Flexible and Adaptive Port Planning

An Icelandic Case of the Ports of Isafjordur Network

(Hafnir Ísafjarðarbæjar)

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<u>Status Report for Grant Years 2018-2020</u>

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PREFACE

Ports are pivotal nodes in the multimodal transport system, where they function as a logistics center for the flow of cargo, containers, and passengers. They are favorite locations for value-added activities and have prominent status in the supply chain and economy of countries. 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. 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. Decision making under uncertainty is challenging. Indeed, in this volatile environment, the dynamic nature of a port system evolves under a high degree of uncertainty including opportunities and vulnerabilities. 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 research presents scientific methods to systematically address uncertainties and deal with them in the port planning process. Furthermore, it facilitates adaptive port planning. This research provides building blocks to improve the quality of port planning under different uncertainties. The methods in this research were demonstrated for an Icelandic case to establish their feasibility for real cases. The application of the proposed methods 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 report is organized into three chapters which are based on the grant years 2018, 2019, and 2020.

Acknowledgment

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 in part by the Doctoral Grants of the University of Iceland Research Fund (Rannsoknarsjodur Haskola Islands), the Icelandic Road and Coastal Administration Research Fund (Rannsoknarsjodur Vegagerdarinnar), and the Municipality of Isafjordur (Isafjardarbaejar).

CHAPTER 1: STUDY AREA

This research was carried out for the Ports of Isafjordur Network (Hafnir Ísafjarðarbæjar) which includes: 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 (see Figure 1.1) of the ports in the northwest of the country give a strategic advantage to the Port Authority for better services to port users.

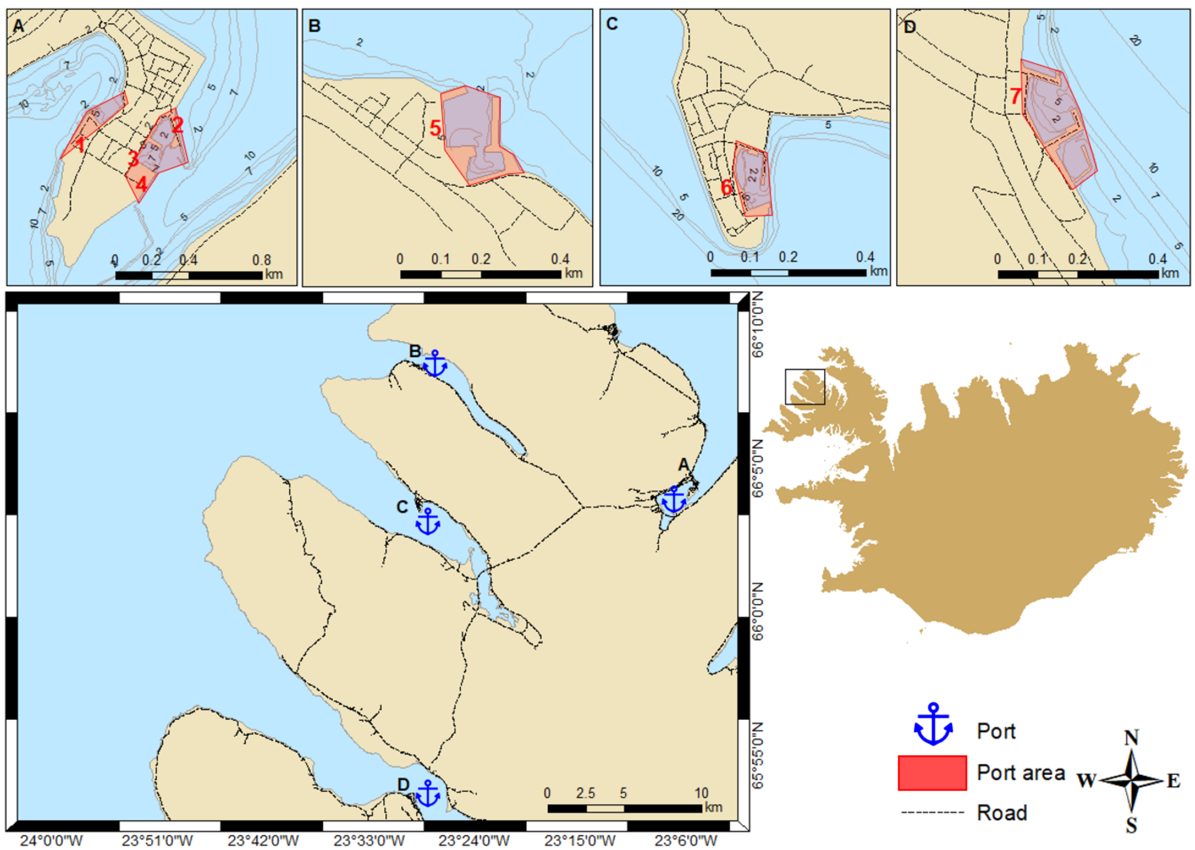

Figure 1.1. The location of the Ports of Isafjordur Network. The study area is shown on the map of Iceland. A, B, C, and D stand for the Ports of Isafjordur, Sudureyri, Flateyri, and Thingeyri, respectively. The numbers are the common-used quays.

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 1.2 shows the development of marine catch unloaded at the port network since 1995.

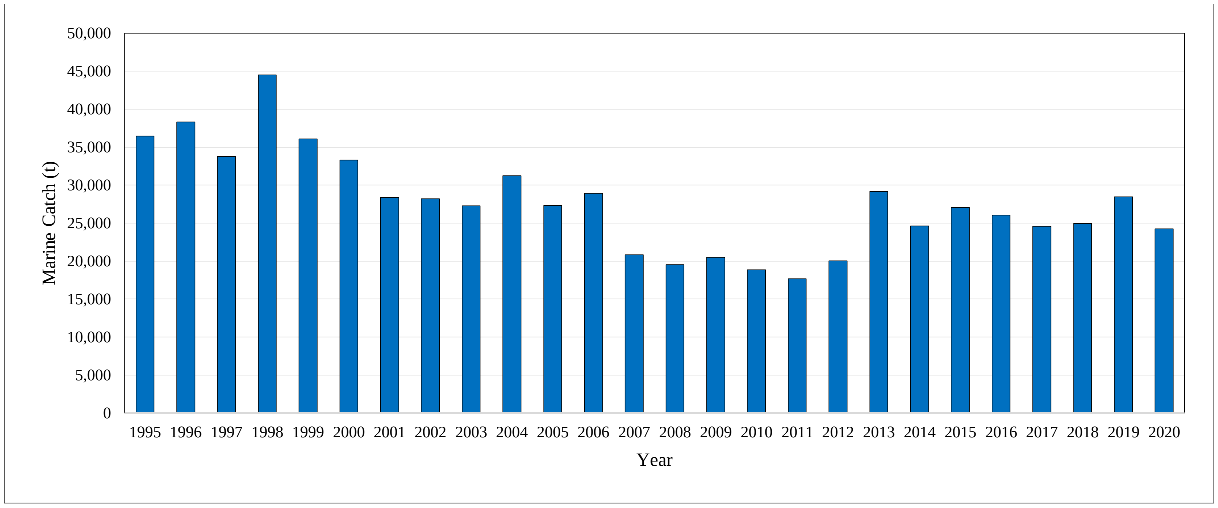

Figure 1.2. Unload of marine catch at the Ports of Isafjordur Network (Icelandic Directorate of Fisheries 2021)

Fish farming and aquaculture activities are the mainstays of the ports network. These activities are thriving in the region (Icelandic Directorate of Fisheries, 2021), which increases the volume of loading and unloading of cargoes and containers at the port.

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 (cargo that is transported in a (refrigerated) container) is based on a Twenty-foot Equivalent Unit (TEU).

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 1.3, 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.

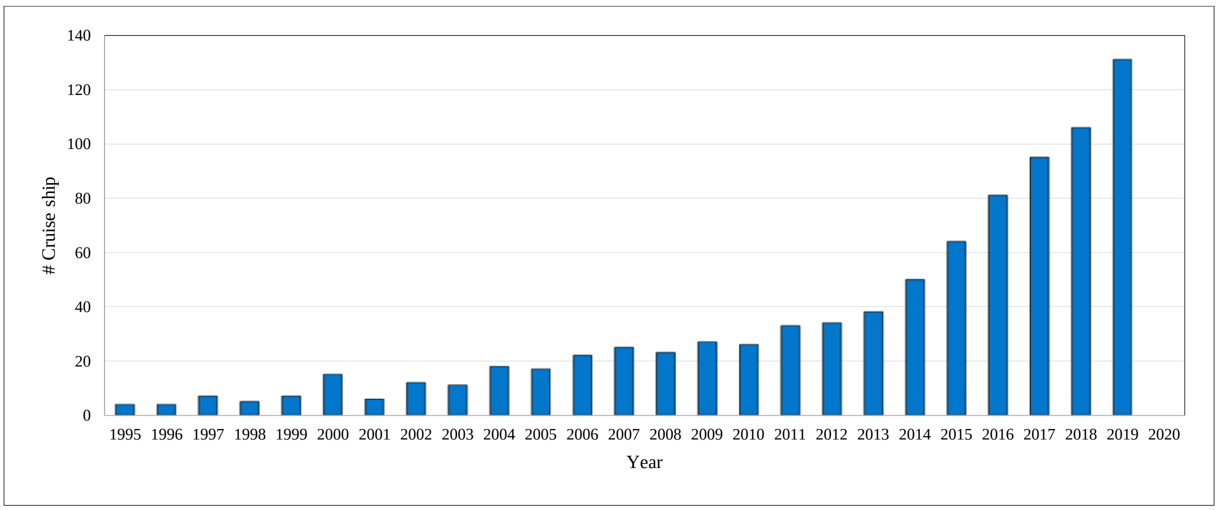

Figure 1.3. Cruise ship call at the port network (Isafjordur Port Authority 2021)

In 2018, the fourth largest cruise ship in the world, the MSC Meraviglia, had three calls at the port (Isafjordur Port Authority 2021). 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 2021).

The seasonality of port activities, restrictions in infrastructure, operations, and services of the port, 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 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 research addresses this concern.

CHAPTER 2: STAKEHOLDER ANALYSIS AND DEFINITION OF SUCCESS IN PORT PLANNING

This chapter is based the on following published peer-reviewed journal articles:

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

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

Abstract

Multiple stakeholders with a wide range of objectives are engaged with a port system in many ways. Ports themselves are faced with many uncertainties in this volatile world. To meet port stakeholders' objectives and deal with the uncertainties, adaptive port planning is increasingly being called for and acknowledged. The planning process starts with defining success in terms of specific objectives of the stakeholders during the projected lifetime of the port. This chapter presents an integrated framework to reach a consensus on the definition of success involving stakeholders with different influences, stakes, and objectives. The framework synthesizes the problem structuring method with stakeholder analysis and combines this with fuzzy logic to support decision makers in formulating a definition of success in the port planning process. A systematic procedure for port stakeholder analysis, comprising identification and grouping of port stakeholders, static stakeholder mapping, and dynamic salience mapping was conducted. In this chapter, values, and preferences of the stakeholders about the port planning were identified and structured around the value-focused thinking method. There were 61 specific sub-objectives of port planning disclosed as a result of 51 face-to-face interviews with all relevant stakeholders. To define the fundamental objective, 8 means objectives were set by creating an appropriate harmony between the sub-objectives. The result shows the leading role of internal stakeholders, such as port authority, on the means objectives of port planning. The main result reveals a fundamental objective that stands as the definition of success by prioritizing increase in competitiveness and effective use of land in the adaptive port planning process for the port in question.

Introduction

Ongoing globalization, constant technological improvements, and environmental and economic changes, among others, have led to the development of ports in order to satisfy new demands for service, operation, and infrastructure (Taneja, Ligteringen, and Walker, 2012; Woo, Moon and Lam, 2017). The dynamic nature of a port system in this volatile world creates a high degree of uncertainty, including opportunities and vulnerabilities in port development projects. Thus, in the port planning process attention should be given to the uncertainties (Taneja, 2013). On the other hand, multiple stakeholders with diverse interests and power cover a broad spectrum of objectives in port planning.

To deal with uncertainties confronting the ports and to fulfill the objectives of the port stakeholders Adaptive Port Planning (APP) has received attention in recent years. APP delivers robust solutions by incorporating uncertainty and flexibility (Taneja, Ligteringen, and Van Schuylenburg, 2010). APP starts with a definition of success to address the desired objectives of port stakeholders during the projected lifetime of the port. APP stipulates a bottom-up approach instead of an autocratic and hierarchical process to identify and consider the preferences of the port stakeholders in the planning process. (Notteboom and Winkelmans, 2002) stressed that the stakeholder approach plays a significant role in order to accomplish sustainable port development. Sustainable port development requires an integrated inter-disciplinary stakeholder inclusive approach that includes the four perspectives of engineering, ecology, economy, and governance (Vellinga, Slinger, Taneja, and Vreugdenhil, 2017). Stakeholders drive decision making in the port planning process and thus the timely involvement of them is a vital part of strategic planning (Heaver, Meersman, Moglia, and Van de Voorde, 2010; T. E. Notteboom and Winkelmans, 2001; Suykens and Voorde, 1998). However, the vast array of port services connects the port authorities to a broad spectrum of national and international stakeholders with specific objectives. The objectives of port stakeholders are in most cases divergent and even conflicting.

Icelandic ports, for instance, are on the verge of a new era in maritime activities through servicing cruise, fishing, cargo, and yacht vessels as well as recreational marine activities, such as whale watching and sailing boats. In this context, the influence and interests of port stakeholders are considerably discrepant on local, regional, and national levels. Thus, in a port planning process, the involvement of all relevant stakeholders at the same level is unlikely. In 2012, the Association of Icelandic Ports (Hafnasamband Islands) discussed the revision of the Icelandic harbor Act and the formulation of long-term policy for the ports of the country. The Association of Icelandic Ports emphasizes the involvement of port stakeholders in order to address their concerns and interests aimed at meeting the coming demands in a port development plan (Hafnasamband Islands, 2014).

