerabilities (the fundamental assumptions) were recognized. Appendix F gives a summary of the SWOT results for the Ports of Isafjordur Network.

Based on the result of the SWOT analysis, the competitive environment can be explained around the functions of the port network. The port network is continuously striving to increase the captive market and market share in the same hinterland that other Icelandic ports serve. A larger captive market for the port network stimulates shipping companies for more frequent services and uses larger ships to benefit from economies of scale. The Port Authority has been investing in port infrastructure and services to meet the demand for fast turnaround time and economies of scale, and consequently attracts more container/cargo flow. The port development decreases the attractiveness of (smaller) ports in the region as they do not have the competitive infrastructure and enough container/cargo volumes to attract the shipping companies to provide regular services. Therefore, the container/cargo can be trucked from these ports to the Port of Isafjordur and distributed to the destination. Furthermore, the port network has a locational advantage in the country as it is close to a rich fishing ground in the North Atlantic Ocean. Thus, the network, including the four ports, competes with other ports in the region for servicing more regional and national companies to increase the market share and benefit from the increase in container/cargo flow. The opening of the new tunnel (Dyrafjardargong) in the south of the region has influenced the development of market share by road transport, especially for marine products as they are time-sensitive cargos. Furthermore, the port network competes for value-added activities due to its proximity to the major local markets and the progressive changes in aquaculture in the region. Development of value-added clusters (e.g., aquaculture and relevant productions, manufacturing, and warehousing) increases the volume of cargo flow (and storage) and further attracts shipping companies (De Langen 2004). The port network also competes for an increasing number of cruise ship visits. The network has been capitalizing on the factors that contribute to its competitive advantage in order to attract more cruise lines. The port network has been upgrading to accommodate cruise ships and handle the significant strain that they place on port facilities and services due to their short turnaround time and services to a large number of passengers.

The results of the SWOT analysis indicate that uncertain developments present a wide range of opportunities and vulnerabilities. In the short-term horizon, the uncertain developments lead to many opportunities. This is because the port network has a competitive position in the region. The port network, particularly the Port of Isafjordur, is supported with sufficient infrastructure, services, and operational facilities to satisfy the demands of port users. In the short-term horizon, a variety of cargos including liquid and dry bulk, and general cargo as well as containers can be handled and stored in the port network. Also, the port network is able to service different types of cargo/container vessel with different sizes. There are enough capacity and land in the port network for ongoing marine production activities, such as processing and packing, in the short-term. Despite servicing a significant number of expedition and cruise ships in the short period of the summer season, the port network (by using the four ports) can still satisfy the demands of this market in the short term.

However, in the middle-term horizon, the port network is confronted with a multiplicity of vulnerabilities derived from uncertainties. These vulnerabilities are mainly due to a lack of infrastructure and land in the port network for satisfying the demands of the increasing number of port users. In the middle-term horizon, the infrastructure of the ports in the network should be developed to meet the needs of the fast-growing business, including fishing and aquaculture and relevant activities. Furthermore, the rapid increase in the number of expedition and cruise ships raises the concern about safe disembarkment and embarkment and providing services to the passengers in the port network. In the middle-term horizon, the port network benefits from the increasing number of port users. However, this increase may lead to a conflict between port users due to the limited capacity and resources, for instance, infrastructure, availability of land, and operational facilities in the port network. This will threaten the competitive position of the port network.

On the other hand, some uncertain developments, for instance, the utilization of renewable energy in the port network, impose new challenges. Appendix G gives the identified alternatives in response to the uncertain developments and the consequent opportunities and vulnerabilities.

6.5.7 Handling of Opportunities and Vulnerabilities

To handle the fundamental assumptions including opportunities and vulnerabilities, effective actions were applied. Thus, the Port Authority can deal with uncertainties by seizing actions to benefit from the opportunities presented from the uncertain developments. On the other hand, shaping, mitigating, and hedging actions can be used to manage vulnerabilities to protect the plan against the downside of any uncertain developments. The implementation of these actions ensures achieving the success of the plan in the projected lifetime.

As the port network has a competitive position in the region, in the short-term horizon the Port Authority can seize opportunities including the increase in storage and flow of cargos and containers, as well as the number of vessel calls. Also, seizing actions can be taken to attract the expedition and cruise markets in the short-term horizon.

In the middle-term horizon, in response to the vulnerabilities derived from the volume of container/cargo flow, the size of vessels, and the number of vessel calls as well as relevant technological developments, shaping and hedging actions can be used. These actions include investment and improvement of infrastructure in the port network to manage the vulnerabilities. Shaping and hedging actions can be taken to strategically improve the smaller ports in the network and satisfy the needs of the cargo sector at these ports.

Shaping actions can be used to handle vulnerabilities derived from uncertainties around marine productions and accommodate fishing and aquaculture industries in the Port of Isafjordur. These actions can include services to the boats that pump live fish to the slaughter/processing factories in the port area, and cross-docking facilities next to the quay for the fish landing and handling container terminals, developing fish terminals and refrigerated storage or warehousing, and providing space for repair and maintenance of the fish cages and other equipment.

The vulnerabilities around the uncertain developments of the expedition and cruise market can be managed by hedging and shaping actions including maximizing the use of the smaller port in the network and strategically improving the ports' infrastructure in the network.

The reduction in landside accessibility and deterioration of port-city relations can be handled by mitigating and shaping actions. These actions can include improving the living environment and stimulating economic and recreational activities in the port network and surrounding towns.

These actions are elaborated in Appendix G. Table G.1 in Appendix G supports the Port Authority for choosing a preferred course of action to deal with uncertainties that emerge in the projected lifetime of the port network. Moreover, these actions can facilitate the implementation of adaptive port planning.

6.6 Discussion

This study has presented a structured framework to deal with uncertainties including opportunities and vulnerabilities in the port planning process. A course of action is planned to seize opportunities and manage vulnerabilities. The value of this framework lies in the nonlinearity of dealing with uncertainties in different time horizons. The framework supports decision makers and port managers for informed decision making under uncertainty in the port planning process.

The application of the framework meaningfully ensures identification of uncertainties that may appear during the projected lifetime of the plan and deals with them in the planning process. However, this carefully addressing uncertainties in port planning, which is the contribution of this framework, is rarely addressed in the existing literature and therefore overlooking uncertainties in planning processes might result. The framework was applied to a case study and effectively identified and dealt with uncertainties during the projected lifetime of the plan. The results showed that the Ports of Isafjordur Network is confronted with many uncertainties, including new demands in terms of functions, scales, and changing expectations.

Fishing and aquaculture stakeholders have high salience (Eskafi et al. 2019a) and their demands should be satisfied by in-time development of the port network. These activities demand the availability of area next to the quay and closely connected to the freight distribution area for the rapid export of marine products to the market (PIANC 1998).

To foster the growth of containerized cargo, an investment in handling and storage of containers is required. The Port of Isafjordur in the network can be used as a hub port to supply the demand for growing businesses in the region. For the smaller ports in the network, the scale is insufficient to make operations commercially viable. Building terminals for these ports is not feasible in the projected lifetime, as they may have a limited volume of container/cargo flow. These ports can be kept as service ports to the community and to provide connectivity in the port network.

Servicing the relatively small expedition and cruise vessels can be decentralized from the Port of Isafjordur to the smaller ports in the network. The Port Authority should maximize the use of these ports in the network. The optimal distribution and decentralization of cruise vessels can decrease the vessel traffic congestion in the Port of Isafjordur. A decrease in vessel traffic congestion would improve the efficiency of the port network (Bellsolà Olba et al. 2017). This requires new infrastructure and hinterland connections.

Building a cruise terminal in the Port of Isafjordur is necessary for safe (dis-)embarkment of passengers. The terminal should be well connected to the town and without conflict with other activities in the port area. To create synergy between related activities in the limited port area and the benefits accrued to them, the port cluster should be developed. The port cluster enhances the competitiveness of the port network (Lam, Ng, and Fu 2013). The clustering of relevant activities alleviates the risk of conflict associated with irrelevant activities in the port area. It facilitates a joint business plan and vertical consolidation and cooperation of companies, for instance, the export of marine products. This would increase value-added activities and thus improve the performance of the port network (De Langen 2002). However, the Port Authority should use the resource proportionally among the port stakeholders due to uncertain demand in the volatile market environment and the changing salience of the stakeholders.

Although the use of fossil fuels and energy efficiency can be optimized by clustering relevant activities (Alzahrani, Petri, and Rezgui 2020), renewable energy facilities should be developed to meet the escalating demand of industries on renewable energy. Furthermore, environmental and climate change concerns should be addressed by stringent contractual requirements with port users.

