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Framework for dealing with uncertainty in the port planning process

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Abstract

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

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

Introduction

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

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

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

Under volatile circumstances, dealing with uncertainties in the planning process increases the success of long-lifetime projects (García-Morales et al. 2015). Taneja et al. (2012a) stated that the main reason for unsuccessful port development projects is inadequate consideration of uncertainty in the planning process. Unsuccessful port projects may result in a loss of investment, failure of the projects, congestion in the port area or hinterland, redundancy and obsolescence of ports, or costly regular adaptations of port infrastructure (e.g., deepening of access channel), operational facilities (e.g., using larger quay crane), and services (e.g., providing renewable energy fuel to vessels) (Taneja et al. 2012a; b). In addition, comes the loss of competitive position, cargo, and revenue during the period that the port cannot be used due to the adaptation.

Traditional linear planning of infrastructure projects usually beset the bad side of uncertainty, without taking advantage of their potential (Taneja 2013). Salling and Nielsen (2015) pointed out that in most transport projects there is no recommendation for doing an ex-ante-based evaluation of uncertainties.

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

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

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

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

This article is structured into six sections. The next section sheds light on port planning under conditions of uncertainty. The method used is characterized in the third section. The fourth section describes the study area and presents the results for the case study of the Ports of Isafjordur Network in Iceland. The fifth section discusses the findings, and the last section draws conclusions on dealing with uncertainties in port planning for the case study.

Planning under uncertainty

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

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

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

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

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

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

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

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

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

Methods

Habegger (2010) stated that a single-issue focus of dealing with uncertainties, including opportunities and vulnerabilities, is no longer sufficient. To deal with uncertainties against projected, probable, plausible, possible futures (Van Dorsser et al. 2018b), a framework needed to be developed and adapted to port planning. The framework is depicted in Figure 1.

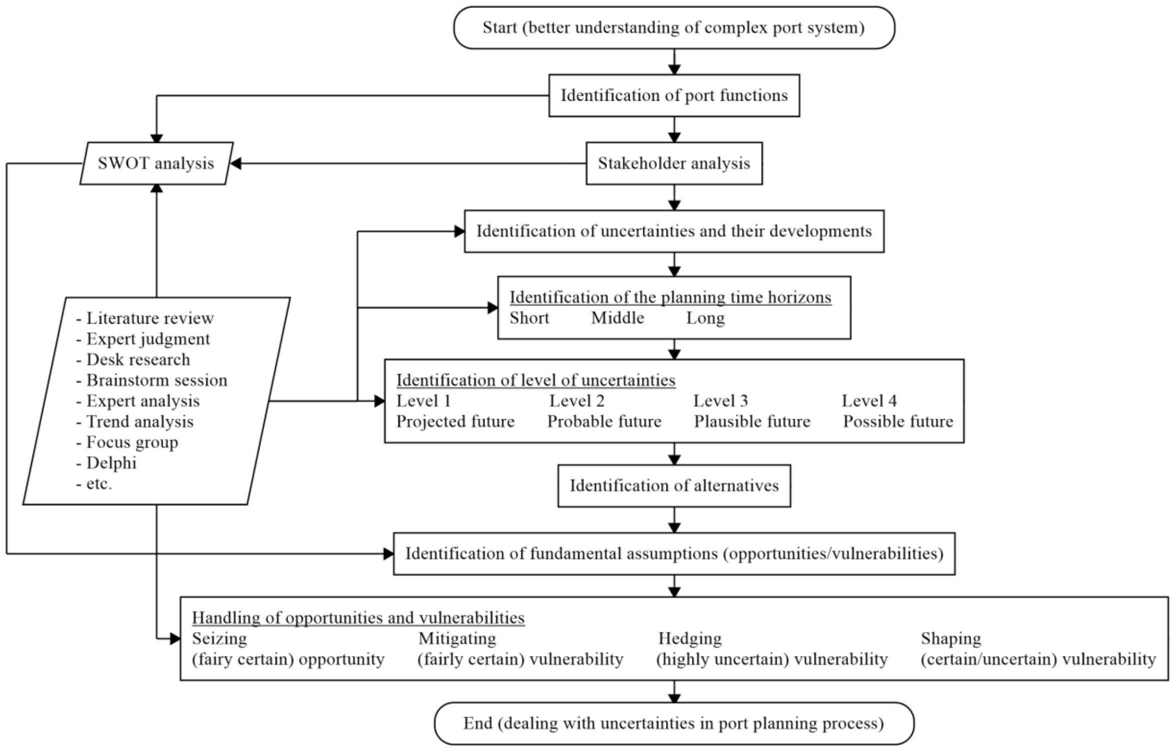

Figure 1. A framework of dealing with uncertainty in the port planning process

The steps in Figure 1 are elaborated throughout this paper.