In a complex decision-making situation where there are a variety of goals from different stakeholders, Problem Structuring Methods (PSM) can facilitate the decision-making process.

Developing an action plan starts with framing the problem and then identification and application of the proportionate approach (Belton and Stewart, 2010). By means of facilitation, participation, dialogue, and analyzing the elements of a problem, PSMs structure the issues across stakeholders (Ackermann, 2012; Midgley et al., 2013; Rosenhead, 1996). To formulate a definition of success in APP, Value Focused Thinking (VFT) method is recognized as an appropriate PSM. The main reason is that in port planning the main values of stakeholders should be identified, harmonized, evaluated, and then prioritized (Arecco et al., 2016; Slinger et al., 2017). Port stakeholders care about their values, which are the primary driving forces in the decision-making process of port planning. 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. In this context, fundamental objectives are defined as ends that decision makers and or stakeholders want to accomplish in a specific decision situation, while the means objectives are identified as actions (or ways) that need to be implemented to achieve the ends/fundamental objective (Keeney and McDaniels, 1999).

In this chapter a systematic decision support framework to formulate a definition of success in APP is presented. The framework guides port planners and decision-makers to achieve a definition of success by using a multi-method approach. The approach is based on the integration of three methods including: 1- stakeholder analysis to identify the port stakeholders and measure their influence and interests on the objectives in the planning process, 2- the VFT method in order to disclose values of port planning for all relevant port stakeholders and set the means objectives for further analysis, and 3- fuzzy logic to reveal the final level of agreement on the fundamental objective among the key stakeholders.

Methods

Stakeholder Salience and Prioritization

As the power and interest of port stakeholders are very diversified, stakeholder analysis should be carried out to enhance the validity of the VFT method aimed at providing a reliable definition of success (the fundamental objective) in port planning. Stakeholder analysis is considered an important process prior to projects aimed at making a better decision in a complex multi-actor situation and managing possible conflict among them (Mayers, 2005). Figure 2.1 depicts the steps of port stakeholder analysis.

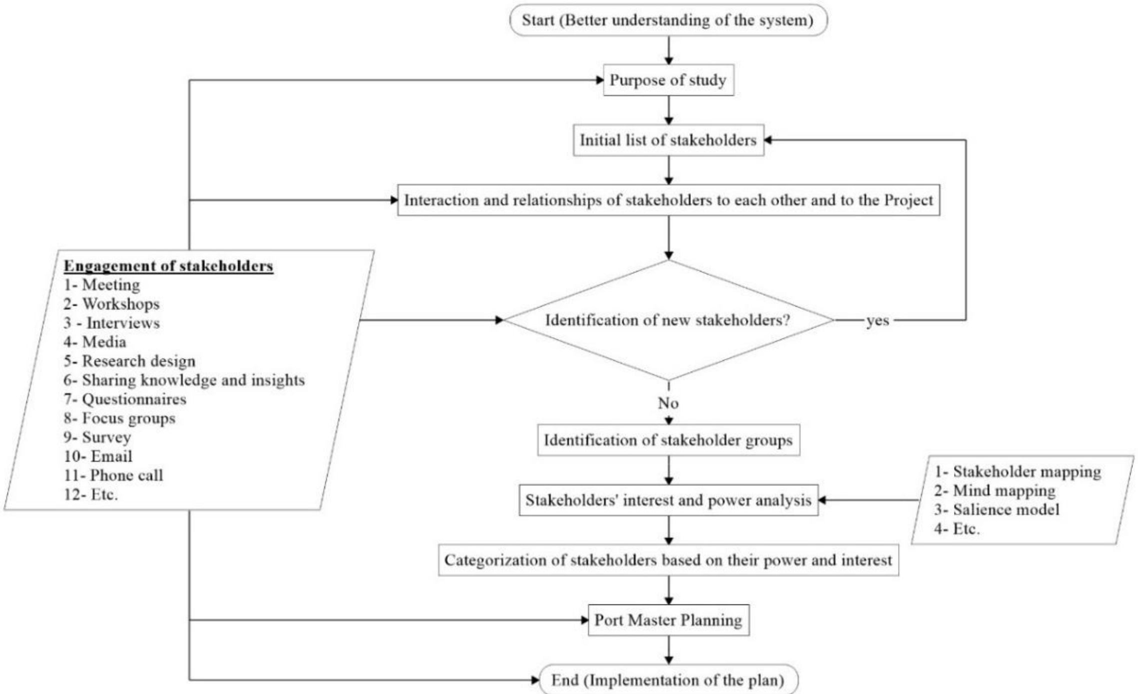

Figure 2.1. Steps in stakeholder analysis and engagement (Eskafi et al., 2019).

Results and Discussion

In this research, an exploratory approach was adopted to uncover port stakeholders. Through literature reviews, expert interviews, and focus groups, the initial list of stakeholders was developed. In order to complete the primary list of port stakeholders, a snowball sampling approach was carried out based on earlier identifications. The snowball technique is a beneficial approach to identify "dormant" or "latent" stakeholders who might have a particular stake and/or influence in the project. To cover the widest range of information that should be taken into consideration in the port planning process, the maximum effort was made to engage stakeholders who directly have a stake and or influence on the planning. The stakeholders were categorized into groups based on similarities in their roles, characteristics, interests, and influence in the case study. Five main groups of port stakeholders were defined including: 1- Internal stakeholders, 2- External stakeholders, 3- Legislation and public policy stakeholders, 4- Community stakeholders, and 5- Academic stakeholder. These stakeholder groups are unbundled in several sub-groups based on the interrelationships of the stakeholders together and their stake in the port planning. The list of stakeholders is shown in Table 2.1.

Table 2.1. List of the port stakeholder group for the port network

Internal Stakeholders	**External Stakeholders**	**Legislation and Public Policy Stakeholders**	**Academics Stakeholders**	**Community Stakeholders**
1. Port authority	1. Associations and NGOs	1. The environment agency of Iceland	1. University of Iceland	1. Small neighboring market/ activities
1.1. Harbor committee	1.1. Association of industries	2. Consumer agency	2. University of Akureyri	1.1. Local fish markets
1.2. Port director	1.2. The federation of Icelandic industries	3. Directorate of fisheries	3. Delft university of technology	1.2. Local stores
1.3. Employee	1.3. Association of fisheries companies	4. Directorate of internal revenue	4. IHE Delft Institute for water education	1.3. Local heritage museum
2. Municipality	1.4. Icelandic association for search and rescue	5. National energy authority	5. University centre of the Westfjords	1.4. Kayak center
2.1. Town council	1.5. Agricultural association of fisheries	6. Icelandic transport authority		1.5. Viking ship association
2.2. Custom	1.6. The port association of Iceland	6.1. Maritime security		2. Land owners
2.3. Planning and building office	1.7. Icelandic regional development institute	6.2. Port installations and maritime navigation		3. Neighboring residences
2.4. Infrastructure, environment, and asset management office	1.8. The Westfjords development association	7. The Icelandic coast guard		4. Ship/ boat owners
2.5. Environmental office	1.9. The Icelandic tourist board	8. The Icelandic road and coastal administration		5. Press/ media
2.6. Fire brigade	1.10. Cruise Iceland	9. National planning agency		6. Blue bank company
2.7. Water suppliers/ utilities	2. Airport	10. Marine and freshwater research institute		7. Local fishermen
	3. Companies and industries	11. Westfjords Iceland nature research center		8. local rescue teams
	3.1. Shipping lines and shippers: Eimskip, Samskip, Nesskip.	12. The Westfjords health administration		
	3.2. Insurance companies	13. National commissioner of the Icelandic police, the department of civil protection and emergency management		
	3.3. Local government loan	14. Ministries		
		14.1. Ministry for foreign affairs		

(Continued)

Table 2.1. (continued) List of the port stakeholder group for the port network

Internal Stakeholders	External Stakeholders	Legislation and Public Policy Stakeholders	Academics Stakeholders	Community Stakeholders
	3.4. Marine products companies:	14.2. Ministry of the environment and natural resources		
	ArcticFish, Hradfrystihusid -Gunnvor, Arnarlax, Jokab Valgeir, Habrun, Klofninguir, West Seafood, Islandssaga, Kampi, Kerecis.	14.3. Ministry of finance and economic affairs		
	Fishing gear companies	14.4. Ministry of industries and innovation		
	Net and aquaculture product/ service companies	14.5. Ministry of transport and local government		
	3.5. Industries: Building materials, Ship building/ repair companies, 3X, Containers service.			
	3.6. Consultant engineering Co.			
	3.7. Stevedoring companies/ operators			
	3.8. Energy companies: Orkubu Vestfjarda, Landsnet, Oil companies.			
	3.9. Cruise agencies: Gara agents, Samskip.			
	3.10. Tourist agenesis: Ferdaskrifstofa Vestfjarda, Fantastic Fjords, West Tours, Fisherman, Borea, Atlantik, Iceland Travel.			

Identification of Value, Sub-Objectives, and Means Objectives

Identification of the stakeholders and engaging them in the planning process leads to disclosing the values and consequently constructing the means objectives of APP. 51 face-to-face semi-structured open-ended interviews were conducted with all who had a stake in the planning of the port of Isafjordur to ensure that a wide range of values would be captured. All concerns and points of view that they raised were collected and carefully analyzed in order to provide a comprehensive list of values regardless of their priorities. Through an in-depth content analysis, common sub-objectives of port planning were obtained from the values. It should be noted that the values could be an idea, thought, need, concern, etc. of the stakeholders about the port planning, but the sub-objectives are what the stakeholders want to achieve, and they should be addressed in the planning. Next, the sub-objectives were clustered to means objectives in terms of their relation to the port planning. Table 2.2 presents the position of the interviewees in their companies/organizations and their stakeholder groups (Eskafi et al., 2020a).

Table 2.2. List of interviewees related to the Planning of the Ports of Isafjordur of 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
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

(Continued)

Table 2.2. (continued) List of interviewees related to the Planning of the Ports of Isafjordur of network

No.	Company/Organization	Position	Stakeholder Group
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
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

In total, 314 values were elucidated from the interviews. The aggregated values of port planning from the stakeholders' standpoint, was identified as 61 specific sub-objectives. Collectively, a set of 8 means objectives were determined, including increasing competitiveness, increasing effective and efficient use of land, increasing safety and security, increasing hinterland connectivity, increasing financial performance, better environmental implications, increasing positive economic and social impacts, and creating flexibility.

Stakeholder Mapping

Stakeholder mapping is a widely used technique by which the levels of interest and power of the stakeholders are determined, for further prioritization and appropriate engagement strategies. In this research, stakeholders are mapped based on the power-interest matrix (Wright and Cairns, 2011). To proceed with the stakeholder analysis, a comprehensive and detailed survey was elaborated aimed at weighing the interest and power of the stakeholder groups in terms of the means objectives in the port planning. The survey was sent to at least three stakeholders from each of the five main groups to ensure consideration of views across diverse port stakeholders and to prevent potential bias in the aggregation of results. Based on the results of the survey, the stakeholder groups were mapped by aggregation of the mean of weights that were allocated to each stakeholder group. Figures 2.2 and 2.3 show the result of the stakeholder mapping for the means objectives of increasing competitiveness and effective and efficient use of land, respectively.