For future port expansion and (operational) growth, the plan should cope with the limited land in the port network, insufficient landside accessibility, hinterland connections, and consequently, increased interactions between the port network and surrounding towns. This is in line with the literature, as increasing the effective and efficient use of land in the port network was demanded by port stakeholders (Eskafi et al. 2020b). The port expansion should be in harmony with the surrounding towns and natural environment to maintain social license to operate and grow (PIANC 2014).

Still, the Port Authority operates under the tool port management model which limits the capability of the Port Authority to satisfy the demand of fast-growing industries. This would coerce the Port Authority to apply the landlord management model to support industries at the preliminary level. Operating under the landlord management model facilitates proactive planning and in-time development by the Port Authority (Notteboom and Rodrigue 2005). This retains the competitive position of the port network (defined as the success of the plan) in the changing market environment. Operating under the landlord management model requires governmental support.

Unknown unknowns (Walker, Lempert, and Kwakkel 2013) as well as black-swan/wild-card events (e.g., natural disasters, viral pandemics, and wars) (Smil 2012) have level 4 uncertainty and can be handled through contingency plans if they emerge in the projected lifetime of the port network (Taneja 2013). Epistemic uncertainties could be reduced by wider engagement of stakeholders based on the functions of the port network and the port activities. However, the salience of stakeholder changes temporally and spatially, which requires stakeholder analysis for their effective and timely engagement (Eskafi et al. 2019a). On the other hand, conducting (several) interviews with many stakeholders is laborious and time consuming or may lead to stakeholder fatigue.

6.7 Conclusions

Uncertainties are part and parcel of the continually volatile world we live in and will continue to be so. Addressing uncertainties is an important task to improve the quality of long-term port planning in this volatile environment.

This study presents a structured framework that benefits from different scientific methods to deal with uncertainties in the port planning process. Key stakeholders were identified and engaged to define the success of the port planning. Uncertainties around stakeholders' activities and objectives were identified by conducting interviews with the key stakeholders. Development of uncertainties as well as their level were determined and then systematically addressed in short- and middle-term planning horizons. A port SWOT analysis was carried out to recognize the opportunities and vulnerabilities derived from uncertainties. To handle opportunities and vulnerabilities, effective actions were planned.

The theoretical contribution of this study is to meaningfully identify uncertainties that manifest during the projected lifetime of the plan and deal with them in the port planning process. Thus, the inevitable changes become part of a recognized process and the plan is not forced to be remade repeatedly on an ad hoc basis. The nonlinearity of dealing with uncertainties by the framework provides a robust and better plan toward its success across a variety of futures. The managerial contribution of this study enables decision makers to choose a preferred course of action and strategically implement the plan in the face of uncertainty. The outcome of the framework facilitates adaptive port planning.

The framework was effectively applied to a case study to develop a plan to consolidate the port's competitive position under volatile and changing circumstances. The main results indicate that fishing, aquaculture, expedition, and cruise activities create the main uncertainties for the Ports of Isafjordur Network. The growth of these activities increases conflict in the port network. Port clusters should be developed to reduce conflict between port users and improve value-added activities in the port areas.

The Port Authority, under the landlord management model, should be proactive and dynamic (instead of reactive and static) in planning and, in-time development used to satisfy fast-growing demands. The port network, therefore, will be functional and prepared to service market-oriented and competition-driven activities in the volatile environment.

Acknowledgments

The time and expertise contributed by the stakeholders in the interviews are gratefully acknowledged. This research was supported in part by the Doctoral Grants of the University of Iceland Research Fund (Rannsoknarsjodur Haskola Islands), the Municipality of Isafjordur (Isafjardarbaejar), and the Icelandic Road and Coastal Administration Research Fund (Rannsoknarsjodur Vegagerdarinnar).

7 Conclusions

Ports are dynamic and complex engineering systems. They have always been evolving to satisfy the new or changing demands of stakeholders. The ever-growing complexity of a port system in a volatile environment creates a high degree of uncertainty in the port planning process. The capital and fixed investments for port infrastructure development with a long technical lifetime call for an effective approach to deal with uncertainties in the planning process. The plan should account for uncertainties (i.e., opportunities and vulnerabilities) that appear during the projected lifetime to protect the plan against failure and move it toward its success. Therefore, in this dissertation, a structured framework was presented to facilitate the identification of uncertainties during the projected lifetime of the plan and deal with them in the planning process. The framework provides supports for informed decision making under uncertainty in port planning. Several scientific methods were used to develop the framework.

These methods are applied to the Ports of Isafjordur Network in Iceland as a case, to demonstrate the potential use of the methods in practice and to explore the capability of the framework in dealing with uncertainty. The methods can be readily used in other ports to meet their practical needs and effectively deal with uncertainties in the planning process.

Stakeholder analysis enhances decision making by rational prioritization of stakeholders and their timely and effective engagement during the port planning process. A structured framework was presented by synthesizing qualitative and quantitative methods to measure the salience of stakeholders in the port planning. A survey and face-to-face interviews were conducted as tools to collect input for the stakeholder analysis based on their port planning objectives. The fuzzy logic 3-dimensional decision surface was used for dynamic salience mapping of the stakeholders. The framework provided an analysis of stakeholders by monitoring their salience with respect to the level of their power and interest. The decision surface disclosed the high salience of the internal stakeholder group. The legislation and public policy stakeholder group had high power and interest in the port planning. The position of the external stakeholder group at a steep slope in the modeled decision surface indicated the influence and critical role of this group in the planning process.

Numerous stakeholders with a wide range of objectives interact with a port system. To reach a consensus among stakeholders on a definition of success in the planning process an integrated qualitative and quantitative approach was conducted. The approach combined stakeholder analysis, the value-focused thinking method, and the fuzzy multi-attribute group decision-making method. Eight means objectives of port planning were identified including increasing competitiveness, increasing effective and efficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, creating flexibility, better environmental implications, and increasing positive economic and social impacts. The highest level of agreement on the definition of success among the stakeholders was identified as prioritizing increasing competitiveness among other means objectives.

Port throughput analysis facilitates the selection of promising markets and characterizes the strategy and direction of port planning projects. However, port throughput analysis is a complex task, as it is interwoven with a variety of cargos handled in the port, which are influenced by numerous factors. Mutual information analysis was used to identify prominent cargos that considerably contribute to the port throughput and investigate the relation between port throughput and macroeconomic variables. Therefore, the application of mutual information reduced epistemic uncertainty in port throughput analysis. The analysis revealed that selection of influencing macroeconomic variables for port throughput forecast models only based on expert judgment and literature review can be insufficient. The results showed that marine product cargo is the main non-containerized export, whereas the non-containerized import is mainly constituted by fuel oil, industrial materials, and marine products. The aggregation of these cargos handled in the port would make up the non-containerized port throughput. The non-containerized port throughput showed relatively high correlations with the national GDP. The results unveiled that the relation between containerized port throughput and the volume of national export trade is stronger than for the relation between other macroeconomic variables.

Port throughput forecasts provide valuable and fundamental input to capacity planning and management. However, epistemic uncertainty associated with parameter uncertainties and model uncertainties impose challenges in port throughput forecasting models. Therefore, forecasting models should account for epistemic uncertainty to meaningfully increased the reliability of results. The mutual information method was used to reduce parameter uncertainties and objectively select input macroeconomic variables in the forecasting model. A Bayesian statistical method was used to account for model uncertainties. The presented model offered a range of port throughput forecasts with confidence intervals that provide useful information for developing flexibility in capacity planning to satisfy changing and uncertain demands. The results showed a growth of containerized throughput and a decline and stabilization in non-containerized throughput over the forecasting period.

Dealing with uncertainty is a crucial task in the port planning process. Uncertainty should (nonlinearly) be addressed in the projected lifetime of the plan with different disciplines of the future field. Then, the plan strategically can be implemented in the face of uncertainty. Based on the functions of the port, interviews with the key stakeholders were conducted to identify uncertainties around their activities and objectives. Development of uncertainties as well as their level were determined and then systematically addressed in different planning horizons. A port SWOT analysis was carried out to recognize the opportunities and vulnerabilities derived from uncertainties. To handle opportunities and vulnerabilities, effective actions were planned to seize opportunities and manage vulnerabilities and thus protect the plan against failures and move the plan toward its success. The main results indicated that fishing, aquaculture, expedition, and cruise activities create the main uncertainties for the Ports of Isafjordur Network. Uncertainties mainly present opportunities in the short-time horizon, while in the middle-time horizon the port network is confronted with multiple vulnerabilities. As these are the main activities in the port network, emphasis should be given to in-time development and providing services to satisfy their new and changing demands. The growth of these activities increases conflict in the port network. Port clusters should be developed to reduce conflict between port users and improve value-added activities in the port area. Value-added activities related to fishing and aquaculture should be planned next to the quay and connected to the freight distribution areas. Servicing relatively small expedition and cruise vessels can be decentralized in the network by the maximum use of smaller ports.