Identification of port functions

The main functions of a port represent the main purposes for which the port is used. Prior to the planning and design of ports, it is necessary to determine their functions (Ligteringen and Velsink 2012). The functions of a port play important roles in decision making for greenfield and brownfield port development plans. Port functions are fulfilled through various port activities. In this study, to determine the port functions and port activities, information was obtained through the literature (Ligteringen and Velsink 2012), port visits, and interviews with the Port Authority.

Stakeholder analysis

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

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

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

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

Identification of uncertainties and their developments

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

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

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

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

Identification of the planning time horizons

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

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

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

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

As can be seen from the literature, and also stated by Nordlund (2012), there is no generally-accepted standard and explicit view for extension of time in terms of specified short-, middle-, and long-term horizons. Correspondingly, Masini (1993) asserted that time horizons vary and closely depend on the subject under consideration. The distinction of time horizons is arbitrary and determined by plausible future changes as well as the project's duration (Taneja 2013).

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

Identification of level of uncertainties

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

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

Identification of alternatives and fundamental assumptions

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

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

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

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

Handling of opportunities and vulnerabilities

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

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

Case study

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

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

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

Identification of port functions

The Ports of Isafjordur Network is located in the northwest of Iceland. The port network plays a significant role in the logistic chain of the region as well as the country. The port network is well connected to the hinterland by coastal shipping and road transportation modes. It has a strategic location with short sailing times to the open sea. The spatial distribution of the ports gives a dominant and competitive position to the port network in the region. Figure 2 depicts the Ports of Isafjordur Network.