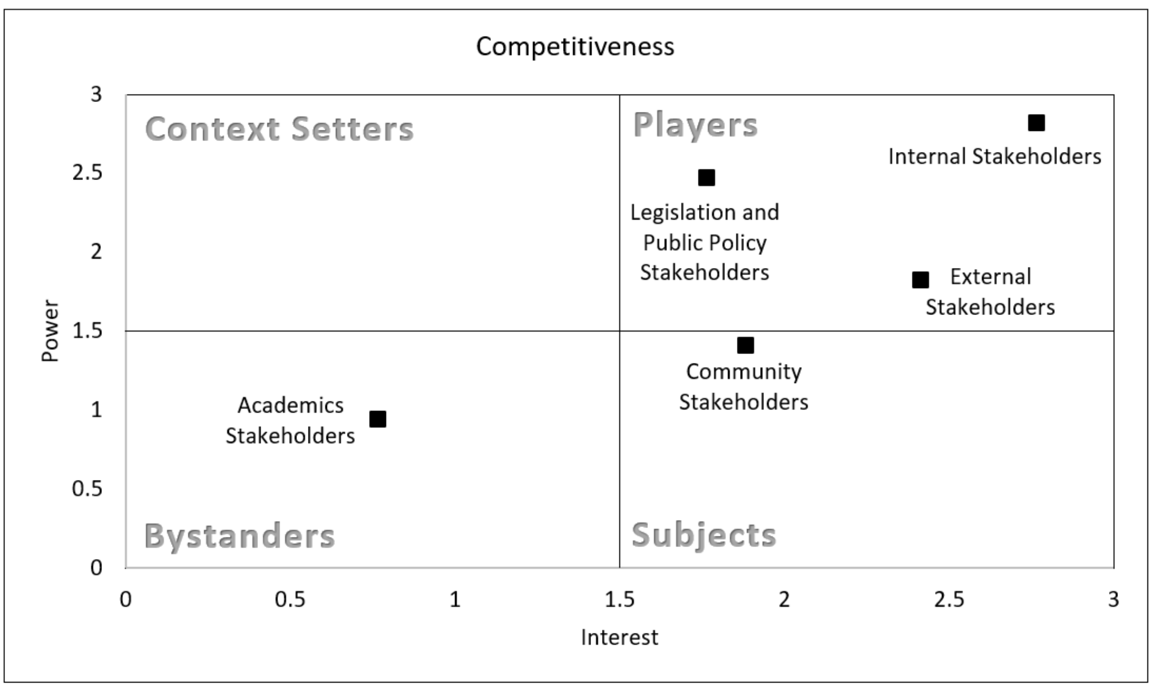

Figure 2.2. Power- interest matrix for competitiveness

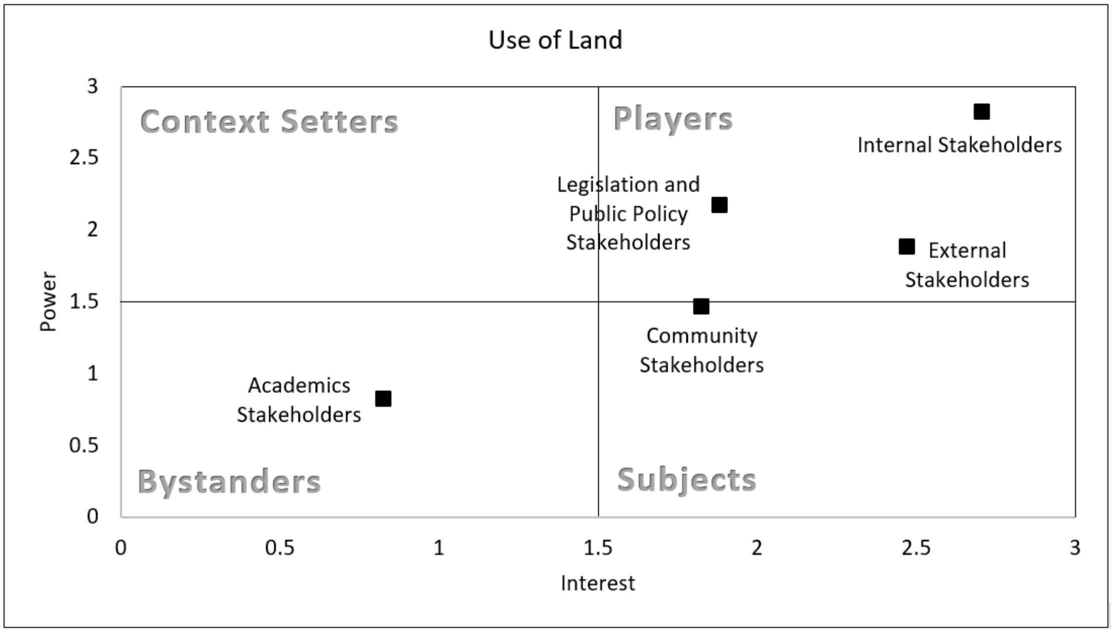

Figure 2.3. Power- interest matrix for use of land

Figure 2.4 depicts the standard deviation of interest and power of all the stakeholder groups for the mean of all criteria. Salience is the attribute of stakeholders in terms of both power and interest together on the means objective of the port planning.

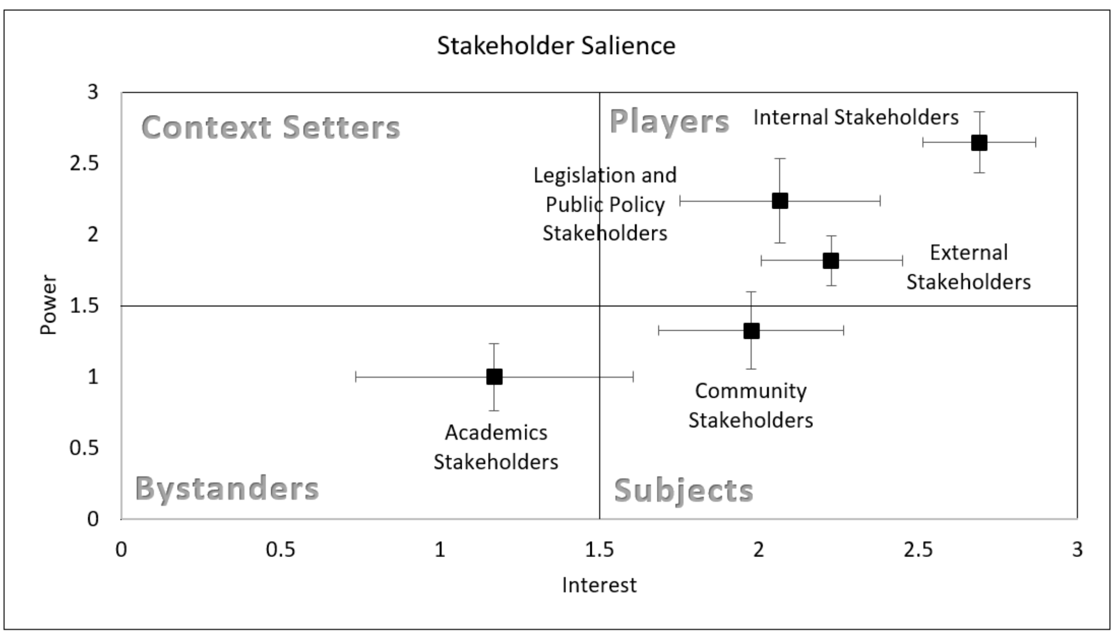

Figure 2.4. Standard deviation and stakeholder salience on the criteria of port planning

As can be seen from Figure 2.4, the internal stakeholder group (see table 2.1) is the main player who endorses and executes the planning, this group has the highest power and interest in the port master planning. This group should be fully engaged in all port planning processes. The legislation and public policy stakeholder group (see table 2.1) is another player in the port master planning. The external stakeholder group (see table 2.1) is identified as the third player in the port master planning. As these three groups are major drivers of any changes in the port master planning process, close collaboration and effective engagement with them are crucial. These three groups should be directly involved as their insight and knowledge leverage the port master planning process towards achieving the objectives.

As internal, external, and legislation and public policy stakeholder groups are assigned to the player quadrant, all groups are basically considered with the same characteristics. Therefore, the same strategy of engagement should be conducted with them in the port planning based on the 2D (power interest matrix) stakeholder analysis. However, this is far from reality in a decision-making process, in particular, with respect to the dynamic nature of the port system. In order to capture precisely, visually, and logically the salience of stakeholders, fuzzy logic was applied. By assessing the level of attributes, a decision surface provides a better understanding of whether a stakeholder might change its position. Thus, it gives a more accurate analysis of stakeholders. Figure 2.5 illustrates the relationship between salience, the range of salience, power, and interest of the players in this research using the decision surface.

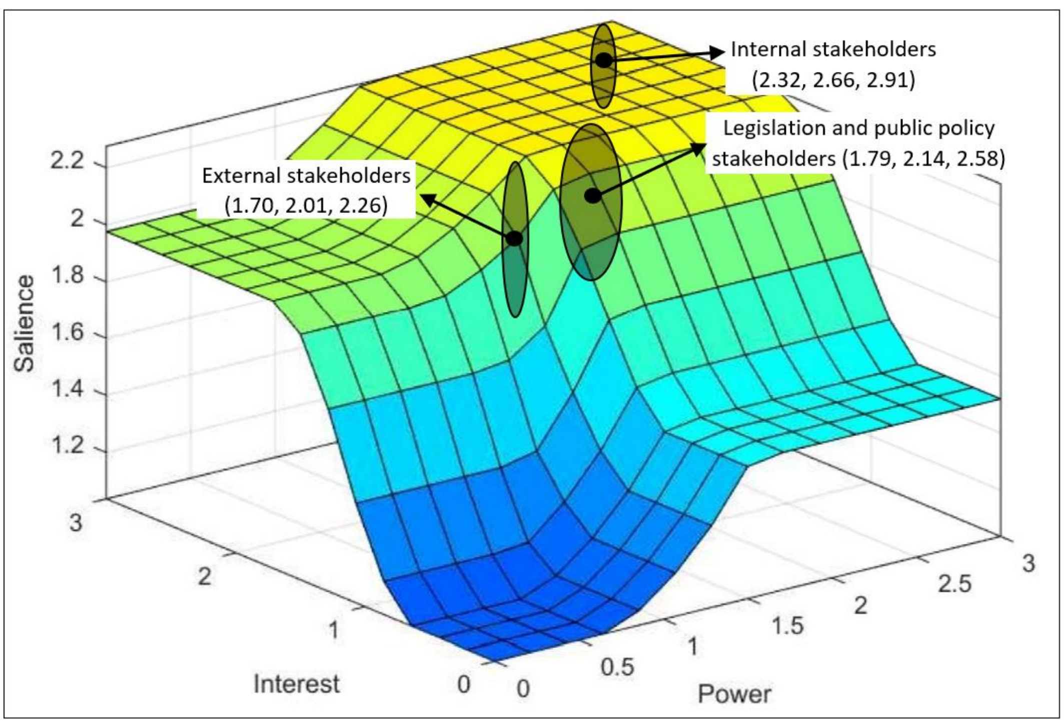

Figure 2.5. Fuzzy logic decision surface for the relationship between power and interest

The acute slope of the decision surface indicates rapid changes in the attributes. The steepest slope in Figure 2.5 is the fuzzy area. Thus, placement of a stakeholder group in this area reveals that possessing a small degree of the attribute might increase suddenly. As can be seen in Figure 2.5, the legislation and public policy and (particularly) the external stakeholder groups are placed on the steep slope of the surface. Thus, these groups can rapidly change their salience in the port master planning process and can become important players. The internal stakeholder group, however, is placed in the flat area of the decision surface with a distinct salience. This reveals a stable dominating role of this group in port planning (Eskafi et al., 2019).

Stakeholder Groups' Attributes

The preferences of stakeholder groups for the means objective clarified their concerns in the decision-making process. Hence, it helped the process of problem structuring toward achieving the fundamental objective. To determine the preferences of different stakeholder groups on the means objectives, radar plots were used. By means of radar plots, the relationship between stakeholder groups, their preferences, and potential conflicts could be visualized. The focus in this chapter was on the key stakeholders who were either decision-makers (on concluding the definition of success in APP) or the main influencer for port development. Figures 2.6 to 2.8 show the preference of the key stakeholders on the means objectives. The numbers in the radar plots indicate the aggregate number of stakeholders in a group that mentioned a sub-objective (and consequently a means objective) in the interviews.