8 Future Research

This work presented a structured framework that facilitates the identification of uncertainties during the projected lifetime of the plan and deals with them in the planning process. The framework was effectively applied to the Ports of Isafjordur Network as a case. However, the port in question is considered a relatively small port (network) with limited functions and port activities. The application of the framework in the planning of large greenfield or brownfield ports can be challenging and may require further development of the framework to effectively deal with national and international uncertainties. The framework was based on the functions of the port and interviews with the key stakeholders to identify uncertainties around their activities and objectives. However, a port system is surrounded by many other (new or changing) uncertainties during a projected lifetime. This requires a knowledge of the various sources of uncertainty in the port planning process. Upgrading the framework to identify these uncertainties and strategically deal with them in the port planning process is recommended for future research. Another recommendation for future scientific research is to quantitatively evaluate the severity and likelihood of uncertainties that manifest in the projected lifetime of the plan, as the qualitative evaluation of uncertainties might be subjective and include bias.

The outcome of the framework addressed steps one, two, and three of the adaptive port planning for the Ports of Isafjordur Network. Implementation of steps four, five, and six of adaptive port planning (Taneja 2013) are recommended for future research aimed at developing a flexible port network. Therefore, in step four, (flexible and sustainable) options are to be identified and incorporated in each alternative. The alternatives should be evaluated and then compared with each other based on pre-defined flexibility and sustainability criteria. The cost and value of flexibility and sustainability (societal, environmental, and economic impacts) during a port's long-projected lifetime should be assessed using a suitable (mixed quantitative and qualitative) evaluation method such as Multi-Criteria Analysis (MCA). As the future is inherently uncertain, it is necessary to account for uncertain factors when evaluating the merits of port projects. Therefore, the results provide support for balanced and informed decision making for long-term investment. Even if a flexible port is developed to be adaptive to changes, still the performance of the port should be monitored and required actions taken if the plan starts failing. In step five, a monitoring system consists of signposts and triggers should be developed. The success of a port plan in a volatile environment, where demands are uncertain and changing, significantly depends on the continued vigilance and monitoring of the internal and external environment (Taneja 2013). Signposts specify the information that should be tracked to determine whether the plan is moving toward its success. A trigger is a timely and critical value of a signpost beyond which required actions (as a part of contingency plans) should be implemented to ensure achieving success of the plan. In step six, to protect the main plan against failing or departures from the pre-defined path toward its success, and to handle unknown unknowns (opportunities and vulnerabilities) (Walker, Lempert, and Kwakkel 2013) and black-swan events (Smil 2012) that manifest in the projected lifetime, contingency plans are to be developed (Chapman and Ward, 2003). The contingency plans, which are provisions/alternatives to the main plan, should consist of timely and effective actions to make the main plan robust. These actions are applied if the signposts are triggered. Adaptive plan ensures flexibility of the port. A flexible port can be altered or employed differently, cost-effectively, to be functional under new, different, or changing demand during its projected lifetime.

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Appendix A

Table A.1 List of port stakeholders for the Ports of Isafjordur Network planning

Stakeholder group				
Internal	External	Legislation and public policy	Academic	Community
1. Port Authority 1.1. Harbor committee 1.2. Port director 1.3. Employees 2. Municipality 2.1. Town Council 2.2. Customs 2.3. Planning and building office 2.4. Infrastructure, environment and asset management office 2.5. Environmental office 2.6. Fire brigade 2.7. Water suppliers/ utilities	1. Associations and NGOs 1.1. The association of industries 1.2. The Federation of Icelandic industries 1.3. The Association of Fisheries Companies 1.4. The Icelandic Association for Search and Rescue 1.5. The agricultural association of fisheries 1.6. The port association of Iceland 1.7. The Icelandic Regional Development Institute	1. The Environment Agency of Iceland 2. Consumer agency 3. The Icelandic Directorate of Fisheries 4. The Directorate of Internal Revenue 5. The National Energy Authority 6. The Icelandic Transport Authority 6.1. Maritime security 6.2. Port installations and maritime navigation 7. The Icelandic Coast Guard 8. The Icelandic Road and Coastal Administration	1. University of Iceland 2. University of Akureyri 3. Delft University of Technology 4. IHE Delft Institute for Water Education 5. University Centre of the West Fjords	1. Small neighboring market/ activities 1.1. Local fish markets 1.2. Local stores 1.3. Local heritage museum 1.4. Kayak center 1.5. Viking ship association 2. Landowners 3. Neighboring residences 4. Ship/boat owners 5. Press/ media

Continued

Table A.1. (Continued) List of port stakeholders for the Ports of Isafjordur Network planning

Stakeholder group				
Internal	External	Legislation and public policy	Academic	Community
	1.8. The Westfjords Development Association	9. National planning agency		6. The Blue bank company
	1.9. The Icelandic Tourist Board	10. Marine and freshwater research institute		7. Local fishermen
	1.10. Cruise Iceland	11. The Westfjords Iceland Nature Research Center		8. Local rescue teams
	2. Airport			
	3. Companies and industries	12. The Westfjords health administration		
	3.1. Shipping lines and shippers: Eimskip, Samskip, Nesskip.	13. The national commissioner of the Icelandic police, the Department of Civil Protection and Emergency Management		
	3.2. Insurance companies			
	3.3. Local government loan	14. Ministries		
	3.4. Marine products companies: Arctic Fish, Hradfrystihusid - Gunnvor, Arnarlax, Jokab Valgeir, Habrun, Klofninguir, West Seafood, Islandssaga, Kampi, Kerecis.	14.1. Ministry for Foreign Affairs 14.2. Ministry of the Environment and Natural Resources 14.3. Ministry of Finance and Economic Affairs		
	Fishing gear companies			
	Net and aquaculture product/ service companies	14.4. Ministry of Industries and Innovation		

Continued

Table A.1. (Continued) List of port stakeholders for the Ports of Isafjordur Network planning

Stakeholder group				
Internal	External	Legislation and public policy	Academic	Community
	3.5. Industries: Building materials, ship building/ repair companies, 3X, Containers service. 3.6. Consultant engineering Companies: Verkis 3.7. Stevedoring companies/ operators 3.8. Energy companies: Orkubu Vestfjarda, Landsnet, Oil companies. 3.9. Cruise agencies: Gara agents, Samskip. 3.10. Tourist agencies: Ferdaskrifstofa Vestfjarda, Fantastic Fjords, West Tours, Fisherman, Borea, Atlantik, Iceland Travel.	14.5. Ministry of Transport and Local Government		

Appendix B

The survey used in this study

Evaluation of stakeholders for the Ports of Isafjordur Network planning

Introduction

This survey is aimed at further research on the Flexible and Adaptive Ports of Isafjordur Network Planning by dynamic evaluation of relevant stakeholder groups, based on their power and interests within identified objectives of the Port Planning. A power-interest matrix as a common stakeholder analysis approach will be created based on the result of the present survey. The power-interest matrix is shown in Figure B.1.

Survey questions should be answered based on your personal knowledge and understanding of the Ports of Isafjordur Network Planning. The answers to the questions are used for the purpose of this university project. Other stakeholders and researchers involved in the project are not able to identify any participant's identity from the answers provided in this survey.