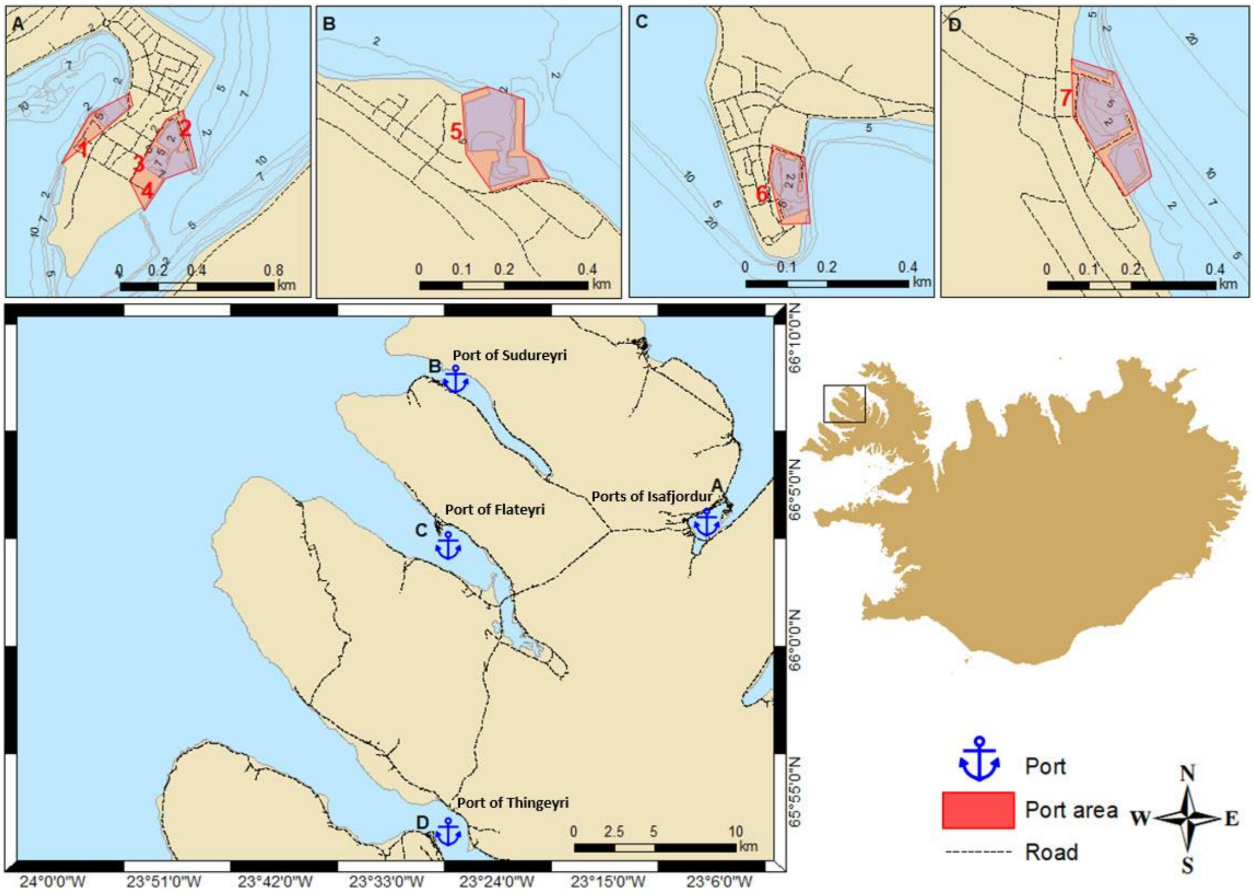

Figure 2. The location of the Ports of Isafjordur Network. The study area is shown on the map of Iceland. A, B, C, and D stand for the Ports of Isafjordur, Sudureyri, Flateyri, and Thingeyri, respectively. The numbers indicate the commonly used quays.

Table 1 describes the main functions and activities of the Ports of Isafjordur Network.

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

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

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

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

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

Stakeholder analysis

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

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

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

Identification of uncertainties and their developments

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

Fishing and aquaculture activities are growing fast with rapid changes to win national and international markets. 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. Vessel size is being increased to utilize economies of scale. Larger vessels demand better handling performance and container handling management. This development affects container throughput and consequently port capacity planning and management.

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

Identification of the planning time horizons

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

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

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

Identification of level of uncertainties

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

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

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

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

Identification of alternatives and fundamental assumptions

To respond to the uncertain developments, different alternatives were generated in the context of planning objectives in the short- and middle-term horizons. To identify fundamental assumptions from the alternative a port SWOT analysis was conducted. Based on the results of the SWOT analysis, in conjunction with the uncertain developments, opportunities and vulnerabilities (the fundamental assumptions) were recognized. Table 2 gives a summary of the SWOT results for the Ports of Isafjordur Network.

Table 2. SWOT analysis of the Ports of Isafjordur Network.

Strength	Weakness	Opportunity	Threat
The port network is connected to cabotage and international shipping.	The ports in the network and towns are sheltered by the mountains, which limits servicing large vessels.	The locations of the ports are close to each other in the network. Relieving congestion problems and reducing waiting time can be achieved by servicing vessels at alternative ports.	Surrounding industrial activities and urban areas may limit the expansion in the port network.
The port network is naturally sheltered by mountains and fjords.	Road connectivity in the port network is limited.	There is a geographic shift of companies to the port network.	Truck accessibility to the port network is not safe and secure. The roads go through towns.
The port network is located near rich fishing grounds in the North Atlantic Ocean.	Depth is limited in the port network.	There is enough fuel storage capacity for new industries in the port area.	The area behind the quay at the Port of Isafjordur is already reserved by industries.
The ports in the network are well distributed in the region and offer good collaboration with neighboring ports.	The berthing capacity of the Sudureyri, Flateyri, and Thingeyri Ports in network are limited.	A flexible and integrated port plan and development can increase the use of the Sudureyri, Flateyri, and Thingeyri Ports in the network.	The trend of using bigger vessels results in the obsolescence of the Sudureyri, Flateyri, and Thingeyri Ports in the network.
There are attractive natural sites and towns around the ports that offer appealing expedition and cruise activities.	There is a lack of (super)infrastructure, i.e. apron, space, quay, and equipment in the Sudureyri, Flateyri, and Thingeyri Ports.	There is land around the Port of Isafjordur that can be used for future expansion.	The development of a new port (in Finnafjord) in the northeast of Iceland could reduce the cargo flow through the port network.
The Port of Isafjordur is supported with competitive (in the region) infrastructure, operation, and a variety of services to handle container, dry and liquid bulk, and general/multipurpose cargos.	The passenger traffic and cargo/container handling are mixed in the port network.	The development of new roads and tunnels in the south of the region will increase cargo distribution access of the port network to the hinterland.	The development of new road connectivity and tunnels in the south of the region will affect the competitive position of the port network.
The Port of Isafjordur is equipped with a logistics optimization system.	The port network does not have a cruise terminal.	The increasing development of industries in the port network creates value-added activities.	The development of the industries increases conflict between port users.
The port network has relatively good navigation accessibility within the region.	There is a lack of infrastructure and facilities for passenger traffic.	The port network has the potential to be used as a hub in the region or for the neighboring countries.	The port's hinterland overlaps with that of other neighboring ports.
The hinterland of the port network is supported by	The hinterland mostly relies on roads which	Port of Isafjordur in the network can be a	There are societal and environmental concerns