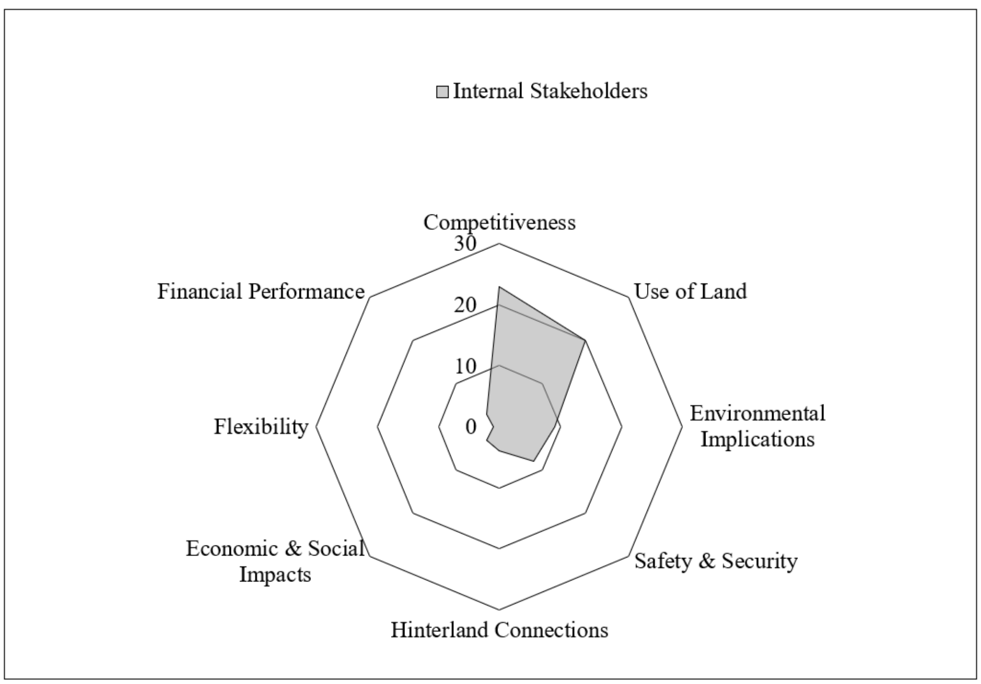

Figure 2.6. Distribution of means objectives for the internal stakeholder group

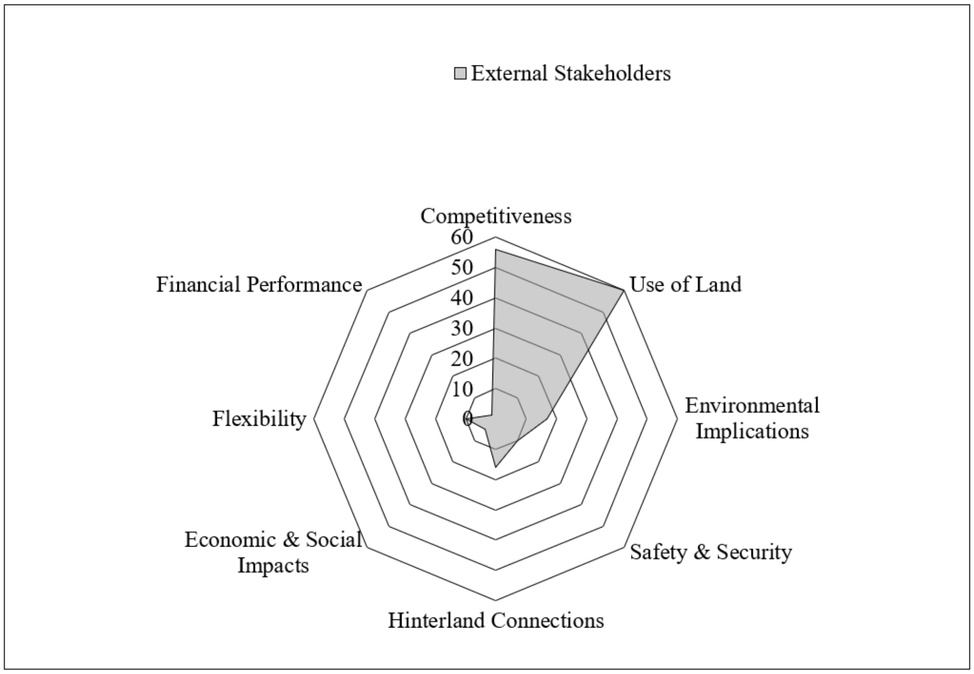

Figure 2.7. Distribution of means objectives for the external stakeholder group

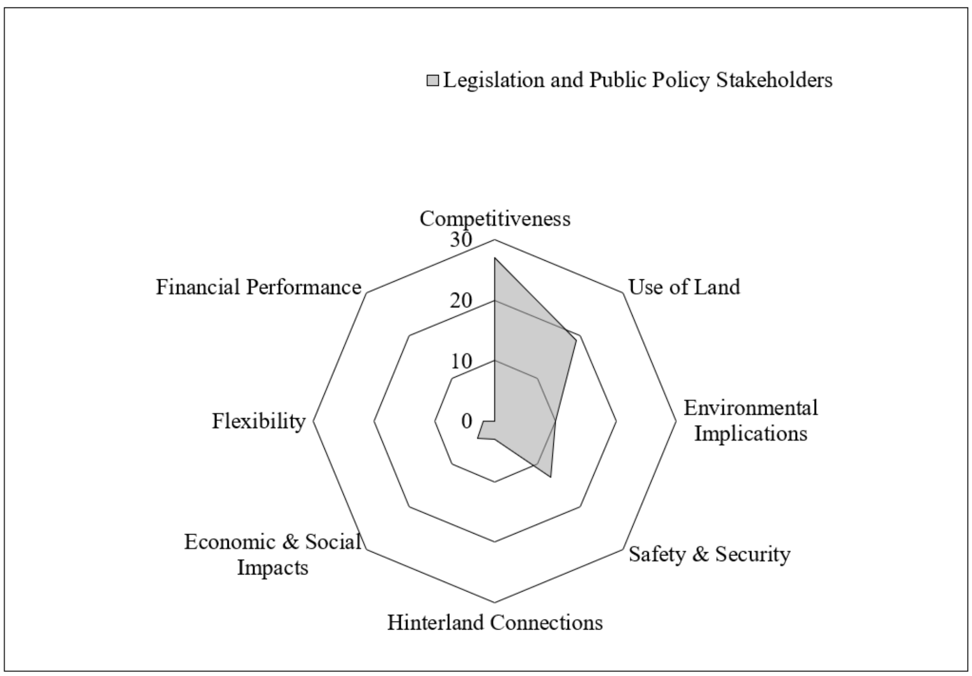

Figure 2.8. Distribution of means objectives for the legislation and public policy stakeholder group

As can be seen a high degree of commonality was evident, especially concerning the increasing competitiveness and effective and efficient use of land among all groups. This led to the extra emphasis on these means objectives in deciding on the fundamental objective.

Framing the Fundamental Objective and Formulating a Definition of Success

Employing a focus group three representatives from each key stakeholder group were selected. The selection of the representatives was based on their power and interests as well as long- and short-term roles in the planning process and the subsequent port development. In three separate meetings, the representatives were asked to indicate their group's preference on the 8 means objectives for the port planning. The outcomes of the meetings were three different preference orderings of the means objectives. By using the fuzzy multi-attribute group decision-making method, the final level of agreement between them on the fundamental objective was ascertained. The final level of agreement was ordered as:

[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 can be considered as the fundamental objective (Eskafi et al., 2020a). The identified order was discussed with the representative of the key stakeholder groups. Regarded with the highest level of agreement, 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 Adaptive Port Planning for the Port of Isafjordur.

Conclusions

The complexity of a port system and the concomitant uncertainties, as well as increasing maritime activities, call for a new port development approach. The Adaptive Port Planning addresses the uncertainties surrounding the port and objectives of port stakeholders in the projected lifetime of the port because it starts with a definition of success.

An integrated qualitative and quantitative framework was conducted to capture all stakeholders' objectives effectively, accounting for the conflicting interests, while at the same time ensuring consistency in the whole process. The framework comprised stakeholder analysis, the Value Focused Thinking method, the existing literature in the fields of port planning, and fuzzy logic. The framework supports decision making in port planning including Adaptive Port Planning to reach the highest level of agreement on the definition of success among the various stakeholders.

The research shows the leading role of the internal stakeholder group in port planning. The legislation and public policy stakeholder group has high power and interest in the port master planning. The external stakeholder group is identified as a highly influential group with great concern about the port master planning. Maximum efforts should be given to ensure that players' concerns have been incorporated. These groups should be directly engaged in the whole planning process and the port planner should prioritize and work closely with them. Eight means objectives of port planning were identified by harmonizing the sub-objectives obtained from interviews with all relevant stakeholders. The means objectives were increasing competitiveness, increasing the 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. In this research, the conflict of interests among the stakeholders was revealed extensively. A consensus was reached among the key stakeholders on the definition of success by prioritizing increasing competitiveness in the Adaptive Port Planning for the Port of Isafjordur.

CHAPTER 3: CARGO FLOW ANALYSIS AND PORT THROUGHPUT FORECAST

This chapter is based the on following published peer-reviewed journal articles:

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*. https://doi.org/10.1108/MABR-05-2020-0030

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*. https://doi.org/10.1057/s41278-021-00190-x

Abstract

Capacity plays a crucial role in a port's competitive position and growth of market share. An investment decision for capacity development should be supported by growing demand. However, in a volatile and competitive market environment, demand is changing and uncertain. Forecasting models themselves are also associated with epistemic uncertainty due to model and parameter uncertainties. This research utilizes mutual information theory to quantify the relative importance of cargos in port throughput. Based on the prominent cargos that describe the port throughput, the method evaluates the relation of port throughput and the macroeconomic variables. A Bayesian statistical method was used to develop a port throughput forecasting model that accounts for epistemic uncertainty. The model has an adaptive capability to provide a continuously or regularly updated port throughput forecast. The model results in a range of port throughput forecasts, in addition to a point estimate. 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. The results show that marine-product cargo is the main export, while the majority of imports are fuel oil, industrial materials, as well as marine-product cargos. The aggregation of these cargos, handled in the port, would meaningfully determine the non-containerized port throughput. The results reveal that the national gross domestic product is the main influencing macroeconomic variable for the non-containerized port throughput. However, containerized cargo flow shows the strongest relation to the volume of national export trade. The forecast results show a growth of containerized throughput during 2020-2025. However, non-containerized throughput declines over the same period.

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 (Guo et al., 2005), and aids the preliminary design of basic infrastructure (Chen et al., 2016) and operational plan and management (Zhang et al., 2013). Financial viability and infrastructure-based investments should be supported by potential (cargo) demands (De Langen et al., 2012). Appropriate investment in port capacity, based on the promising cargoes, helps to win market share and strengthen the competitive position of the port (Taneja et al., 2010). On the other hand, inaccurate statements about the likely course of demand lead to an improper development plan (Peng and Chu, 2009). This research, therefore, applies Mutual Information (MI) theory to evaluate the dependencies between the flow of different types of cargo and the port throughput and identifies the prominent cargos that would describe the port throughput. In information theory, mutual information measures the amount of information that one variable contains about the other. In other words, the 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).

The long design lifetime of port infrastructure and changes in type and volume of cargo/containers, face decision makers with many uncertainties in the planning process. To increase the reliability of port throughput forecasts, the epistemic uncertainty of forecast models should be taken into account. A Bayesian model is developed that accounts for epistemic uncertainties in a port throughput forecast. Epistemic uncertainty includes model uncertainties (choice of variables, assumptions, and processes) and parameter uncertainties (quantity and quality of data used). To select the influencing macroeconomic variables, 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 taken into account using the Bayesian method by treating the regression coefficients as random variables and considering their distributions conditional on the data. The model 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. The forecast model 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 and facilitates informed decision making in port capacity planning and management.

Methods

Mutual Information

Mutual information is an important concept in information theory to handle uncertainties and abstraction of the notion of information. 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 measures the level of correlation between variables and then determining their dependency on each other by quantifying the amount of information held in a variable through another variable. Therefore, the mutual information that provides information by one variable about another gives a unique measure of dependence between the two variables, which is also connected to the concept of entropy and Kullback-Leibler divergence. For a pair of random variables (X, Y) with marginal probability distributions of $\mu_x(x)$ and $\mu_y(y)$, the 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 et al., 2004):

$$I(X, Y) = \iint \mu(x, y) \log \frac{\mu(x, y)}{\mu_x(x)\mu_y(y)} dxdy \tag{1}$$

On the other hand, the 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:

$$H(X) = -\int_{x \in X} p(x) \log_2 p(x) dx \tag{2}$$

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

$$\begin{aligned} I(X, Y) &= H(X) + H(Y) - H(X, Y) \\ &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X) \end{aligned} \tag{3}$$

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:

$$H(X|Y) = -\iint \mu(x, y) \log \mu(x|y)\, dxdy \tag{4}$$

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). The mutual information illustrates the distributions of the information measures in terms of interdependency between variables. In this vein, the 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. Eskafi et al. (2020b) 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.

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. To utilize the Bayesian method, the prediction models can be linearized by a simple expression of the following form:

$$\log \mathrm{y_i} = \mathrm{C_0} + \mathrm{C_1x_1} + \mathrm{C_2x_2} + \mathrm{C_3x_3} + \mathrm{C_4x_4} + \mathrm{C_5x_5} + \mathrm{C_6x_6} \tag{5}$$

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

$$\mathrm{X} = \begin{bmatrix} \mathrm{x_{11}} & \mathrm{x_{12}} & \cdots & \mathrm{x_{1k}} \\ \vdots & \vdots & \vdots & \vdots \\ \mathrm{x_{n1}} & \mathrm{x_{n2}} & \cdots & \mathrm{x_{nk}} \end{bmatrix} \tag{6}$$

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

$$\mathrm{E(y_i|\theta, X)} = \theta_1 \mathrm{x_{i1}} + \cdots + \theta_k \mathrm{x_{ik}} \tag{7}$$

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:

$$p(\theta|y) \propto p(\theta)p(y|\theta) \tag{8}$$

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 paper, the logarithm of the port throughput is assumed to follow a normal distribution, so that:

$$p(y|\sigma^2, \theta, X) = \prod_{i=1}^{N} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(y_i - (X\theta)_i)^2}{2\sigma^2}\right) \tag{9}$$

where N is the number of available historic 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:

$$p(\theta, \sigma^2|y, X) \propto p(\theta, \sigma^2|X)p(y|\sigma^2, y, X) \propto \sigma^2 \prod_{i=1}^{n} N(y_i|(X\theta)_i, \sigma^2) \tag{10}$$

The posterior distribution of the unknown parameters θ is obtained by using Equation 6. 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 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.

Data Used

In this research, two types of port throughput data are collected: containerized throughput in a Twenty-foot Equivalent Unit (TEU), and non-containerized throughput in tonnes. The latter includes fuel oil, marine products, and industrial materials. 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. These variables are 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. Historic and forecast values of these variables refer to 1990-2019 and 2020-2025 respectively (Statistics Iceland Office 2021).

Results and Discussion

Port Throughput Analysis

The results of the mutual information values of the handled non-containerized cargos at the port with export and import are depicted in Figure 3.1. The cargos are fuel oil (x1), road construction and maintenance materials (x2), fertilizer and fish food (x3), marine products (x4), industrial materials (x5), small general cargo (x6) (Eskafi et al., 2020b).

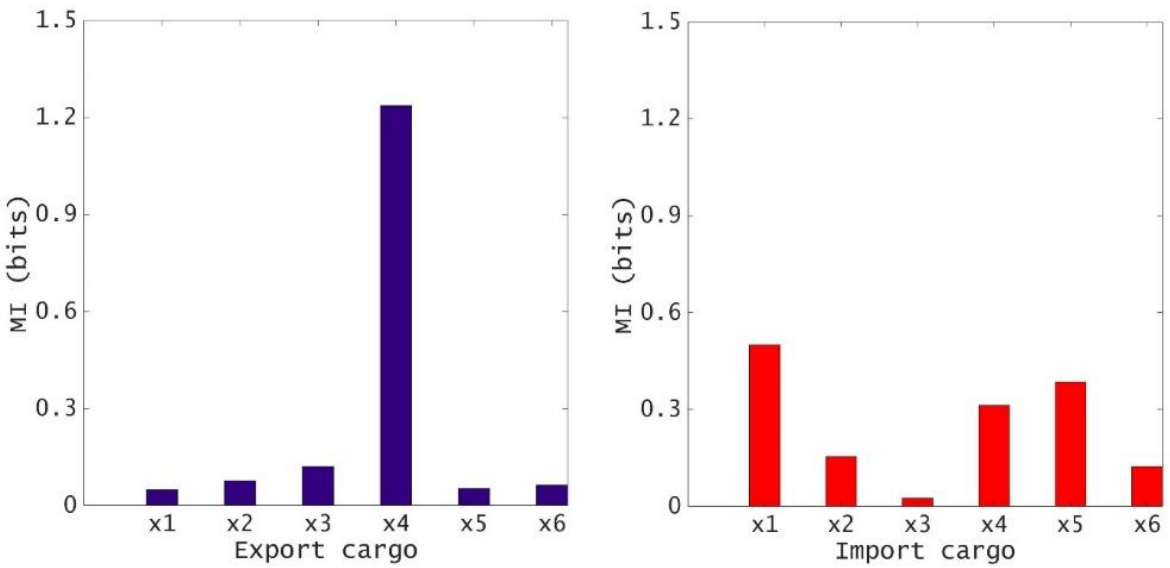

Figure 3.1. The mutual information value of the non-containerized cargos (export (left) and import (right)).