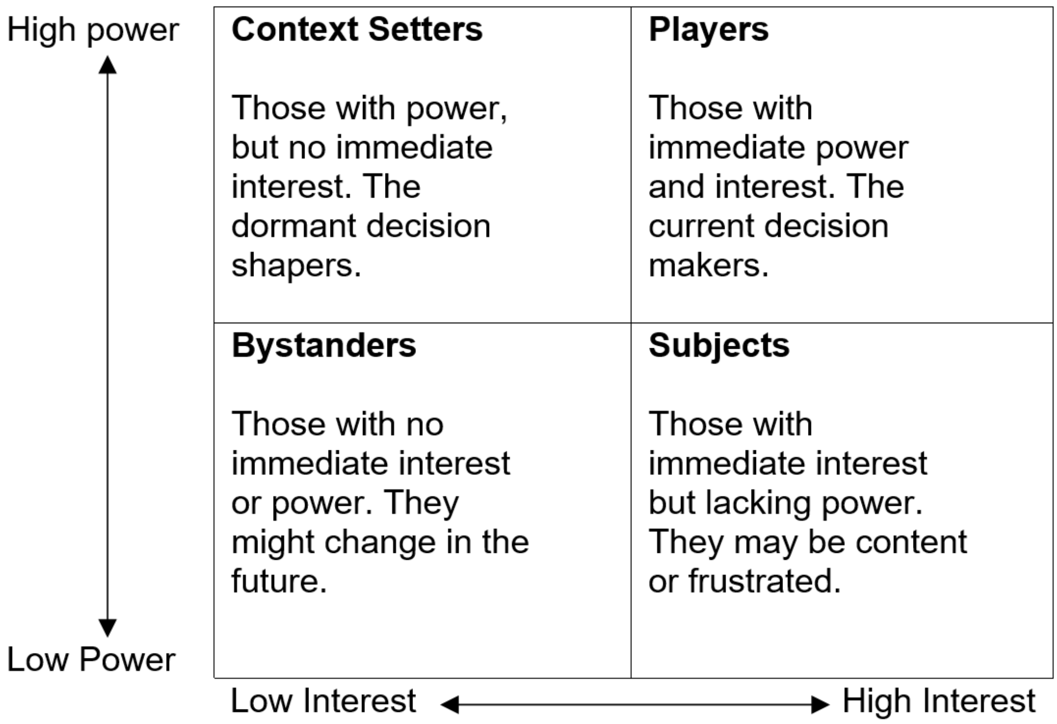

Figure B.1 Stakeholder power-interest matrix (based on Wright and Cairns, 2011)

Definitions

Stakeholder

Stakeholders are defined as “any individual or group of individuals that can influence or are influenced by the achievement of the organization’s objectives” (Freeman 1984). For this analysis, the "objectives" refers to the Ports of Isafjordur Network Planning.

Power

Power is referred to as the ability of stakeholders to exercise influence, which could be political, using coercive, utilitarian, or normative means (Etzioni 1964). Stakeholder power is also defined as “the ability of those who possess the power to bring about the outcomes they desire” (Salancik and Pfeffer 1974).

Interest

Interest refers to the interest and concern of the stakeholder in relation to the problem that the project is seeking to address (Maley 2012). Within this context, stakeholder group interest is referred to how much each stakeholder group is interested or concerned regarding a particular objective of the Ports of Isafjordur Network Planning. Interest also refers to how the Port Planning can either positively or negatively affect a group.

Methodology

Based on the result of this survey, four categories of stakeholders will be identified:

1- Players or key stakeholders who have significant power and interest in the Port Planning,

2- Subjects who have a significant interest in the Port Planning but little power,

3- Context setters who have significant power but low interest or stake in the Port Planning,

4- Bystanders who are stakeholders with low interest and low power in the Port Planning.

Stakeholder group

According to Gul Denktas and Cimen Karatas (2012) and Slinger et al. (2017), the following five main stakeholder groups are identified for the Ports of Isafjordur Network Planning.

Group 1- Internal stakeholders

Parties inside the port authorities’ organizational boundaries such as managers, board members, employees, shareholders, unions.

Group 2- External stakeholders

Two main parties that invest directly and indirectly in the port area. The first group includes terminal operators, stevedore companies, forwarders, shipping agencies, industrial companies in the port area, supporting industries such as ship repairs and port labor pools; the second group consists of port customers, trading companies, importers/exporters.

Group 3- Legislation and public policy stakeholders

Legislative or governmental departments responsible for transport and economic affairs, environmental department and spatial planning authorities.

Group 4- Academic stakeholders

Institute and research centers and universities in order to answer the challenges that occur through research and development of new knowledge.

Group 5- Community stakeholders

Civil society organizations, the general public, the press and the other small market, land and small boat owners, conventional and heritage activities.

Objectives of the port planning

The following eight objectives of the Ports of Isafjordur Network planning are selected based on the result of the interview with stakeholders and literature review. In this survey, you will be asked to evaluate the power and interest of the different stakeholder groups in terms of each of the following objectives. For each objective, three examples are provided as the sub-objectives of the Port Planning based on the result of the interviews.

Objective 1- Competitiveness

- Efficient and responsive operability system;
- Minimum downtime* of the port;
- Reduce service and operating costs.

Objective 2- Financial performance

- Provide financial benefits for customers and have good business prospects;
- Financially autonomous;
- Efficient management of income, cost and investments.

Objective 3- Use of land

- Efficient use of land for port users as well as businesses in the port area;
- Easy access to activities in the port area to the quayside for (un)loading;
- Reduce conflict between activities.

Objective 4- Hinterland connectivity

- Develop and sustain integrated and better connections with the hinterland**;
- Increase regional, national and international sea trade and sea trade connections;
- Expanding competition margins***.

*Downtime is considered when a port is not in operation or is idle, caused by a lack or shortage of infrastructure, facilities, met-ocean factors, etc.

**Hinterland is considered as an area over which a port has the (dominant) market share and is therefore considered as the site of the majority of port-related activities for export and/or import from/to the port.

***The competition margins are considered as areas where two or more ports are in competition. Port users can, therefore, choose either port for their purposes, based on factors such as convenience, costs, capacity, etc.

Objective 5- Economic and social impact

- Assuring remuneration to the society and improving the positive societal impact;
- Contribution to economic development and promote economic growth to support regional, national and international trade;
- Supporting sustainable development.

Objective 6- Environmental implication

- Act consistently and precisely with the public's environmental consideration to wildlife ecosystems, fauna and flora, and global impacts;
- Maximize aesthetics of the port area and minimize the impacts of nuisance in the port and surrounding areas;
- Comply and support environment standards with respect to European directives as well as national policy programs and regulations.

Objective 7- Safety and security

- Comply and support international law, European directives and national policy programs and regulation in terms of safety standards of maritime navigation as well as port operation and installations;
- Minimize detrimental health and safety impacts to the locals and port users in terms of mortality and morbidity (by sidewalk, signs, marks, passage, etc.);
- Increase port security against any possible threat such as vandalism and terrorist attacks.

Objective 8- Flexibility

- Deal with future uncertainties, especially for existing port activities;
- Adaptive to (technological, environmental, social, legislation, etc.) changes;

Part 1- Ranking stakeholder groups based on their power.

Here participants are asked to rank the stakeholder groups from 0 - 3 based on their power to influence the Ports of Isafjordur Network planning in terms of each identified objective.

"What is the stakeholder groups' power to impact the Ports of Isafjordur Network Planning in terms of [each individual objective]?"

Ranking explanations:

- 0: No Power
- 1: Low Power
- 2: Some Power
- 3: High Power

The survey starts here:

Objective 1- Competitiveness

"What is the stakeholder group's power to impact the Port Planning in terms of competitiveness?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 2- Financial performance

"What is the stakeholder group's power to impact the Port Planning in terms of financial performance?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□

	0	1	2	3
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 3- Use of land

"What is the stakeholder group's power to impact the Port planning in terms of the use of land?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 4- Hinterland connectivity

"What is the stakeholder group's power to impact the Port planning in terms of hinterland connectivity?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 5- Economic and social impact

"What is the stakeholder group's power to impact the Port planning in terms of economic and social impact?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 6- Environmental implication

"What is the stakeholder group's power to impact the Port planning in terms of environmental implication?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 7- Safety and security

"What is the stakeholder group's power to impact the Port planning in terms of safety and security?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 8- Flexibility

"What is the stakeholder group's power to impact the Port planning in terms of flexibility?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Part 2- Ranking stakeholder groups based on their interest

This part asks the participants to rank the stakeholder groups from 0 - 3 based on their interest in the Ports of Isafjordur Network planning in terms of each identified objective.

"What is the stakeholder groups' interest or stake in the Ports of Isafjordur Network Planning concerning [each individual objective]?"