industrial activities from all over the country.	are not easily developed because of the geography of the country and difficult terrain.	gateway port and distribution center for the region.	about increasing the vessel/truck traffic and industries in the port network.
The port network is ice-free throughout the year.	The port network is relatively far from the international airport for the quick export of fresh marine products.		There are some companies without port-related activities in the port network.
There is a nearly certain number of industries with port activities in the port network (constant demand).			The port network is highly dependent on a few industries and activities.

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

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

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

On the other hand, some uncertain developments, for instance, the utilization of renewable energy in the port network, impose new challenges. Table 3 in the Appendix gives the identified alternatives in response to the uncertain developments and the consequent opportunities and vulnerabilities.

Handling of opportunities and vulnerabilities

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

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

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

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

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

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

These actions are elaborated in Table 3 in the Appendix. This table supports the Port Authority for choosing a preferred course of action to deal with uncertainties that emerge in the projected lifetime of the port network. Moreover, these actions can facilitate the implementation of adaptive port planning.

Discussion

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

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

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

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

Servicing the relatively small expedition and cruise vessels can be decentralized from the Port of Isafjordur to the smaller ports in the network. The Port Authority should maximize the use of these ports in the network. The optimal distribution and decentralization of cruise vessels can decrease the vessel traffic congestion in the Port of Isafjordur. A decrease in vessel traffic congestion would improve the efficiency of the port network (Bellsolà Olba et al. 2017). This requires new infrastructure and hinterland connections. Building a cruise terminal in the Port of Isafjordur is necessary for safe (dis-)embarkment of passengers. The terminal should be well connected to the town and without conflict with other activities in the port area.

To create synergy between related activities in the limited port area and the benefits accrued to them, the port cluster should be developed. The port cluster enhances the competitiveness of the port network (Lam et al. 2013). The clustering of relevant activities alleviates the risk of conflict associated with irrelevant activities in the port area. It facilitates a joint business plan and vertical consolidation and cooperation of companies, for instance, the export of marine products. This would increase value-added activities and thus improve the performance of the port network (De Langen 2002). However, the Port Authority should use the resource proportionally among the port stakeholders due to uncertain demand in the volatile market environment and the changing salience of the stakeholders.

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

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

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

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

Conclusion

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

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

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

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

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

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Appendix

Table 3 summarizes the results of dealing with uncertainties based on the presented framework for the Ports of Isafjordur Network.

Table 3. Dealing with uncertainty based on the port functions during the projected planning horizons. Acronyms stand for the level of uncertain development (LUD), method of addressing uncertain development (AUD), opportunity (OPP), vulnerability (VUL).

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

		fish feed in containers. - Furthermore, rising temperatures in the Arctic region could open new opportunities for potential shipping (summer ice-free sea route by 2030 (Wright 2013)).		- Integrate and collaborate with other regional ports (operate under one Port Authority) to achieve a certain degree of optimization. This is also plausible for other cargos.	- Existing road capacity and port accessibility are limited and cause congestion (VUL).	*Hedging:* Create alliances with the neighboring ports including the Bolungarvik and Sudavik Ports. *Shaping:* Improve hinterland connection in the interface between port and hinterland infrastructure and provide sufficient capacity for container transport.
	Increase in container vessel size	- In response to the increase in marine products, bigger vessels are used to meet economies of scale.	Short (1, Deterministic forecast)	- Use the existing container handling infrastructure and facilities of the port network.	- Container vessels are serviced in the Port of Isafjordur (OPP).	*Seizing:* Attract the market (e.g., by attractive services in terms of price and quality) as the port has enough infrastructure compared to neighboring ports.
			Middle (1, Deterministic forecast)	- Increase the quay length, berthing capacity, and access channel in the Port of Isafjordur to service vessels.	- Quay constructions, dredging, and reclamation land increase environmental concern (VUL). - The Port of Isafjordur is protected naturally, thus restricting the sailing of large vessels to the port area (VUL).	*Shaping:* Conduct Environmental Impact Assessment (EIA). *Shaping:* Improve the required nautical accessibility in terms of infrastructure (e.g., deepen and widen the channel), navigation facilities