From Figure 3.1, marine products cargo is the only variable with a significant contribution to the export. Thus, marine products can be considered as the main export cargo. This is because, the core businesses in the region are fishery, fish farming, aquaculture (algae, mussel, calcified seaweed), and further production including processing and packing. Therefore, these activities can significantly influence the export. For the import, the mutual information values for several cargos have a relatively large value. These cargos, however, have small differences in their mutual information value for the import. The results show that fuel oil has the largest mutual information value. The industrial materials cargo has a moderate influence but higher than the marine products in the import.

As is shown in Figure 3.1, it can be inferred that the non-containerized port throughput has a great dependency on marine products (export) and fuel oil, marine products, and industrial materials (import). This result is utilized to calculate the correlation between the macroeconomic variable and non-containerized port throughput including the identified main cargos in export and import.

Relation Between Port Throughput and Macroeconomic Variables

Based on the identified main flow of cargos, Figure 3.2 shows the results of the mutual information values between port throughput and macroeconomic variables. The variables are the national GDP (X1), the average yearly CPI (X2), the world GDP (X3), the volume of national export trade (X4), the volume of national import trade (X5), and the national population (X6).

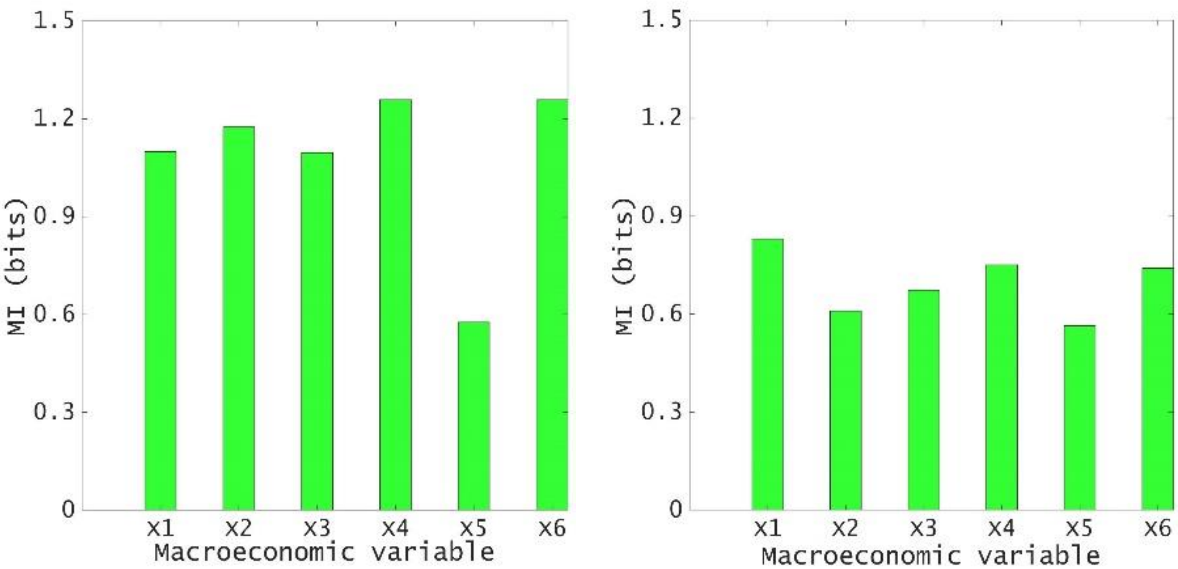

Figure 3.2. The mutual information values between port throughput and macroeconomic variables (containerized (left), non-containerized (right)).

There is a maximum relation between the non-containerized port throughput and national GDP and then the volume of national export trade. However, the volume of national import trade has the lowest correlation with the non-containerized port throughput. The close relation of the national export trade with the port throughput, as mentioned by (Gökkuş et al., 2017), is expected in island countries. The non-containerized port throughput and GDP are intercorrelated as they are both affected by import (national consumption) and the export (productivity) of goods (Van Dorsser et al., 2012).

The relation between the container flow and the volume of national export trade is the strongest. This is because containerized cargo can be transported efficiently over long distances, and easily transferred between modes of transport. The next variables, with slightly lower mutual information values, are the national population, the average yearly CPI, and the national GDP. The average yearly CPI partly determines the annual value of the national GDP (Gosasang et al., 2010) and GDP is a good indicator of container port throughput (Van Dorsser et al., 2012). Population growth stimulates greater trade flows due to increased labor force and economic improvements (Hanushek and Kimko, 2000).

Port Throughput Forecast

As depicted in Figure 3.2, the containerized and non-containerized port throughput are influenced by the six macroeconomic variables. Therefore, these variables are used as independent variables to build the port throughput forecasting model.

Figure 3.3 shows the development of the historic and the forecasted port throughput with the gray shaded area for different confidence intervals of the forecast. The confidence limits indicate the future port throughput forecasts while associating the epistemic uncertainties, including model uncertainties and parameter uncertainties (Eskafi et al. 2021b).

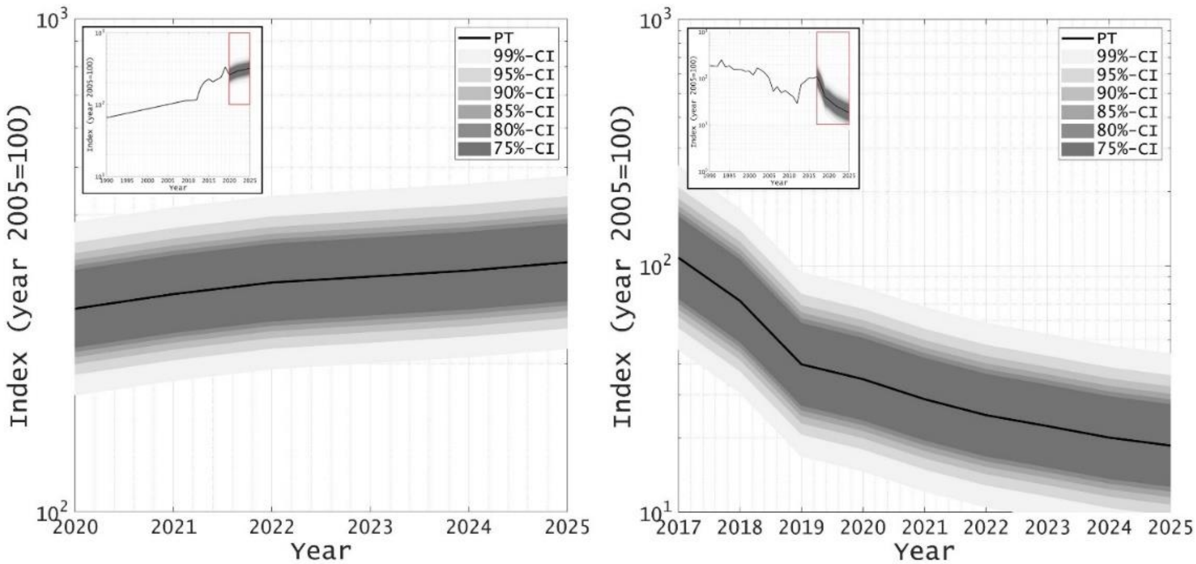

Figure 3.3. Historic and forecasted containerized (left) and non-containerized (right) Port Throughput (PT) developments, and Confidence Interval (CI). The forecasted port throughput is surrounded by the red box in the inserted graph including the historic data.

As shown in Figure 3.3, containerized throughput has a growing trend since 1990. However, 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 in cargo/container flow.

The forecasted containerized throughput follows an increasing trend. 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. The increase in containerized throughput is supported by the causal relation with the increasing macroeconomics. 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 research.

Non-containerized throughput follows the historic data trend and continuously decreases until 2025. The decline in non-containerized throughput reached 19 tonnes in 2025 (19/100=0.19 times tonnes of the non-containerized throughput of the indexed year 2005). Non-containerized throughput is forecasted to decrease by 82% from 2017 through 2025. 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 ongoing containerization is driving non-containerized throughput down, as non-containerized cargo is increasingly transported by containers. 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. 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, port logistics, and terminal and hinterland connections capacity (Eskafi et al. 2020a).

Conclusions

Port throughput analysis necessitates investigating the relation of port throughput with macroeconomic variables. This research used mutual information theory as a quantitative method to measure the linear and nonlinear correlation between variables. The presented method was able to indicate the relative importance of the main flow of cargos at the port as well as determine the relation between macroeconomic variables and port throughput. Furthermore, port throughput forecasts provide valuable and fundamental input to capacity planning and management, and thus adjusts the direction of port development. In addition 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 paper presented a port throughput forecasting model using the Bayesian statistical method. The 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. The Bayesian method accounted for the uncertainty associated with the macroeconomic variables, considered to be random variables following given probability distribution. The model 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. The results of port throughput analysis showed that marine product cargo is the main flow of non-containerized export, while the non-containerized import is mainly constituted by fuel oil, industrial materials, and marine products. The aggregation of these cargos handled at the port would make up the non-containerized port throughput. The non-containerized port throughput showed a correlation between the national GDP and the volume of national export trade. The results unveiled the strong relation between containerized cargo flow and the volume of national export trade.

The results of the port throughput forecast show growth of containerized throughput. 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. 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.

CHAPTER 4: DEALING WITH UNCERTAINTIES; SUSTAINABLE AND FLEXIBLE CRITERIA; EVALUATION METHODS IN PORT PLANNING PROCESS

This chapter is based the on following published 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

Abstract

Ports are complex engineering systems and subject to external influences. Ports have always been evolving to satisfy new demands on their infrastructure, operation, and service. The ever-growing complexity and emerging trends in ports and shipping sectors in a volatile world create a high degree of uncertainty in port development projects. To improve the long-time functionality of ports, addressing the uncertainties in the planning process is critical. This research presents a framework to deal with uncertainties in the planning of a complex port system. Stakeholder analysis, SWOT analysis, and a policy for dealing with uncertainty were jointly used. A literature review and face-to-face interviews with key stakeholders were conducted to address planning horizons and corresponding uncertainties. To reinforce the plan against uncertainty, timely decisions are committed together with necessary actions. The results show that fast-growing fishing, aquaculture, expedition, and cruise activities create the main uncertainties. The growth of these activities increases conflict in the port area. Port clusters should be materialized to increase safety and improve value-added activities in the port area. Furthermore, accounting for four dimensions of sustainability (i.e., economic, social, environmental, and institutional) has become a high-profile objective of decision making in port planning processes. A port plan should improve the societal integration of the port in harmony with the surrounding natural environment. A literature review and desk research are conducted to point out drivers, enablers, and barriers of flexibility and draw attention to sustainable dimensions in the port planning process. To safeguard the main port plan against uncertainties, contingency plans are developed. A contingency plan includes effective actions to seize opportunities and manage vulnerabilities that appear during the projected lifetime of a port plan. These actions are defensive, capitalizing, corrective, reassessment. To identify a suitable evaluation method that accounts for the costs and benefits of flexibility and sustainability in the port planning process, the advantage and disadvantages of evaluation methods are elaborated on. Simulation methods are useful as they include uncertainties and can evaluate flexibility. Furthermore, to assess the costs and benefits of flexibility and sustainability, multi-criteria analysis methods are suitable for port project appraisal.

Introduction

The world has entered a new era of complexity (Hoehn et al., 2017). Today, decision makers face fast-paced, transformative, and often surprising changes. In a volatile world, where uncertainty is an inherent property of the future, policy and subsequent decisions are usually made at the beginning of a project. However, under uncertainties decision makers do not know what will happen during the projected lifetime of a plan. A port is recognized as a complex set of functions, as it has emergent and non-linear behavior in which multiple interactions between different components are possible (Bettis and Hitt, 1995). The complexity of a port system is engaged to unlimited geographic boundaries and trading network, long lifetime, multiple worldwide uncertainties (for instance technological and political), its numerous stakeholders, and its intricacy with society, environment, and economy (Herder et al., 2008; Taneja et al., 2010).

Taneja et al. (2012) stated that the main reason for unsuccessful port development projects is inadequate uncertainty consideration in the planning process. Unsuccessful port projects may result in loss of investment, failure of the project, congestion in the port area or hinterland, redundancy and obsolescence of ports or costly regular adaptations (Taneja et al., 2012), and loss of competitive position, cargo, and revenue during the period that the port cannot be used due to the adaptation (Prakoso et al., 2018). Traditional linear planning of infrastructure projects usually beset the bad side of uncertainty, without taking their potential advantages (Taneja, 2013). A new approach calls for non-linear addressing of uncertainties to traditional linear port planning.

In this research, through the collection of existing views of dealing with uncertainties, a framework is developed upon three methods: 1. stakeholder analysis to a) identify port stakeholders, b) disclose stakeholder's objectives and subsequently define a port's success, and c) determine different planning horizons and corresponding uncertain developments and trends around the objectives and activities of the stakeholders, 2. SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to identify load-bearing uncertainties, opportunities, and vulnerabilities, and 3. a policy of dealing with uncertainties to make timely decisions and apply required actions to seize opportunities and manage vulnerabilities.