Ranking explanations:

- 0: No Interest
- 1: Low Interest
- 2: Some Interest
- 3: High Interest

Objective 1- Competitiveness

"What is the stakeholder group's interest or stake in the Port Planning concerning competitiveness?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	◻	◻	◻	◻
Stakeholder group 2- External stakeholders	◻	◻	◻	◻
Stakeholder group 3- Legislation and public policy stakeholders	◻	◻	◻	◻
Stakeholder group 4- Academic stakeholders	◻	◻	◻	◻
Stakeholder group 5- Community stakeholders	◻	◻	◻	◻

Objective 2- Financial performance

"What is the stakeholder group's interest or stake in the Port Planning concerning financial performance?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	◻	◻	◻	◻
Stakeholder group 2- External stakeholders	◻	◻	◻	◻
Stakeholder group 3- Legislation and public policy stakeholders	◻	◻	◻	◻
Stakeholder group 4- Academic stakeholders	◻	◻	◻	◻
Stakeholder group 5- Community stakeholders	◻	◻	◻	◻

Objective 3- Use of land

"What is the stakeholder group's interest or stake in the Port Planning concerning use of land?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	◻	◻	◻	◻
Stakeholder group 2- External stakeholders	◻	◻	◻	◻

Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 4- Hinterland connectivity

"What is the stakeholder group's interest or stake in the Port Planning concerning hinterland connectivity?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 5- Economic and social impact

"What is the stakeholder group's interest or stake in the Port Planning concerning economic and social impact?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 6- Environmental implication

"What is the stakeholder group's interest or stake in the Port Planning concerning environmental implication?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 7- Safety and security

"What is the stakeholder group's interest or stake in the Port Planning concerning safety and security?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Objective 8- Flexibility

"What is the stakeholder group's interest or stake in the Port Planning concerning flexibility?"

	0	1	2	3
Stakeholder group 1- Internal stakeholders	□	□	□	□
Stakeholder group 2- External stakeholders	□	□	□	□
Stakeholder group 3- Legislation and public policy stakeholders	□	□	□	□
Stakeholder group 4- Academic stakeholders	□	□	□	□
Stakeholder group 5- Community stakeholders	□	□	□	□

Participant name

Appendix C

Table C.1 List of interviewees related to the adaptive port planning of the Ports of Isafjordur Network

No.	Company/Organization	Position	Stakeholder Group
1	Icelandic Transport Authority	Head of Maritime Security	Legislation and public policy
2	Icelandic Transport Authority	Port installations and maritime navigation specialist	Legislation and public policy
3	Icelandic Road and Coastal Administration	Senior coastal engineer	Legislation and public policy
4	Icelandic Coast Guard	Managing Director	Legislation and public policy
5	National Planning Agency	Director of the division of master planning, Expert in master planning	Legislation and public policy
6	Westfjords Health Administration	Health officer	Legislation and public policy
7	Environmental Agency of Iceland	Nature, water and sea specialist, advisor	Legislation and public policy
8	Westfjords Iceland Nature Research Center	Director, Ecologist	Legislation and public policy
9	Marine and Freshwater Research Institute-Isafjordur	Head	Legislation and public policy
10	Municipality of Isafjardarbaer	Former Mayer and chairman of the town council	Internal
11	Municipality of Isafjardarbaer	Port director	Internal
12	Municipality of Isafjardarbaer	Deputy director of environmental and asset management	Internal
13	Municipality of Isafjardarbaer	Environmental specialist	Internal
14	Municipality of Isafjardarbaer	Director of Customs	Internal
15	Municipality of Isafjardarbaer	Planning and building specialist	Internal

Continued

Table C.1 (Continued) List of interviewees related to the adaptive port planning of the Ports of Isafjordur Network

No.	Company/Organization	Position	Stakeholder Group
16	IHE Delft, Institute for Water Education	Instructor and logistics project manager	Academic
17	University of Iceland	Transportation and logistics management	Academic
18	University center of the Westfjords	Director	Academic
19	Icelandic Regional Development Institute	Regional development specialist	External
20	Port Association of Iceland	Chair	External
21	Westfjords Development Association	Managing Director	External
22	Agricultural Association of Fisheries	Manager	External
23	Westfjords Tourist Information Office	Director	External
24	Gara Cruise Agency	Managing Director	External
25	West Tour Agency	Chief Executive Officer	External
26	Transport company, Eimskip (Headquarters)	Senior Manager	External
27	Transport company, Eimskip (Isafjordur)	Area manager, Port operator	External
28	Transport company, Eimskip (Isafjordur)	Employee	External
29	Transport company, Samskip (Isafjordur)	Supervisor for West Iceland	External
30	Industry (Skaginn 3X)	Director of the operation	External
31	The main power company in the region	Director of Energy, electrical engineer	External
32	Marine product company Hradfrystihusid-Gunnvor	Production Manager, Fleet Manager, employee	External
33	Marine product company Arctic fish	Chief Financial Officer	External
34	Marine product company Habrun	Manager	External
35	Marine product company Kampi	Production Manager, Operation Manager, Quality Managers, Accountant	External
36	Marine product company, Kerecis	Director of Manufacturing	External

Continued

Table C.1 (Continued) List of interviewees related to the adaptive port planning of the Ports of Isafjordur Network

No.	Company/Organization	Position	Stakeholder Group
37	Marine product company Islands Saga	Manager	External
38	Marine product company Klofningur	Managing Director	External
39	Marine product company IS 47	Owner	External
40	Marine product company, West Seafood	Owner	External
41	Kayak center	Manager	Community
42	Local heritage museum	Manager	Community
43	Blue Bank company	Manager	Community
44	Local fish market	Manager	Community
45	Local rescue team	Employee	Community
46	Local store	Manager	Community
47	Harbor employee in Isafjordur	Boat owner	Community
48	Harbor employee in Thingeyri	Local	Community
49	Harbor employee in Isafjordur	Local	Community
50	Construction company	Manager	Community
51	Marine and Freshwater Research Institute- Isafjordur	Local	Community

Appendix D

The color-scaled level of agreement within the interviewees and the list of sub-objectives and means objectives of port planning are presented in Tables D.1 and D.2. In Table D.2, IS, ES, LS, AS and CS are, respectively, the internal stakeholder, external stakeholder, legislation and public policy stakeholder, academic stakeholder and community stakeholder. Numbers in the color-scaled table under the stakeholder groups represent the percentage of stakeholders in a group that pointed out a sub-objective. The color-scaled table shows the level of agreement within the interviewees of each stakeholder group regarding whether a sub-objective was relevant to achieve the fundamental objective.

Table D.1 Color-scaled level of agreement within the interviewees of each stakeholder group

(none)	No level of agreement among interviewees	(0)
Red	Low level of agreement among interviewees	(1-33 %)
Yellow	Medium level of agreement among interviewees	(34-75 %)
Green	High level of agreement among interviewees	(76-100 %)

Table D.2 list of sub-objectives and means objectives

		Stakeholder groups				
	Sub-objectives	IS	ES	LS	AS	CS
A	Increasing competitiveness					
1	Reduce the logistical costs and improve logistical performance	0	0	11	33	0
2	Increase efficiency and (responsive) operability of the system	67	24	33	33	17
3	Improve the quality of services and port performance	33	14	22	67	0
4	Increase current port capacity with constant and integrated port development to meet future demand	67	62	44	67	42
5	Reduce down time at the port	17	29	22	67	0
6	Increase optimal service and provide available area for different vessels (sailing, fishing, cruise, container) for (un)loading, maintenance, mooring, etc.	50	48	56	100	42
7	Increase port facilities, infrastructure, technology and IT	50	24	56	67	8
8	Quicker response to market changes and market signals	0	0	0	67	0
9	Improve connections and synergy between the port and the domestic airport	0	0	0	33	0
10	Increase and update port services such as providing enough (green) energy to vessels and port activities	17	33	22	67	25

Continued

Table D.2 (Continued) list of sub-objectives and means objectives

		Stakeholder groups				
	Sub-objectives	IS	ES	LS	AS	CS
11	Improve ability to supply different fuels to vessels	0	0	0	33	0
12	Increase possibility of sharing port facilities between activities	0	10	0	0	8
13	Reduce service and operational costs	0	5	11	0	0
14	Increase reputation of the port	17	0	0	33	8
15	Quicker emergency response and evacuation plan	0	0	22	33	8
16	Keep (multi)functionality of the port and create a balance between functions	67	19	0	33	33
B	Improve financial performance					
1	Increase financial benefits for customers and good business prospects	17	10	0	0	0
2	Improve independency of the port from governmental support	17	0	0	0	0
3	Increase income of the port and investments in the port area	17	0	0	0	0
C	Increasing effective and efficient use of land					
1	Increase efficiency of port land use for tourist passengers, processing and storing products, servicing, cargo handling, and customs, as well as other businesses	83	43	56	100	17
2	Minimize the cost of a development plan in the port area	0	5	11	0	0
3	Improve clustering of activities in the port area	50	43	22	33	17
4	Increase access to the activities in the port area	0	38	11	67	58
5	Increase the availability of a multiuser and shared land in the port area in high seasonal activities for port users, in particular, in the summer season when the port bustles with cruise and excursion activities	17	19	11	0	0
6	Reduce conflict between activities	33	48	22	33	25
7	Improve the buffer zone between the port area and the city; port city planning should be addressed	50	5	11	33	0
8	Increase access to taxi or bus stations in the port area for excursion services and visiting the town	0	0	0	33	0
9	Increase opportunity for providing a warehouse or area for cargo that can be used as a distribution center at the regional and national levels	0	0	0	0	8
10	Improve planning and better use of land to provide parking areas for port users, staff and tourists	17	10	0	33	0
11	Reduce traffic in the port area	0	0	0	33	0