						(e.g., buoy and beacon), and auxiliary services (e.g., pilotage, towage) Port of Isafjordur.
Dry bulk and general cargo flow	Increase in dry bulk and general cargo vessel calls	- Fish feed is imported in bulk. -The raw material for the possible new industries (aluminum, silicon, etc.) in the region can be unloaded in the Port of Isafjordur. Then, the cargos can be distributed to the region from the port.	Short (1, Deterministic forecast)	- Use the existing handling infrastructure and facilities of the port network.	- Cargos are handled in the Port of Isafjordur (OPP).	*Seizing:* Attract the market (e.g., by lower port dues, attractive prices for labor) as the port has a competitive position in the region.
			Middle (2, Probabilistic forecast)	- Use the existing handling infrastructure and facilities of the port network.	- Cargo vessels call at the Port of Isafjordur and cargos are handled in the port (OPP).	*Seizing:* Attract the market (e.g., by lower port dues, attractive prices for labor) as the Port of Isafjordur has a competitive position in the region.
				- Maximize the use of the Sudureyri, Flateyri, and Thingeyri Ports in the network for cargo handling.	- The Ports of Sudureyri, Flateyri, and Thingeyri, have limited infrastructure and facilities (VUL).	*Shaping:* Improve the quay length and berthing capacity of the Sudureyri, Flateyri, and Thingeyri Ports in the network. *Hedging:* Optimize and distribute the cargo handling to the Sudureyri, Flateyri, and Thingeyri Ports in the network.

Storage of cargo	Storage of containers	Increase in the storage of containers	- Containerization trend shifts from break bulk, dry bulk into containers. - Scale and concentration in the world container markets are increasing.	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- Cargos are stored at the Port of Isafjordur (OPP).	*Seizing:* Attract the market (e.g., by attractive prices for port dues, import/export tariff, land, and energy) as the port has a competitive position in the region.
				Middle (2, Probabilistic forecast)	- Invest in a multi-user terminal at a strategic location in the port network.	- The port network does not have a specified area to store containers (VUL). - The materialization of digitalization, automation, robotics, and artificial intelligence, sensor techniques in the port network, and dependence on technology increase IT vulnerability and cyber attacks (VUL).	*Shaping:* Build a container terminal using the land behind the Port of Isafjordur. *Hedging:* Build a container terminal in the flat land behind the Port of Thingeyri. *Mitigating:* Increase safety against cyber attacks.
	Dry bulk storage	Increase in dry bulk storage	- An increase in aquaculture increases the need for fish feed and medicine which require clean and cold storage.	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- Cargos are stored in the port network (OPP).	*Seizing:* Attract the market (e.g., by attractive prices for port dues, land, and energy) as the port network has a competitive position in the region.
				Middle (2, Probabilistic forecast)	- Invest at a suitable location for dry bulk storage in the port network.	- The port network does not have a specified area for the depot (VUL).	*Shaping:* Build the required storage area using land behind the Port of Isafjordur.

						Hedging: Use the land behind the Sudureyri, Flateyri, and Thingeyri Ports in the network.
Storage of liquid bulk	Increase in liquid bulk storage	- The industrial activities in the ports area are increasing.	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The liquid bulk is stored in the port network (OPP).	*Seizing:* Attract the market (e.g., by attractive prices for port dues, and utilities) as the port network has enough tanker capacity and bunkering facilities.
			Middle (2, Probabilistic forecast)	- Increase tanker capacity and improve bunkering facilities.	- The safety zone distance from the existing liquid storage terminal in the port network to the residential area is limited (VUL).	*Shaping:* Provide a suitable location for the new tanker that meets the ISPS requirements. *Shaping:* Upgrade mooring and berthing facilities of the port network.
	A decrease in liquid bulk storage	- The port states and the flag states are responsible for enforcement of the regulations agreed at the Kyoto Climate Change Summit in 1997 and national demands for GHG emission reduction (Wright 2013). This leads to a decline in	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The liquid bulk is stored in the port network (OPP).	*Seizing:* Attract the market (e.g., by lower port dues, and utilities) as the port network has enough tanker capacity and bunkering facilities.
			Middle (2, Probabilistic forecast)	- Invest in the required infrastructure in the port area for	- The port network does not have a specified area and infrastructure for the production	*Shaping:* Build the infrastructure and provide the