Eskafi et al. (2019) pointed out that port planning is affected by salient stakeholders during the projected lifetime of a port. Port sectors are in the state of radical changes, and the biggest challenge in port planning is to deal with confronting uncertainties during their long lifetime (Taneja, Ligteringen, and Walker 2012). In this context, Eskafi et al. (2021a) presented a framework to deal with uncertainties in the port planning process, aimed at seizing opportunities and managing vulnerabilities in different time horizons of the plan. Accounting for flexibility in the port planning stage avoids the downside of vulnerabilities and exploits the upside of opportunities. A flexible port can be adapted to a wide range of changes and thus prolongs the useful lifetime of port infrastructure and maintains the functionality of the port. Furthermore, flexibility facilitates achieving sustainable goals under market-driven conditions and satisfies the needs of stakeholders (Taneja, Ligteringen, and Walker 2012). The importance of sustainability and lifecycle considerations in port planning and design has increasingly been acknowledged (Sislian, Jaegler, and Cariou 2016). The next 20 years are expected to be dominated by innovation and development in sustainability and digital connectivity (Van Dorsser and Taneja 2020). Port development should 1- be in harmony with the surrounding community to maintain the social license to operate and grow, 2- responsible for the natural environment and fulfill environmental regulations, 3- promote economic development (PIANC 2014). To develop a sustainable port, a balanced paradigm of economic, social, environmental, and institutional dimensions should be taken into account. Investigation on sustainability in the port planning process facilitates decision making for strategic port planning to ensure sustainability in ports. Based on the sustainable dimensions a set of key performance indicators (KPIs) can be defined to interpret, develop, and evaluate sustainable port development plans. This research highlights the drivers, enablers, and barriers of flexibility and four dimensions of sustainability in port planning.

To protect a port plan against failing or departures from the pre-defined path, move it toward its success and 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 safeguard the main port plan by using timely and effective actions in order to make the main plan robust. Contingency plans are developed to avoid the creation of unprofitable capital-intensive at the beginning of the development plan.

A port development plan should not be assessed only based on a monetary value as the port development affects the surroundings (i.e., environment and society) either during the development phase, or exploitation phase when the port (activities) is operational. The importance of project appraisal in the port industry arises from accurately valuing the plan to identify the maximum profit for stakeholders. The valuation of the port development plan should account for a projected lifetime since the value of a project depends on future prices, future technology, and future conditions of the market (Taneja 2013). The use of a single best estimate of cost and value is not recommended for port development projects due to many surrounding uncertainties. Under uncertainty, the value of a plan is driven by the flexibility it provides for adaptation. Therefore, in project appraisal, flexibility should be evaluated, otherwise, the true value of a project is underestimated. To account for flexible and sustainable values, Multi-Criteria Analysis (MCA) is acknowledged as a suitable evaluation method in port planning (PIANC 2014, 1998).

Methods

Habegger (2010) stated that a single-issue focus of dealing with uncertainties is no longer sufficient. To deal with uncertainties against a broad range of present trends, possible, probable, preferable, panoramas (Marien, 2002), and wildcard futures, a stepwise framework is developed in the context of port planning. This framework is explained in this chapter.

Port Function and Port Activity

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 and Velsink, 2012). The functions of a port play an important role in decision making during the port planning process. These main functions are fulfilled by various port activities. To determine the port functions and port activities, information is obtained by literature (Ligteringen and Velsink, 2012; Rodrigue et al., 2010), port visits, and interviews with the Port Authority.

Stakeholder Analysis

Stakeholder engagement develops insights into a complex decision-making process. Timely and effective stakeholder engagement helps to uncover the drivers of port development that are aligned to their needs (Vellinga et al., 2017). Based on the functions of the port, stakeholder analysis is conducted to identify 1. Port stakeholders, 2. stakeholder's objectives (and ultimately define the success of the port planning), 3. different planning horizons and corresponding uncertain developments and trends around their objectives and activities. Based on stakeholder values, the Port Authorities should determine policy in the port planning process to be ahead of legislation (PIANC, 2014).

Identification of Time Horizon

Brier (2005) noted that forecasting with a long-time horizon is challenging as instability and uncertainties of variables are increased. Flechtheim (1971) stressed that studies about the future should always be connected in a time horizon. With a predefined time horizon, only the assumptions that change during a time horizon are considered vulnerable (Dewar, 2002). A linear demarcation of a time horizon from the present time to the future is a simplification and pragmatic. Masini (1993) asserted that time horizons are closely related to the subject under consideration. The time horizon was demarcated in terms of plausible changes and turbulence in a given timescale, rather than as an actual number of years.

Identification of Uncertainty

Uncertain developments and trends are part of the eternal cycle of the world and will stay forever. Van Dorsser et al. (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). To obtain insights into uncertain trends and developments, a separate in-depth face-to-face interview was conducted with representatives of key stakeholders. In the interview, uncertain trends and developments over the lifetime of the project were discussed.

Treatment of Uncertainty

To deal with uncertainties, the encountered level of them was taken into consideration. This leads to an appropriate approach to handle uncertainties (Walker, Lempert, and Kwakkel 2013). Based on the 4 levels of uncertainties (Walker, Marchau, and Kwakkel 2013), they can systematically be addressed (Van Dorsser et al., 2018) in the planning process. Hence, projected futures and level 1 uncertainty is addressed by deterministic forecasting. Probable futures and level 2 uncertainty is handled by probabilistic forecasting (Armstrong, 2001). Plausible futures and level 3 uncertainty is considered by strategic foresight (Van Dorsser and Taneja, 2020). Possible futures and level 4 uncertainty is accounted for by (non-fiction) visualization of any possible future (Haasnoot et al., 2013).

SWOT Analysis

Ward and Chapman (2003) stated that uncertainty can be either an opportunity or a vulnerability. Based on uncertainty, Dewar (2002) identified load-bearing assumptions as explicit and implicit assumptions that are made in a planning process. If an assumption is in favor of the plan, it is called an opportunity, and if it causes the plan to fail it is a vulnerability. To identify the opportunities and vulnerabilities, a port SWOT analysis was carried out. SWOT analysis is a straightforward process to recognize the capability and inability of a system.

Dealing with Uncertainty in the Port Planning Process

In the presence of deep uncertainty, a successful method is to consider a large range of futures and systematically explore the consequences of load-bearing assumptions (Walker, Lempert, and Kwakkel 2013). By analyzing the strengths and weaknesses of the port in conjunction with the vulnerabilities and opportunities a multiplicity of actions can be crafted. These actions, which are taken in response to the load-bearing assumptions, are described as: 1- shaping actions to affect and reduce vulnerable assumptions, change their nature, prevent their development, and direct them towards a preferred plan; 2- mitigating actions to affect certain vulnerable assumptions and reduce the potential adverse effects; 3- hedging actions to spread and reduce highly uncertain adverse effects of vulnerable assumptions. These three actions are taken if the assumptions start to fail. Finally, 4- seizing actions are to take advantage of fairly certain opportunities.

Flexibility and Sustainability

To deal with uncertainty and adapt to changes, flexibility in port planning should be accounted for (Taneja 2013). To develop flexibility in the port planning process, its drivers, barriers, and enablers of flexibility in the port sector should be identified. Furthermore, well-known initiatives in port sustainability (i.e., economic, social, environmental impact) such as sustainable ports, eco-ports, and green ports have been developed by the European Sea Ports Organization (ESPO) or the World Association for Waterborne Infrastructure (PIANC). Increase attention to global warming and climate change has created a greater emphasis on the environmental impact of port development projects. In this vein, PIANC stressed, "an economic green growth strategy", "working with nature philosophy", "corporate social responsibility", and "stakeholder participation" (PIANC 2014). Sislian, Jaegler, and Cariou (2016) reviewed the literature on port sustainability and stated that sustainable port development should be addressed globally based on economic, social, and environmental dimensions. However, an institutional dimension has been advocated in sustainable port development. The institutional dimension is a transparent and independent form of governance to formulate policies by institutions to ensure the development and equilibrium of the other three dimensions (Laxe et al. 2017). Therefore, economic, social, and environmental dimensions are the effects of the institutional one (Molina Serrano et al. 2018).

Contingency Plan

A contingency plan is a provision/alternative plan that safeguards the main plan. Taneja (2013) presented four different types of action that can be applied in a contingency plan to reduce the negative impact of the vulnerabilities and seize/increase the positive impact of opportunities. These actions are as follows:

- Defensive actions: as long as the plan is moving toward its success, these actions are applied to preserve incoming benefits.

- Capitalizing actions: using these actions adjustments are made to seize new opportunities and further improve the performance of the main plan.

- Corrective actions: these actions are developed to meet challenges and handle vulnerabilities that appear in the projected lifetime of the main plan.

- Reassessment actions: these actions are initiated to reassess the (entire) plan and execute required changes when the plan loses its validity and is not moving toward its success anymore.

Limitations and Advantages of Evaluation Methods

To assess the feasibility of port investments Discounted Cash Flow methods (DCF) are used. In DCF, the cash flow of a project is determined and financial parameters including Internal Rate of Return (IRR) or Net Present Value (NPV) are estimated. However, IRR is not suitable to compare alternative plans that are substantially different in size and outcome. IRR does not account for risks. NPV is better than IRR, as it considers the entire lifetime of the investment and the time value of money, as well as risk levels by using different discount rates. Another disadvantage of DCF is that the method uses the expected (or most likely) value of an investment and potential revenues. However, the expected value can deviate from the actual value and cash flow is not fixed over a projected lifetime of the plan. This discrepancy leaves serious drawbacks in the project appraisal. DCF methods are suitable for consistent risk, clear investment choices, and contingent decisions. Therefore, the methods may not be suitable for a port project due to the existence of many uncertainties in the long lifetime of the port (Dixit and Pindyck 1994). Flexibility increases the value of port projects, but it cannot be accounted for in DCF as these methods assume a stable environment and a fixed cash flow during the projected lifetime of a plan. These methods do not evaluate (costs and values) the environmental and societal impacts of port projects (Taneja 2013).

Decision Tree Analysis (DTA) is ideal when the investment alternatives/choices and contingent decisions are well-defined, and the likelihood and timing of critical uncertainties are understood (De Neufville et al. 2008). However, DTA is difficult to be used when there are multiple sources of uncertainty and the choice of discount rate is subjective (Taneja 2013). Real Options Analysis (ROA) methods include partial differential equations that are solved using closed-form solutions, analytical approximations, and numerical methods. In ROA, financial options are subject to market and non-market uncertainties and input data for models are difficult to be obtained. Another disadvantage of ROA is its inherent complexity and black-box nature of the analysis. A real options analysis may not be suitable in the port project appraisal, as many assumptions that should be considered in financial options are invalid for port projects (Taneja 2013). Simulation methods describe uncertain variables in a cash flow model in terms of probability distributions. Simulation using stochastic methods is useful, as it includes uncertainties and evaluates costs and benefits of flexibility. Furthermore, simulation can provide additional risk information and thus facilitates decision making on marginal projects. It also results in a range and distribution of the possible outcomes and likelihood of their occurrences. In simulation methods, the uncertainty inherent in all estimates can be made explicit. Multiple variables can be used as input in simulation methods. An example of simulation methods in port project appraisal is the Monte-Carlo Simulation (MCS) of NPV that calculates the expected return of the project. Furthermore, the statistical information (e.g., mean, standard deviation, min, max) obtained from simulation provides useful information in the project appraisal (Taneja 2013).

Results and discussion

Port Functions and Port Activities

The main functions of the Ports of Isafjordur Network are: 1- transfer and storage of cargo, including container, dry bulk, liquid bulk, general cargo; 2- industrial value-added activities, including marine productions and fish processing; 3- recreational activities, including servicing expedition and cruise ships, servicing small private and sailing boats, and water sport activities.

Identification of Uncertainties

The result of stakeholder analysis for port master planning in Iceland (Eskafi et al., 2019) concluded that internal, external, legislation and public policy stakeholder groups are the key stakeholder groups. In the present research, separate interviews were held with representatives of these three groups, aimed at deliberating the broadest range of uncertainties.

Table 4.1. Dealing with uncertainty based on the functions of the port during the projected planning horizon.

Port function	Uncertainty	Underlying assumption	Time horizon (uncertainty level)	Alternative	Load-bearing assumption	Action
Transfer of cargo	Container flow	Increase in container-vessel calls	Short (1)	Using the existing container handling infrastructures and facilities of the network.	The Port of Isafjordur has enough capacity.	*Seizing:* Attract the market as the port has a competitive position in the region.
			Middle (2)	Change the distribution of cargo to the hinterland by the coastal shipment (use intermodal and co-modal).	An increase in the shipping traffic proves hazardous for nautical safety. Existing road capacity and port accessibility cause congestion.	*Seizing:* Attract the market by lower terminal handling costs and coastal shipping capacity.
		Increase in container vessel size	Short (1)	Using the existing container handling infrastructures and facilities of the network.	The Port of Isafjordur has enough capacity.	*Seizing:* Attract the vessels as the network has enough infrastructures.
			Middle (1)	Improve the quay length, berthing capacity, and access channel. Although the	Capital investment is required. Dredging material and reclamation land may increase environmental concerns.	*Shaping:* Improve the required infrastructure and facilities at the Port of Isafjordur.
	Dry bulk and general cargo flow	Increase in dry bulk and general cargo vessel calls	Short (1)	Using the existing handling infrastructures and facilities of the network.	The Port of Isafjordur has enough capacity.	*Seizing:* Attract the market as the port of Isafjordur has a competitive position in the region.

(Continued)

Table 4.1. (Continued) Dealing with uncertainty based on the functions of the port during the projected planning horizon.