Continued

Table D.2 (Continued) list of sub-objectives and means objectives

		Stakeholder groups				
	Sub-objectives	IS	ES	LS	AS	CS
12	Increase access of activities (fish factories, transport companies, etc.) to the quayside for (un)loading	17	24	11	0	0
13	Increase effectiveness and cooperation between port stakeholders	17	19	11	33	8
14	Fulfil the regional and national strategies, policies and guidelines in terms of planning	17	10	22	0	0
15	Increase opportunities to distribute port activities and collaborating with other ports in the municipality or neighboring ports to relieve pressure on the area	17	14	22	67	25
16	Keeps the history (culture and heritage) of the port along with new industrial activities in the port area	0	0	0	0	8
17	Increase tourism, leisure, recreational and urban activities in the port area	17	10	0	0	33
D	Increasing hinterland connectivity					
1	Expanding hinterland (area over which the port has market share)	0	14	0	33	0
2	Expanding competition margins (area where two or more ports are in competition)	0	0	0	33	0
3	Expanding foreland	0	5	0	0	0
4	Improve integration/connections with/to the hinterland	33	29	11	67	0
5	Increase regional, national and international sea trade and sea trade connections	33	29	22	67	8
E	Increasing positive economic and social impacts					
1	Improve positive societal impact and assure quality of life of the society	17	10	11	0	17
2	Improve information services and provide a data bank or open data exchange for different purposes such as scientific research and operational work	0	0	0	33	0
3	Improve knowledge and provide research and scientific grounds for scientific communities	0	0	0	100	0
4	Increase private-public investment in the port and the region (value added)	0	5	0	0	0
5	Promote economic growth and contribution to economic development to support regional, national and international trade	17	10	22	0	25
6	Improve sustainable development of the port	17	0	11	100	0
F	Better environmental implications					
1	Comply and support environmental standards with respect to European directives as well as national policy programs and regulations	17	19	33	33	0

Continued

Table D.2 (Continued) list of sub-objectives and means objectives

		Stakeholder groups				
	Sub-objectives	IS	ES	LS	AS	CS
2	Maximize scenic/aesthetics and attractiveness of the port area	33	24	0	0	42
3	Minimize nuisance in the port and surrounding areas	33	14	0	33	42
4	Increase sustainable and environmentally friendly port operations	50	10	33	67	25
5	Improve ballast water management and waste treatment from the ships	0	0	11	33	0
6	Improve consistently and precisely port activities in line with the public's environmental concerns regarding wildlife ecosystems, fauna and flora and global impacts	17	14	33	67	33
G	Increasing safety and security					
1	Comply and support international law, European directives and national policy programs and regulation in terms of safety standards of maritime navigation, port operation and installations	33	10	78	33	8
2	Minimize detrimental health and safety impacts to the locals and port users in terms of mortality and morbidity (by distinct sidewalk, signs, marks, passages, etc.)	67	38	33	67	67
3	Increase security and safeguarding in the ports and fulfil regulatory framework in terms of port security ISPS from IMO and European union regulation work	0	0	22	0	0
4	Increase monitoring, controlling and security system	33	0	11	0	0
H	Creating flexibility					
1	Increasing flexibility of the port to deal with future uncertainties specially for existing port activities	17	29	11	67	25
2	Increase awareness of port stakeholders for effective implementation of adaptive port planning (translation from theory to real case)	0	0	0	33	0
3	Increasing flexibility of the port to adapt to any possible interchange of port function	0	0	0	33	0
4	Increasing flexibility of the port to adapt to external changes such as technological, environmental, social, legislative, etc.	0	19	11	67	8

Appendix E

Table E.1 Functions and activities of the Ports of Isafjordur Network

Port function	Port activity	Infrastructure	Operation	Service
The Port of Isafjordur				
Transfer of cargo	Transfer of container	Quay 3: 120 m Quay 4: 190 m	Draft: 7 m Draft: 7.8 m	Pilotage, towage
	Transfer of dry bulk	Quay 3: 120 m Quay 4: 190 m	Draft: 7 m Draft: 7.8 m	
	Transfer of liquid bulk	Quay 2: 70 m	Draft: 8 m	
	Transfer of general cargo	Quay 1: 270 m Quay 3: 120 m Quay 4: 190 m	Draft: 10 m Draft: 7 m Draft: 7.8 m	
	Transfer of other types of cargos	Quay 1: 270 m Quay 3: 120 m Quay 4: 190 m	Draft: 10 m Draft: 7 m Draft: 7.8 m	
Storage of cargo	Storage of containers	Quay 3: 120 m Quay 4: 190 m	Draft: 7 m Draft: 7.8 m	Reach stacker
	Storage of liquid bulk	Quay 2: 70 m Fuel tankers	Draft: 8 m	Bunkering
	Storage other types of cargos	Quay 3: 120 m Quay 4: 190 m	Draft: 7 m Draft: 7.8 m	
Industrial activities	Marine production and fish processing	Quay 4: 190 m	Draft: 7.8 m	
Recreational activities	Servicing expedition and cruise ships	Quay 1: 270 m Quay 3: 120 m Quay 4: 190 m	Draft: 10 m Draft: 7 m Draft: 7.8 m	Pilotage-(dis-) embarkment
	Servicing private boat, yacht, sailing boat	Marina	Draft: 7 m	
	Recreational services			Water sports (kayaking, jet skiing, water skiing, snorkeling, diving)
The Port of Sudureyri				
Transfer of cargo	Transfer of marine products	Quay 5: 120 m	Draft: 5 m	
Recreational activities	Servicing private boat, yacht, sailing boat	Marina	Draft: 5 m	
The Port of Flateyri				
Transfer of cargo	Transfer of marine products	Quay 6: 105 m	Draft: 5 m	
Recreational activities	Servicing private boat, yacht, sailing boat	Marina	Draft: 5 m	
The Port of Thingeyri				
Transfer of cargo	Transfer of marine products	Quay 7: 80 m	Draft: 6 m	
Recreational activities	Servicing private boat, yacht, sailing boat	Marina	Draft: 5 m	

Appendix F

Table F.1 SWOT analysis of the Ports of Isafjordur Network

Strength	Weakness	Opportunity	Threat
The port network is connected to cabotage and international shipping.	The ports in the network and towns are sheltered by the mountains, which limits servicing large vessels.	The locations of the ports are close to each other in the network. Relieving congestion problems and reducing waiting time can be achieved by servicing vessels at alternative ports.	Surrounding industrial activities and urban areas may limit the expansion in the port network.
The port network is naturally sheltered by mountains and fjords.	Road connectivity in the port network is limited.	There is a geographic shift of companies to the port network.	Truck accessibility to the port network is not safe and secure. The roads go through towns.
The port network is located near rich fishing grounds in the North Atlantic Ocean.	Depth is limited in the port network.	There is enough fuel storage capacity for new industries in the port area.	The area behind the quay at the Port of Isafjordur is already reserved by industries.
The ports in the network are well distributed in the region and offer good collaboration with neighboring ports.	The berthing capacity of the Sudureyri, Flateyri, and Thingeyri Ports in network are limited.	A flexible and integrated port plan and development can increase the use of the Sudureyri, Flateyri, and Thingeyri Ports in the network.	The trend of using bigger vessels results in the obsolescence of the Sudureyri, Flateyri, and Thingeyri Ports in the network.
There are attractive natural sites and towns around the ports that offer appealing expedition and cruise activities.	There is a lack of (super)infrastructure, that is, apron, space, quay, and equipment in the Sudureyri, Flateyri, and Thingeyri Ports.	There is land around the Port of Isafjordur that can be used for future expansion.	The development of a new port (in Finnafjord) in the northeast of Iceland could reduce the cargo flow through the port network.