			fossil fuel throughput. - Iceland's use of fossil fuels will be insignificant by 2030. There is a long-term vision for the reduction of net emissions of greenhouse gases to 50-75% by 2050, using 1990 emissions as a baseline (Icelandic Ministry for the Environment and Natural Resources 2007).		the production and/or storage of renewable energy.	and/or storage of renewable energy (VUL).	required facilities in the Port of Isafjordur. *Shaping:* Refurbish the existing oil tankers in the Port of Isafjordur.
Industrial / value-added activities	Marine production	Increase in marine productions, processing, and packing	- Fishery management and growing interest in sustainable fish farming affect the growth and productivity of Icelandic fishing industries. - There will be an increase in marine production (offshore, sea, and land aquaculture and further processing) activities if the fish farm companies receive licenses from the Icelandic government. - Wild catch processing may be stabilized or decline	Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The value-added activities are planned in the Port of Isafjordur (OPP).	*Seizing:* Attract the market (e.g., by attractive prices for port dues, land, and energy) as the Port of Isafjordur has enough infrastructure, facilities, and surrounding land.
				Middle (3, foresight)	- Strategically develop port cluster in the port of Isafjordur based on the growing port activities.	- Climate change impacts, directly and indirectly, the port's infrastructure, service, and operation, and thus affects the industries in the Port of Isafjordur. This affects the competitive position of the port (Asariotis et al. 2017) (VUL).	*Seizing:* Disseminate investment opportunities (e.g., by advertising, frequent publicity in news, publications, and conference) and attract new markets (e.g., by inviting ports users, port

	due to the quota system or climate change. - Foreign trawlers can be serviced in the port network if the port network has the required license to service. - There is a possibility of algae, mussel, calcified seaweed farming development in the region. - Installation and maintenance of fish farm facilities, create recycling and dismantling activities in the port network.			- Port expansion and land-side accessibility are limited due to living around the port network, reserved land, and acquisition in the port area (VUL).	marketing, encouraging port charge and tariff) to facilitate developing infrastructure and facilities for the port cluster. *Shaping:* Develop the required infrastructure and facilities in the Port of Isafjordur based on the demand of port users in the cluster. *Shaping:* In response to climate change, build required coastal protection in the Port of Isafjordur.
			- Strategically accommodate some of the value-added activities in the Sudureyri, Flateyri, and Thingeyri Ports in the network.	- The expansion of the ports is limited due to the surrounding residential area (VUL).	*Hedging:* Develop the required facilities and infrastructure in and around the Sudureyri, Flateyri, and Thingeyri Ports in the network/towns based on the demand of port users for value-added activities.

	Renewable energy usage	Provide renewable energy for vessels, and the operations in the port network	- Black oil use in Icelandic territorial waters has been prohibited from 2020 (Regulation no. 124/2015, Iceland). - The export of technology and knowledge in the field of renewable energy from Iceland (nearly 100% of electricity and 75% of total energy is from renewable sources) move the industries toward the application of renewable energy (Icelandic Ministry for the Environment and Natural Resources 2007). - European policies emphasize the Paris agreement on reducing carbon emissions, limiting fossil fuel consumption, moving towards optimized use of fuels, developing alternative sustainable fuel production and renewable energy activities in the port.	Short (1, Deterministic forecast)	- This development is not materialized.	-	-
				Middle (3, foresight)	- Strategically Develop smart grid solutions in the Port of Isafjordur to supply renewable energy demands of port users.	- There is a lack of infrastructure and facilities in the port (VUL).	*Shaping:* Build the infrastructure and provide the required facilities in the Ports of Isafjordur.