Port function	Uncertainty	Underlying assumption	Time horizon (uncertainty level)	Alternative	Load-bearing assumption	Action
			Middle (2)	Using the existing handling infrastructures and facilities. Using the potential of other ports in the network.	The Port of Isafjordur has enough capacity. The facility and infrastructure of the Ports of Flateyri, Sudureyri, Thingeyri should be upgraded.	*Seizing:* Attract the market as the Port of Isafjordur has a competitive position in the region. *Shaping:* Improve the smaller ports in the network.
Storage of cargo	Storage of containers	Increase in use of containers	Short (1)	Use the existing port capacity.	The Port of Isafjordur has enough capacity.	*Seizing:* Attract the market as the port has a competitive position in the region.
			Middle (2)	Invest in a multi-user terminal at a strategic location.	Capital investment is required. Society's acceptance of port expansion is unclear.	*Shaping:* Build the container terminal using the land behind the Port of Isafjordur.
	Dry bulk storage	Increase in dry bulk	Short (1)	Use the existing port capacity.	The port network has enough capacity.	*Seizing:* Attract the market as the Port of Isafjordur has a competitive position in the region.
			Middle (2)	Use the land behind the Port of Isafjordur.	There is no specific area for the depot and land is limited.	*Shaping:* Build the required storage area at the Port of Isafjordur.
	Storage of liquid bulk	Increase in liquid bulk storage	Short (1)	Use the existing capacity in the network.	The ports in the network have enough tanker capacity and bunkering facilities.	*Seizing:* Attract the market.
			Middle (3)	Building a tanker with enough capacity. Increase in bunkering facilities.	Change in safety zone distance for the port activities (e.g., liquid storage terminal) from the residential area.	*Shaping:* Upgrade Mooring and berthing facilities. *Shaping:* Provide a suitable location for the new tanker.

(Continued)

Table 4.1. (Continued) Dealing with uncertainty based on the functions of the port during the projected planning horizon.

Port function	Uncertainty	Underlying assumption	Time horizon (uncertainty level)	Alternative	Load-bearing assumption	Action
		A decrease in liquid bulk storage	Short (1)	Use the existing capacity in the network.	The ports in the network have enough tanker capacity and bunkering facilities.	*Seizing:* Attract the market.
			Middle (2)	Building the required infrastructure in the port area to produce or store renewable energy.	Capital investment is required.	*Shaping:* Build the infrastructure and provide the required facilities in the Port of Isafjordur.
Industrial/ value-added activities	Marine production	Increase in marine productions, processing, and packing	Short (1)	Use the existing potential of the ports in the network.	The Port of Isafjordur has enough facilities.	*Seizing:* Attract the market.
			Middle (3)	Cluster the activities in the port of Isafjordur. Develop fish terminals and refrigerated storage or warehousing, fish landing, handling, and cross-docking facilities next to the quay.	Climate change has direct and indirect impacts on the layers of the ports (infrastructure, service, and operation) and thus affect the industries in the port area. This affects the competitive position of the port (Asariotis et al., 2017; Wright, 2013).	*Seizing:* Attract new markets by providing infrastructure and facilities. *Hedging:* Accommodate fish landing facilities in other ports. *Mitigating:* Improve the port infrastructure and facilities.
	There is a possibility of servicing vessels with renewable energy.		Short (1)	This development is not materialized.	-	-
			Middle (3)	Development of smart grid solutions.	Capital investment is needed. The Port of Isafjordur should provide infrastructure and facilities.	*Shaping:* build the infrastructure and provide the required facilities in the ports.
Recreational services	Servicing expedition/cruise ships	Increase in expedition/cruise ship calls	Short (1)	Use the existing potential of all ports in the network.	The Port of Isafjordur has enough facilities.	*Seizing:* Attract the market by amenities of the ports for tourists.

(Continued)

Table 4.1. (Continued) Dealing with uncertainty based on the functions of the port during the projected planning horizon.

Port function	Uncertainty	Underlying assumption	Time horizon (uncertainty level)	Alternative	Load-bearing assumption	Action
				Expedition vessels can be serviced at the smaller ports in the network.	However, at this port servicing cruise ships (4 or more) on the same day increases congestion and decreases the quality of service.	*Hedging:* Use the small ports in the network for the small expedition/ cruise ships.
			Middle (2)	Increase berthing capacity and infrastructures of the Port of Isafjordur.	The Port of Isafjordur should be upgraded.	*Shaping:* Provide enough infrastructure and facilities at the port.
		Increase in cruise ship size	Short (1)	Use the existing potential of the ports in the network.	The Port of Isafjordur has enough facilities.	*Seizing:* Attract the market.
			Middle (2)	Use the existing potential of the ports in the network.	The Port of Isafjordur should be upgraded. There may be a growing public opposition against the environmental impacts of large cruise vessels and the safety/congestion.	*Shaping:* Increase berthing and embarkment capacity. *Mitigating:* Service more environmentally friendly vessels to create a better attitude from society.
	Servicing small private, yacht, sailing boats	Increase in the number of vessels.	Short (1)	Use the existing infrastructure and facilities of the ports in the network.	The network has enough facilities.	*Seizing:* Attract the market.
			Middle (1)	Upgrade the infrastructure and facilities of the ports in the network.	Capital investment is required.	*Shaping:* Provide the required infrastructure.
	Recreational activities	Sport activities	Short (1)	Use the existing infrastructure and facilities of the ports in the network.	The network has enough facilities.	*Seizing:* Attract the market.
			Middle (1)	Upgrade the existing infrastructure and facilities of the ports.	These activities in the port area require safety distance from the port activities and sailing routes.	*Shaping:* Provide the required infrastructure and facilities.

In a bid to reduce possible bias and cover a wider possible range of information that should be accounted for in the analysis, five representatives in the external stakeholder group were interviewed based on the functions of the ports network, including: 1- fishing, 2- aquaculture, 3- cargo handling and transportation, 4- expedition and cruise, and 5. the Port Association of Iceland. Table 4.1 summarizes the identified uncertainties and corresponding assumptions in conjunction with the results of the SWOT analysis. The required actions in response to the assumptions are described to move the plan toward its success (Eskafi et al., 2021a).

Time Horizon

Five years (2020-2025) and 25 years (2025-2050) were considered short- and middle-time horizons, respectively. Five years are chosen as the short-time horizon because this is a development phase in the Port of Isafjordur. The project is expected to be accomplished before 2025. Also, this time horizon covers the duration of the Icelandic Road and Coastal Administration’s policy from 2020 to 2025 (Icelandic Road and Coastal Administration, 2019). The ports network users, including fisheries and related activities, for instance, processing and packing of marine products, and transportation companies, are developing their commerce in the port area. The 25-year middle-time horizon would capture their socio-techno-economic developments and innovative activities.

Transferability of Uncertainty Analysis

For future port expansion and (operational) growth, the plan should cope with the limited land in and around the ports, insufficient landside accessibility, hinterland connections, and consequently, increased interactions between the ports and towns. This is in line with the literature, wherein increasing the effective and efficient use of land in and around the port was demanded by the port stakeholders (Eskafi et al., 2020a).

Servicing the relatively small cruise and expedition vessels can be decentralized from the Port of Isafjordur to the smaller ports in the network. The Port Authority should maximize the use of the ports in the network. This results in changes in optimal distribution and decentralization of activities, which requires new infrastructure and a hinterland connection.

Fishing and aquaculture activities are growing fast with rapid changes to win national and international markets. These external stakeholders have high salience (Eskafi et al., 2019) and their demand should be satisfied by, in time development of the network. Otherwise, these stakeholders may use neighboring ports, which could threaten the competitive position of the port network. Export of farmed and wild, frozen and fresh, 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. The relative market sector has a high potential for growth and earnings. Vessel size has increased to utilize economies of scale. To foster this growth, investment in terms of 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 of growing businesses in the network, in the region, and even in neighboring countries.

To create synergy between related activities in the port area and the benefits accrued to them, port clusters should be used. The clustering of relevant activities would alleviate 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 the export of marine catches and products. This increases professionalism in the port and value-added activities wherein several industries operate.

Flexibility and Sustainability in the Port Planning

Increasing volatility, policy changes, limited space for port expansion, increased competition, higher productivity and efficiency requirements, and new technology that leads to changing requirements are some of the drivers of flexibility. A lifecycle perspective, new design and construction methods, new technologies and innovation in port infrastructure, operation, and services, new evaluation methods that account for flexibility in the port planning process are enablers of flexibility. Different perceptions/contexts of flexibility, by various stakeholders involved in a port development project, is one of the barriers to incorporate flexibility in the planning process. Port planning projects are usually fixed in terms of costs and schedules. Therefore, including flexibility may be seen as a risk to on-time and on-budget port planning and development. This is usually the case in short-term horizon port planning whereas the planning process is not confronted with uncertainty (Taneja 2013).

Laxe et al. (2017) stated that to address sustainability in port planning, port authorities can use the global synthetic indexes of sustainability. Table 4.2 gives a summary of indicators of sustainable dimension that can be taken into consideration in the port planning process (Laxe et al. 2017; Di Vaio, Varriale, and Alvino 2018).

Table 4.2. Dimensions and subtopic of sustainability in port planning

Dimension	Subtopic
Economic	economic structure, business, and servicing, benefit, market share, hinterland connection, logistic chain from a supply place to a receipt place connectivity, the financial situation of port and turnover improvement, concessional revenues growth, debt risk reduction, profitable investment in port assets
Environmental	environmental management, eco-efficiency, environmental quality (water, air, soil, noise, sight), area productivity, ecological and biodiversity risks consideration, natural resources conservation, reduction in the negative environmental impact of port activities, accident reduction, energy-saving/emission-reducing, waste handling
Social	social capital, human capital, fairness, well-being (human rights, education), urbanization, job market, public welfare, human resources policy (training, competency-based management, safety and health, legal changes promotion, market competition recognition, port community development, port-city relationship
Institutional	institutional capacity, protection of human and natural capital, market-driven objectives, financial feasibility, institutional communication, operational efficiency, service quality, motivated and committed management system, human resources development

Conclusions

Addressing uncertainties is an important task to improve the quality of long-term port planning in a volatile world. This research presents a framework that benefits from different scientific methods to deliver a policy for port planning under uncertainties that better stand the vagaries of the future. The framework deals with uncertain developments and trends that emerge over the projected lifetime of the port plan. Thus, the inevitable changes become part of a recognized process and the plan is not forced to be re-made repeatedly on an ad-hoc basis. The non-linearity of dealing with uncertainties by the framework presented in this research provides a better plan toward its success. Thus, the Port Authority can strategically develop the port in the face of uncertainty.

The results indicate that fishing, aquaculture, and expedition/cruise activities have the main uncertainties for the Ports of Isafjordur Network. The growth of these activities increases conflict in and around the port areas. Port clusters should be materialized to increase safety and improve value-added activities in the port areas. The Port Authority should be proactive (instead of reactive) 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 a volatile environment.

Accounting for costs and benefits of flexibility in the port planning process provides useful information to decision makers and port planners to develop flexibility in the port layers including infrastructure, operation, and services. Therefore, a developed port can better meet new, changing, and uncertain demands. Furthermore, focused on dimensions of sustainability including economic, social, environmental, and institutional dimensions, a set of indicators were developed. A scientific bottom-up assessment and implications of the indicators in the planning process facilitate achieving sustainability in port development and management. Nevertheless, sustainability in port has focused much attention on environmental issues rather than other dimensions of sustainability. Sustainable port planning is mostly focused on improving environmental performance, natural conservation, and ecological protection. To develop a sustainable port, a balance paradigm of dimensions should be examined in the planning process. To protect a port plan against failure by handling opportunities and vulnerabilities and move it toward its success, contingency plans are developed. The contingency plans include timely and effective actions (i.e., defensive, capitalizing, corrective, reassessment) in order to make the main plan robust. To achieve a useful and consistent comparison of alternatives in the port planning process the economic analysis methods for instance simulation or decision tree analysis are to be adequate. These methods give relatively insightful and realistic results and thus provide support for decision makers in the port planning process. To account for the costs and benefits of flexible and sustainable values, multi-criteria analysis is a suitable evaluation method.

Reference

Ackermann, F. (2012). Problem structuring methods "in the Dock": Arguing the Case for Soft or. *European Journal of Operational Research*, 219(3), 652–658. https://doi.org/10.1016/j.ejor.2011.11.014

Arecco, P., Vellinga, T., Hertogh, M., Oosting, M., Taneja, P., and Vervoorn, P. (2016). Formulating goals towards success for Adaptive Port Planning Applied case: Europoort at Port of Rotterdam. *Proceedings of the 9th PIANC-COPEDEC 2016 Conference*. P.20. Rio de Janeiro, Brazil.

Armstrong, J. S. (2001). *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Springer US. https://www.springer.com/gp/book/9780792379300

Asariotis, R., Benamara, H., and Mohos-Naray, V. (2017). *Port Industry Survey on Climate Change Impacts and Adaptation* (No. 18; p. 66). UNCTAD. https://unctad.org/en/PublicationsLibrary/ser-rp-2017d18_en.pdf

Bettis, R. A., and Hitt, M. A. (1995). The new competitive landscape. *Strategic Management Journal*, 16(S1), 7–19. https://doi.org/10.1002/smj.4250160915

Belton, V., and Stewart, T. (2010). *Problem Structuring and Multiple Criteria Decision Analysis, Trends in Multiple Criteria Decision Analysis*. Springer.

Brier, D. J. (2005). Marking the future: A review of time horizons. *Futures*, 37(8), 833–848. https://doi.org/10.1016/j.futures.2005.01.005

Chapman, C., and Ward, S. (2003). *Project Risk Management. Process, Techniques, and Insights. Second Edition*. John Wiley and Sons. https://eprints.soton.ac.uk/35839/.

Chen, Z., Chen, Y., and Li, T. (2016). *Port cargo throughput forecasting based on combination model*. Joint International Information Technology, Mechanical and Electronic Engineering Conference. https://doi.org/10.2991/jimec-16.2016.25

De Langen, P. W., Van Meijeren, J., and Tavasszy, L. A. (2012). Combining Models and Commodity Chain Research for Making Long-Term Projections of Port Throughput: An Application to the Hamburg-Le Havre Range. *European Journal of Transport and Infrastructure Research*, 12 (3). http://resolver.tudelft.nl/uuid:e157a61d-3ac6-46df-a47f-308fc0b2ab3d

De Neufville, R., Hodota, K., Sussman, J., and Scholtes, S. (2008). Real Options to Increase the Value of Intelligent Transportation Systems. *Transportation Research Record* 2086 (1), 40–47. https://doi.org/10.3141/2086-05.