Continued

Table F.1 (Continued) SWOT analysis of the Ports of Isafjordur Network

The Port of Isafjordur is supported with competitive (in the region) infrastructure, operation, and a variety of services to handle container, dry and liquid bulk, and general/multipurpose cargos.	The passenger traffic and cargo/container handling are mixed in the port network.	The development of new roads and tunnels in the south of the region will increase cargo distribution access of the port network to the hinterland.	The development of new road connectivity and tunnels in the south of the region will affect the competitive position of the port network.
The Port of Isafjordur is equipped with a logistics optimization system.	The port network does not have a cruise terminal.	The increasing development of industries in the port network creates value-added activities.	The development of the industries increases conflict between port users.
The port network has relatively good navigation accessibility within the region.	There is a lack of infrastructure and facilities for passenger traffic.	The port network has the potential to be used as a hub in the region or for the neighboring countries.	The port's hinterland overlaps with that of other neighboring ports.
The hinterland of the port network is supported by industrial activities from all over the country.	The hinterland mostly relies on roads which are not easily developed because of the geography of the country and difficult terrain.	Port of Isafjordur in the network can be a gateway port and distribution center for the region.	There are societal and environmental concerns about increasing the vessel/truck traffic and industries in the port network.
The port network is ice-free throughout the year.	The port network is relatively far from the international airport for the quick export of fresh marine products.		There are some companies without port- related activities in the port network.
There is a nearly certain number of industries with port activities in the port network (constant demand).			The port network is highly dependent on a few industries and activities.

Appendix G

Table G.1 summarizes the results of dealing with uncertainties based on the presented framework for the Ports of Isafjordur Network. The Acronyms in the Table stand for the level of uncertain development (LUD), method of addressing uncertain development (AUD), opportunity (OPP), vulnerability (VUL).

Table G.1 Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
Transfer of cargo	Container flow	Increase in container vessel calls	- The importance of marine transport opportunities increases the Icelandic coastal shipment for container transport. - Increasing the focus on sustainability will demand a shift toward a more environmentally friendly form of transport from the road to the sea. - There is an increasing need for a reliable and quick export of marine catch and products which are considered as time-sensitive cargos in containers.	Short (1, Deterministic forecast)	- Use the existing container handling infrastructure and facilities of the port network.	- Containerized cargos are handled in the Port of Isafjordur (OPP).	Seizing: Attract the market (e.g., by lower port dues) as the port has a competitive position in the region.
				Middle (2, Probabilistic forecast)	- Use optimal handling of containers in the port network and distribute containers from all ports in the network (use intermodal and co-modal, or hub and spoke system).	- An increase in shipping traffic is hazardous for the limited nautical safety (of the Sudureyri, Flateyri, and Thingeyri Ports) in the network (VUL). - Existing road capacity and port accessibility are limited and cause congestion (VUL).	Shaping: Invest and improve turnaround time for vessels (increase quay/terminal productivity) in the Port of Isafjordur. Hedging: Improve and use the capacity of the Sudureyri, Flateyri, and Thingeyri Ports in the network. Shaping: Improve hinterland connection and provide sufficient capacity for container transport.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			Also, there is an increasing demand for the importation of fish feed in containers. - Furthermore, rising temperatures in the Arctic region could open new opportunities for potential shipping [summer ice-free sea route by 2030 (Wright 2013)].		- Integrate and collaborate with other regional ports (operate under one Port Authority) to achieve a certain degree of optimization. This is also plausible for other cargos.	- Existing road capacity and port accessibility are limited and cause congestion (VUL).	Hedging: Create alliances with the neighboring ports including the Bolungarvik and Sudavik Ports. Shaping: Improve hinterland connection in the interface between port and hinterland infrastructure and provide sufficient capacity for container transport.
		Increase in container vessel size	- In response to the increase in marine products, bigger vessels are used to meet economies of scale.	Short (1, Deterministic forecast)	- Use the existing container handling infrastructure and facilities of the port network.	- Container vessels are serviced in the Port of Isafjordur (OPP).	Seizing: Attract the market (e.g., by attractive services in terms of price and quality) as the port has enough infrastructure compared with neighboring ports.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
				Middle (1, Deterministic forecast)	- Increase the quay length, berthing capacity, and access channel in the Port of Isafjordur to service vessels.	- Quay constructions, dredging, and reclamation land increase environmental concern (VUL). - The Port of Isafjordur is protected naturally, thus restricting the sailing of large vessels to the port area (VUL).	Shaping: Conduct Environmental Impact Assessment (EIA). Shaping: Improve the required nautical accessibility in terms of infrastructure (e.g., deepen/widen the channel), navigation facilities (e.g., buoy, beacon), and auxiliary services (e.g., pilotage, towage) of the port.
	Dry bulk and general cargo flow	Increase in dry bulk and general cargo vessel calls	- Fish feed is imported in bulk. -The raw material for the possible new industries (e.g., aluminum, silicon) in the region can be	Short (1, Deterministic forecast)	- Use the existing handling infrastructure and facilities of the port network.	- Cargos are handled in the Port of Isafjordur (OPP).	Seizing*:* Attract the market (e.g., by lower port dues, attractive prices for labor) as the port has a competitive position in the region.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			unloaded in the Port of Isafjordur. Then, the cargos can be distributed to the region from the port.	Middle (2, Probabilistic forecast)	- Use the existing handling infrastructure and facilities of the port network.	- Cargo vessels call at the Port of Isafjordur and cargos are handled in the port (OPP).	Seizing: Attract the market (e.g., by lower port dues, attractive prices for labor) as the Port of Isafjordur has a competitive position in the region.
					- Maximize the use of the Sudureyri, Flateyri, and Thingeyri Ports in the network for cargo handling.	- The Ports of Sudureyri, Flateyri, and Thingeyri, have limited infrastructure and facilities (VUL).	Shaping: Improve the quay length and berthing capacity of the Sudureyri, Flateyri, and Thingeyri Ports in the network. Hedging: Optimize and distribute the cargo handling to the Sudureyri, Flateyri, and Thingeyri Ports in the network.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
Storage of cargo	Storage of containers	Increase in the storage of containers	- Containerization trend shifts from break bulk, dry bulk into containers. - Scale and concentration in the world container markets are increasing.	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- Cargos are stored at the Port of Isafjordur (OPP).	Seizing: Attract the market (e.g., by attractive prices for port dues, import/export tariff, land, and energy) as the port has a competitive position in the region.
				Middle (2, Probabilistic forecast)	- Invest in a multi-user terminal at a strategic location in the port network.	- The port network does not have a specified area to store containers (VUL). - The materialization of digitalization, automation, robotics, artificial intelligence, sensor techniques, and dependence on technology increase IT vulnerability and cyberattacks (VUL).	Shaping: Build a container terminal using the land behind the Port of Isafjordur. Hedging: Build a container terminal in the flat land behind the Port of Thingeyri. Mitigating: Increase safety against cyberattacks.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
	Dry bulk storage	Increase in dry bulk storage	- An increase in aquaculture increases the need for fish feed and medicine which require clean and cold storage.	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- Cargos are stored in the port network (OPP).	Seizing*:* Attract the market (e.g., by attractive prices for port dues, land, and energy) as the port network has a competitive position in the region.
				Middle (2, Probabilistic forecast)	- Invest at a suitable location for dry bulk storage in the port network.	- The port network does not have a specified area for the depot (VUL).	Shaping*:* Build the required storage area using land behind the Port of Isafjordur. Hedging*:* Use the land behind the Sudureyri, Flateyri, and Thingeyri Ports in the network.
	Storage of liquid bulk	Increase in liquid bulk storage	- The industrial activities in the ports area are increasing.	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The liquid bulk is stored in the port network (OPP).	Seizing*:* Attract the market (e.g., by attractive prices for port dues, and utilities) as the port network has tanker capacity and bunkering facilities.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
				Middle (2, Probabilistic forecast)	- Increase tanker capacity and improve bunkering facilities.	- The safety zone distance from the existing liquid storage terminal in the port network to the residential area is limited (VUL).	Shaping: Provide a suitable location for the new tanker that meets the ISPS requirements. Shaping: Upgrade mooring and berthing facilities of the port network.
		A decrease in liquid bulk storage	- The port states and the flag states are responsible for enforcement of the regulations agreed at the Kyoto Climate Change Summit in 1997 and national demands for GHG emission reduction (Wright 2013). This leads to a decline in fossil fuel throughput. - Iceland's use of fossil fuels will be	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The liquid bulk is stored in the port network (OPP).	Seizing: Attract the market (e.g., by lower port dues, and utilities) as the port network has enough tanker capacity and bunkering facilities.
				Middle (2, Probabilistic forecast)	- Invest in the required infrastructure in the port area for the production and/or storage of renewable energy.	- The port network does not have a specified area and infrastructure for the production and/or storage of renewable energy (VUL).	Shaping: Build the infrastructure and provide the required facilities in the Port of Isafjordur. Shaping: Refurbish the existing oil tankers