Recreational services	Servicing expedition/ cruise ships	Stagnant and/or increase in expedition/cruise ship calls	- The current COVID-19 pandemic has created a high degree of concern about the outbreak of the COVID-19 Virus. Countries with cruise ship arrivals and departures have a higher outbreak and infection rate of the Virus (Ito et al. 2020). - The change in demographics and rising inequality drive the cruise market for the next 10 to 20 years. The aging population in North America, Europe, and Asia provides business opportunities in the cruise market. Geopolitical unrest could further boost the European cruise market since the majority of Europe is relatively safe and stable (Van Dorsser et al. 2018a). - Travel agencies and cruise companies are increasingly looking for new experiences or destinations (Tsamboulas et al. 2013), which creates	Short (2, Probabilistic forecast)	- Use the existing capacity of the port network.	- Expedition and cruise ships are serviced in the port network (OPP).	*Seizing:* Attract the market (e.g., by advertising in news, publications, and conference, invite liners for port visit/tour, attractive prices for port dues, and utilities) as the port network has a competitive position in the region. *Hedging:* Use the Sudureyri, Flateyri, and Thingeyri Ports in the network for the smaller expedition/cruise ships.
				Middle (1, Deterministic forecast)	- Increase berthing capacity and infrastructure of the Port of Isafjordur.	- There is limited land in the port of Isafjordur to service cruise ships (VUL). - Growth in the number of vessels increases societal and environmental concerns as well as congestion (VUL). - Urban development, utility services, and excursions to attractions are limited in the port network (VUL).	*Shaping:* Extend the ports and provide enough infrastructure (e.g., extend the quay, deepen the access channel) and facilities in the port network. *Mitigating:* Service more environmentally friendly vessels to create a better attitude from the society. *Shaping:*

		opportunities for the port network. - There is a great opportunity for winter cruise ship calls at the port network. - There is a possibility for short stay calls in the port network by cruise ships that are sailing to/from Greenland (Municipality of Isafjordur 2013).				Provide vessels with renewable energy. *Shaping:* Build a cruise terminal at the Port of Isafjordur at a safe and appealing location with good accessibility to buses to transport passengers to major attractive areas.
				- Increase the use of the Sudureyri, Flateyri, and Thingeyri Ports in the network	- There are navigation restrictions and limited infrastructure in the Sudureyri, Flateyri, and Thingeyri Ports in the network (VUL). - Urban development, local activities, utility services, excursions to attractions are limited (VUL).	*Hedging:* Use the Sudureyri, Flateyri, and Thingeyri Ports in the network for shallow-draft vessels. *Shaping:* Upgrade the port infrastructure (e.g., extend the quay) and facilities in the Sudureyri, Flateyri, and Thingeyri Ports in the network. *Shaping:* Improve urban development, local services, and attractions.
	Increase in cruise ship size		Short (1, Deterministic forecast)	- Use the existing capacity of the port network.	- The cruise ships call the port network (OPP).	*Seizing:* Attract the market (e.g., by attractive services in terms of price and quality) as the Port of Isafjordur has

							enough infrastructure and facilities.
				Middle (1, Deterministic forecast)	- Use the existing capacity of the port network.	- There is a limited capacity for servicing large cruise ships in the Port of Isafjordur (VUL).	*Shaping:* Increase berthing and embarkment capacity.
	Servicing yacht, and sailing boats	Increase in the number of boats.		Short (1, Deterministic forecast)	- Use the existing infrastructure and facilities of the port network.	- The boats use the infrastructure and facilities of the port network (OPP).	*Seizing:* Attract the market (e.g., by attractive services in terms of price, quality, and utilities) as the port network has a competitive position in the region.
				Middle (1, Deterministic forecast)	- Decentralize services to the boats and use all ports in the network.	- There is a lack of capacity in the port network to service private, yacht, and sailing boats (VUL).	*Shaping:* Upgrade facilities and infrastructure (e.g., upgrade the existed marina) of the Sudureyri, Flateyri, and Thingeyri Ports in the network.
	Water sports activities	Increase in sports activities		Short (1, Deterministic forecast)	- Use the existing infrastructure and facilities of the port network.	- Sports activities are carried out in the port network (OPP).	*Seizing:* Attract the market (e.g., advertise in news, publications, and conference, port visit/tour, stimulate recreational and multi-cultural activities) as the port network has enough

				infrastructure and facilities.
	Middle (1, Deterministic forecast)	- Use the infrastructure and facilities of the port network.	- There is a lack of safety distance between sports activities and sailing routes (VUL). - There is a lack of infrastructure such as hotels, guesthouses, and parking space in the port network (VUL).	*Shaping:* Upgrade facilities and infrastructure (e.g., piers, jetties, information center, utilities) of the port network. *Shaping:* Improve safety (e.g., increase navigational aid and set up monitoring system), urban development, and local services.