Dewar, J. A. (2002). *Assumption-Based Planning* [Cambridge Books]. Cambridge University Press. https://econpapers.repec.org/bookchap/cupcbooks/9780521001267.htm

Di Vaio, A., Varriale, L., and Alvino, F. (2018). Key Performance Indicators for Developing Environmentally Sustainable and Energy Efficient Ports: Evidence from Italy. *Energy Policy,* 122 (November): 229–40. https://doi.org/10.1016/j.enpol.2018.07.046.

Dixit, A, and Pindyck, R. (1994). *Investment Under Uncertainty*. N.J: Princeton University Press.

Eskafi, M., Fazeli, R., Dastgheib, A., Taneja, P., Ulfarsson, G. F., Thorarinsdottir, R. I., and Stefansson, G. (2019). Stakeholder salience and prioritization for port master planning, a case study of the multi-purpose Port of Isafjordur in Iceland. *European Journal of Transport and Infrastructure Research*, 19(3), 214–260. https://doi.org/10.18757/ejtir.2019.19.3.4386

Eskafi, M., Fazeli, R., Dastgheib, A., Taneja, P., Ulfarsson, G. F., Thorarinsdottir, R. I., and Stefansson, G. (2020a). 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), 403–31. https://doi.org/10.1057/s41278-019-00134-6

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

Eskafi, M., Dastgheib, A., Taneja, P., Ulfarsson, G. F., Stefansson, G., and Thorarinsdottir, R. I. (2021a). 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

Eskafi, M., Kowsari, M., Dastgheib, A., Ulfarsson, G. F., Stefansson, G., Taneja, P., and Thorarinsdottir, R. I. (2021b). A model for port throughput forecasting using Bayesian estimation. *Maritime Economics and Logistics*. https://doi.org/10.1057/s41278-021-00190-x

Flechtheim, O. K. (1971). *Futurologie. Der Kampf um die Zukunft*. Wiss. u. Pol., Köln.

Fraser, A. M., and Swinney, H. L. (1986). Independent coordinates for strange attractors from mutual information. *Physical Review A,* 33(2), 1134.

Geweke, J., and Whiteman, C. (2006). Handbook of economic forecasting, Chapter 1 Bayesian forecasting. In G. Elliott, C. W. J. Granger, and A. Timmermann (Eds.), *Handbook of economic forecasting* (Vol. 1, pp. 3-80). Elsevier. https://doi.org/10.1016/S1574-0706(05)01001-3

Gökkuş, Ü., Yıldırım, M. S., and Aydin, M. M. (2017). Estimation of container traffic at seaports by using several soft computing methods: a case of Turkish seaports. *Discrete Dynamics in Nature and Society*, 2017. https://doi.org/10.1155/2017/2984853

Gosasang, V., Chandraprakaikul, W., and Kiattisin, S. (2010). An application of neural networks for forecasting container throughput at Bangkok Port. *Proceedings of the World Congress on Engineering*, *1*.

Guo, Z., Song, X., and Ye, J. (2005). A Verhulst model on time series error corrected for port throughput forecasting. *Journal of the Eastern Asia Society for Transportation Studies*, 6, 881-891.

Haasnoot, M, Kwakkel, J. H., Walker, W. E., and Ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Habegger, B. (2010). Strategic foresight in public policy: Reviewing the experiences of the UK, Singapore, and the Netherlands. *Futures*, 42(1), 49–58. https://doi.org/10.1016/j.futures.2009.08.002

Hanushek, E. A., and Kimko, D. D. (2000). Schooling, labor-force quality, and the growth of nations. *The American Economic Review*, 90(5), 1184-1208.

Hafnasamband Íslands. (2014). *Skýrsla stjórnar Hafnasambands Íslands* (Report of the Board of the Icelandic Association of Icelandic Association 2012-2014). Iceland: Hafnasamband Íslands. http://hafnasamband.is/wp-content/uploads/2014/09/Sk%C3%BDrsla-stj%C3%B3rnar-2014.pdf

Heaver, T., Meersman, H., Moglia, F., and Van de Voorde, E. (2010). Do mergers and alliances influence European shipping and port competition?, 27(4), 363–373. https://doi.org/10.1080/030888300416559

Herder, P. M., Bouwmans, I., Dijkema, G. P. J., Stikkelman, R. M., and Margot P.C.W. (2008). Designing infrastructures using a complex systems perspective. *Journal of Design Research*, 7(1), 17–34. https://doi.org/10.1504/JDR.2008.018775

Hoehn, A. R., Solomon, R. H., Efron, S., Camm, F., Chandra, A., Knopman, D., Laird, B., Lempert, R. J., Shatz, H. J., and Yost, C. (2017). *Strategic Choices for a Turbulent World, In Pursuit of Security and Opportunity*. RAND Corporation. https://www.rand.org/content/dam/rand/pubs/research_reports/RR1600/RR1631/RAND_RR1631.pdf

Icelandic Directorate of Fisheries. (2021). *Find ship, Individual vessels, Web Directorate of Fisheries*. Vefur Fiskistofu. http://www.fiskistofa.is/english/quotas-and-catches/total-catches-by-harbours-months-and-vessel-type/

Icelandic Road and Coastal Administration. (2019). Policy "*Stefna" 2020-2025*. http://www.vegagerdin.is/vefur2.nsf/Files/Stefna_2020-2025/$file/stefna%20fyrir%20vef.pdf

Isafjordur Port Authority. (2021). *Port of Isafjordur, Cruise ship 2018*. Skemmtiferðaskip 2018. http://port.isafjordur.is/index.php?pid=1&w=s

Keeney, R. L., and McDaniels, T. L. (1999). Identifying and Structuring Values to Guide Integrated Resource Planning at BC Gas. *Operations Research*, 47(5), 651–662. https://doi.org/10.1287/opre.47.5.651

Kraskov, A., Stögbauer, H., and Grassberger, P. (2004). Estimating mutual information. *Physical Review E*, 69(6), 066138.

Laxe, F. G., Bermúdez, F. M., Palmero, F. M., and Novo-Corti, I. (2017). Assessment of Port Sustainability through Synthetic Indexes. Application to the Spanish Case. *Marine Pollution Bulletin*, 119 (1), 220–25. https://doi.org/10.1016/j.marpolbul.2017.03.064.

Ligteringen, H., and Velsink, H. (2012). *Ports and terminals*. VSSD.

Maes, F., Collignon, A., Vandermeulen, D., Marchal, G., and Suetens, P. (1997). Multimodality image registration by maximization of mutual information. *IEEE Transactions on Medical Imaging*, 16(2), 187-198.

Marien, M. (2002). Futures studies in the 21st century: A reality-based view. *Futures*, 34(3–4), 261–281. Scopus. https://doi.org/10.1016/S0016-3287(01)00043-X

Masini, E. (1993). *Why Futures Studies?* Grey Seal Books.

Mayers, J. (2005). *Stakeholder power analysis*. International Institute for Environment and Development (IIED). http://www.policy-powertools.org/Tools/Understanding/docs/stakeholder_power_tool_english.pdf

Midgley, G., Cavana, R. Y., Brocklesby, J., Foote, J. L., Wood, D. R. R., and Ahuriri-Driscoll, A. (2013). Towards a new framework for evaluating systemic problem structuring methods. *European Journal of Operational Research*, 229(1), 143–154. https://doi.org/10.1016/j.ejor.2013.01.047

Molina Serrano, B., González-Cancelas, N., Soler-Flores, F., Awad-Nuñez, S., and Camarero Orive, A. (2018). Use of Bayesian Networks to Analyze Port Variables in Order to Make Sustainable Planning and Management Decision. *Logistics*, 2 (1). Multidisciplinary Digital Publishing Institute: 5. https://doi.org/10.3390/logistics2010005.

Notteboom, T. E., and Winkelmans, W. (2001). Reassessing Public Sector Involvement in European Seaports. *International Journal of Maritime Economics*, 3(2), 242–259. https://doi.org/10.1057/palgrave.ijme.9100008

Notteboom, T, and Winkelmans, W. (2002). Stakeholder Relations Management in ports: dealing with the interplay of forces among stakeholders in a changing competitive environment.

In *Maritime Economics: setting the foundations for port and shipping policies (IAME)*. Panama City, Panama.

Prakoso, A., Taneja, P., and Velinga, T. (2018). Adaptive Port Planning under Disruptive Trends with focus on the case of The Port of Kuala Tanjung, Indonesia. *MATEC Web of Conferences*, 147, 05006. https://doi.org/10.1051/matecconf/201814705006

Peng, W.Y., and Chu, C.W. (2009). A comparison of univariate methods for forecasting container throughput volumes. *Mathematical and Computer Modelling*, 50(7), 1045-1057. https://doi.org/10.1016/j.mcm.2009.05.027

PIANC. (1998). Planning of Fishing Ports. 18. Brussels: The World Association for Waterborne Transport Infrastructure.

PIANC. (2014). Sustainable Ports, a Guide for Port Authorities. 150. Brussels: The World Association for Waterborne Transport Infrastructure.

Rosenhead, J. (1996). What's the problem? An introduction to problem structuring methods. *Interfaces*, 26(6), 117–131. https://doi.org/10.1287/inte.26.6.117

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27(3), 379-423.

Sislian, L., Jaegler, A., and Cariou, P. (2016). A Literature Review on Port Sustainability and Ocean's Carrier Network Problem. *Research in Transportation Business and Management* 19: 19–26. https://doi.org/10.1016/j.rtbm.2016.03.005.

Slinger, J., Taneja, P., Vellinga, T., and Van Dorsser, C. (2017). *Stakeholder inclusive design for Sustainable Port Development*. Presented at the MTEC2017, Singapore.

Smil, V. (2012). *Global Catastrophes and Trends: The Next Fifty Years*. Cambridge, The MIT Press.

Soofi, E. S., Zhao, H., and Nazareth, D. L. (2010). Information Measures. *Wiley Interdisciplinary Reviews: Computational Statistics*, 2 (1). Wiley Online Library: 75–86.

Statistics Iceland Office. (2021). Statistics Iceland. *Hagstofa*. https://statice.is.

Suykens, F., and Voorde, E. V. D. (1998). A quarter a century of port management in Europe: objectives and tools. *Maritime Policy and Management*, 25(3), 251–261. https://doi.org/10.1080/03088839800000037

Taneja, P. (2013). The Flexible Port. Delft, the Netherlands: Delft university of technology. https://doi.org/10.4233/uuid:a9f0c128-d4c3-41a2-8790-13aec89dca63.

Taneja, P., Ligteringen, H., and Van Schuylenburg, M. (2010). Dealing with uncertainty in design of port infrastructure systems. *Journal of Design Research*, *8*(2), 101–118. https://doi.org/10.1504/JDR.2010.032073

Taneja, P., Ligteringen, H., and Walker, W.E (2012). Flexibility in Port Planning and Design. *European Journal of Transport and Infrastructure Research,* 1 (12), 66–87. https://doi.org/10.18757/ejtir.2012.12.1.2950.

Van Dorsser, J.C.M, and Taneja, P. (2020). An Integrated Three-Layered Foresight Framework. *Foresight,* 22 (2). https://doi.org/10.1108/FS-05-2019-0039.

Van Dorsser, J. C. M., Wolters, M., and Van Wee, B. (2012). A very long-term forecast of the port throughput in the Le Havre-Hamburg range up to 2100. *European Journal of Transport and Infrastructure Research, 12*(1). https://doi.org/10.18757/ejtir.2012.12.1.2951

Van Dorsser, J. C. M., Walker, W. E., Taneja, P., and Marchau, V. A. W. J. (2018). Improving the link between the futures field and policymaking. Futures, 104, 75–84. https://doi.org/10.1016/j.futures.2018.05.004

Vellinga, T., Slinger, J., Taneja, P., and Vreugdenhil, H. (2017). Integrated and Sustainable Port Development in Ghana. Presented at the Proceedings of MTEC2017, Singapore. http://sustainableportsafrica.com/onewebmedia/Integrated%20and%20Sustainable%20Port%20Development%20in%20Ghana.pdf

Walker, W. E., Lempert, R. J., and Kwakkel, J. H. (2013). Deep Uncertainty. In *Encyclopedia of Operations Research and Management Science*, edited by S. I. Gass and M. C. Fu, 395–402. Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-1153-7_1140.

Walker, W. E., Marchau, V. A. W. J., and Kwakkel, J. H. (2013). Uncertainty in the Framework of Policy Analysis. In W. A. H. Thissen and W. E. Walker (Eds.), *Public Policy Analysis: New Developments* (pp. 215–261). https://doi.org/10.1007/978-1-4614-4602-6_9

Ward, S., and Chapman, C. (2003). Transforming project risk management into project uncertainty management. *International Journal of Project Management*, 21(2), 97–105. https://doi.org/10.1016/S0263-7863(01)00080-1

Wright, G., and Cairns, G. (2011). *Scenario thinking: Practical approaches to the future*. Basingstoke, UK: Palgrave Macmillan. ISBN 13: 9780230271562

Wright, P. (2013). Impacts of climate change on ports and shipping. *Marine Climate Change Impacts Partnership: Science Review*, 263–270. https://doi.org/doi:10.14465/2013.arc28.263-270

Woo, J.K., Moon, D. S. H., and Lam, J. S. L. (2017). The impact of environmental policy on ports and the associated economic opportunities. *Transportation Research Part A: Policy and Practice*. https://doi.org/10.1016/j.tra.2017.09.001