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			insignificant by 2030. Greenhouse gases net emissions is to be reduced 50-75% by 2050, using 1990 emissions as a baseline (Icelandic Ministry for the Environment and Natural Resources 2007).				in the Port of Isafjordur.
Industrial/ value-added activities	Marine production	Increase in marine productions, processing, and packing	- Fishery management and growing interest in sustainable fish farming affect the growth and productivity of Icelandic fishing industries. - There will be an increase in marine production (offshore, sea, and land aquaculture and further	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The value-added activities are planned in the Port of Isafjordur (OPP).	Seizing: Attract the market (e.g., by attractive prices for port dues, land, and energy) as the Port of Isafjordur has enough infrastructure, facilities, and surrounding land.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			processing) activities if the activities if the fish farm companies receive licenses from the Icelandic government. - Wild catch processing may be stabilized or decline due to the quota system or climate change. - Foreign trawlers can be serviced in the port network if the port network has the required license to service. - There is a possibility of algae, mussel, calcified seaweed farming development in the region.	Middle (3, foresight)	- Strategically develop port cluster in the port of Isafjordur based on the growing port activities.	- Climate change impacts, directly and indirectly, the port's infrastructure, service, and operation, and thus affects the industries in the Port of Isafjordur. This affects the competitive position of the port (Asariotis, Benamara, and Mohos-Naray 2017) (VUL). - Port expansion and land-side accessibility are limited due to living around the port network, reserved land, and acquisition in the port area (VUL).	Seizing: Disseminate investment opportunities (e.g., by advertising, frequent publicity in news, publications, and conference) and attract new markets (e.g., by inviting ports users, port marketing, encouraging port charge and tariff) to facilitate developing infrastructure and facilities for the port cluster. Shaping: Develop the required infrastructure and facilities in the Port of Isafjordur based on the demand of port users in the cluster.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			- Installation and maintenance of fish farm facilities, create recycling and dismantling activities in the port network.				Shaping*:* In response to climate change, build required coastal protection in the Port of Isafjordur.
					- Strategically accommodate some of the value-added activities in the Sudureyri, Flateyri, and Thingeyri Ports in the network.	- The expansion of the ports is limited due to the surrounding residential area (VUL).	Hedging*:* Develop the required facilities and infrastructure in and around the Sudureyri, Flateyri, and Thingeyri Ports in the network/towns based on the demand of port users for value-added activities.
	Renewable energy usage	Provide renewable energy for vessels, and the operations in the port network	- Black oil use in Icelandic territorial waters has been prohibited from 2020 (Regulation no. 124/2015, Iceland).	Short (1, Deterministic forecast)	- This development is not materialized.	-	-

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Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			- The export of technology and knowledge in the field of renewable energy from Iceland (nearly 100% of electricity and 75% of total energy is from renewable sources) move the industries toward the application of renewable energy (Icelandic Ministry for the Environment and Natural Resources 2007). - European policies emphasize the Paris agreement on reducing carbon emissions, limiting fossil fuel consumption, moving toward	Middle (3, foresight)	- Strategically Develop smart grid solutions in the Port of Isafjordur to supply renewable energy demands of port users.	- There is a lack of infrastructure and facilities in the port (VUL).	Shaping: Build the infrastructure and provide the required facilities in the Ports of Isafjordur.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			optimized use of fuels, developing alternative sustainable fuel production and renewable energy activities in the port.				
Recreational services	Servicing expedition and cruise ships	Stagnant and/or increase in expedition/cruise ship calls	- The current COVID-19 pandemic has created concerns about the outbreak of the COVID-19 disease. Countries with cruise ship arrivals and departures have a higher outbreak and infection rate of the Virus (Ito, Hanaoka, and Kawasaki 2020). - The change in demographics and rising inequality drive the cruise market for the	Short (2, Probabilistic forecast)	- Use the existing capacity of the port network.	- Expedition and cruise ships are serviced in the port network (OPP).	Seizing*:* Attract the market (e.g., by advertising in news, publications, and conference, invite liners for port visit/tour, attractive prices for port dues, and utilities) as the port network has a competitive position. Hedging*:* Use the Sudureyri, Flateyri, and Thingeyri Ports in the network for the smaller expedition and cruise ships.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			next 10 to 20 years. The aging population in North America, Europe, and Asia provides business opportunities in the cruise market. Geopolitical unrest could further boost the European cruise market since the majority of Europe is relatively safe (Van Dorsser, Taneja, and Vellinga 2018). - Travel agencies and cruise companies are increasingly looking for new experiences or destinations (Tsamboulas, Moraiti, and Koulopoulou	Middle (1, Deterministic forecast)	- Increase berthing capacity and infrastructure of the Port of Isafjordur.	- There is limited land in the port of Isafjordur to service cruise ships (VUL). - Growth in the number of vessels increases societal and environmental concerns as well as congestion (VUL). - Urban development, utility services, and excursions to attractions are limited in the port network (VUL).	Shaping*:* Extend the ports and provide enough infrastructure (e.g., extend the quay, deepen the access channel) and facilities in the port network. Mitigating*:* Service more environmentally friendly vessels to create a better attitude from the society. Shaping*:* Provide vessels with renewable energy. Shaping*:* Build a cruise terminal at the Port of Isafjordur at a safe and appealing location with good accessibility to buses to transport

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
			2013), which creates opportunities for the port network. - There is a great opportunity for winter cruise ship calls at the port network. - There is a possibility for short stay calls in the port network by cruise ships that are sailing to/from Greenland (Municipality of Isafjordur 2013).				passengers to major attractive areas.
					- Increase the use of the Sudureyri, Flateyri, and Thingeyri Ports in the network	- There are navigation restrictions and limited infrastructure in the Sudureyri, Flateyri, and Thingeyri Ports in the network (VUL). - Urban development, local activities, utility services, excursions to attractions are limited (VUL).	Hedging: Use the Sudureyri, Flateyri, and Thingeyri Ports in the network for shallow-draft vessels. Shaping: Upgrade the port infrastructure (e.g., extend the quay) and facilities in the Sudureyri, Flateyri, and Thingeyri Ports in the network. Shaping: Improve urban development, local services, and attractions.
		Increase in cruise ship size		Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The cruise ships call the port network (OPP).	Seizing: Attract the market (e.g., by attractive services in terms of price and quality)

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
							as the Port of Isafjordur has enough infrastructure and facilities.
				Middle (1, Deterministic forecast)	- Use the existing capacity of the port network.	- There is a limited capacity for servicing large cruise ships in the Port of Isafjordur (VUL).	Shaping: Increase berthing and embarkment capacity.
	Servicing yacht, and sailing boats	Increase in the number of boats.		Short (1, Deterministic forecast)	- Use the existing infrastructure and facilities of the port network.	- The boats use the infrastructure and facilities of the port network (OPP).	Seizing: Attract the market (e.g., by attractive services in terms of price, quality, and utilities) as the port network has a competitive position.
				Middle (1, Deterministic forecast)	- Decentralize services to the boats and use all ports in the network.	- There is a lack of capacity in the port network to service private, yacht, and sailing boats (VUL).	Shaping: Upgrade facilities and infrastructure (e.g., upgrade the existed marina) of the Sudureyri, Flateyri, and Thingeyri Ports in the network.

Continued

Table G.1 (Continued) Dealing with uncertainty based on the port functions during the projected planning horizons.

Port function	Uncertainty	Uncertain development	Remark	Time horizon (LUD, AUD)	Alternative	Fundamental assumption	Action
	Water sports activities	Increase in sports activities		Short (1, Deterministic forecast)	- Use the existing infrastructure and facilities of the port network.	- Sports activities are carried out in the port network (OPP).	Seizing*:* Attract the market (e.g., advertise in news, publications, and conference, port visit/tour, stimulate recreational and multi-cultural activities) as the port network has enough infrastructure and facilities.
				Middle (1, Deterministic forecast)	- Use the infrastructure and facilities of the port network.	- There is a lack of safety distance between sports activities and sailing routes (VUL). - There is a lack of infrastructure such as hotels, guesthouses, and parking space in the port network (VUL).	Shaping*:* Upgrade facilities and infrastructure (e.g., piers, jetties, information center, utilities) of the port network. Shaping*:* Improve safety (e.g., increase navigational aid and set up monitoring system), urban development, and local services.

Continued