TOWARDS SUSTAINABLE PORT INFRASTRUCTURE THROUGH PLANNED ADAPTATION

by

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ABSTRACT

In the present turbulent environment, adaptability and robustness belong under the overarching definition of sustainability. Sustainable infrastructures should not only achieve economic, environmental, and social objectives, but should be robust and adaptable under uncertainty. This paper examines the current guidelines for port development and concludes that a comprehensive planning approach that systematically accounts for uncertainty during planning, to result in a sustainable plan, is missing. It proposes an approach for port planning based on planned adaptation. Case studies illustrating how planned adaptation can effectively help to deal with short- and long term vulnerabilities, and seize opportunities to come up with sustainable plans that are able to achieve economic, environmental, and social objectives for a long-term uncertain future, are presented.

Keywords: Adaptive port planning, planned adaptation, flexibility, infrastructure planning, sustainable infrastructure, maritime port planning, uncertainty

1. INTRODUCTION

1.1 Background

Infrastructures, such as ports and waterways, have a design life of several decades and they need to accommodate today's needs as well as tomorrow's. Therefore, nowadays, long-term planning of infrastructure is interwoven with the concept of sustainability.

Ports an waterways play a strategic role in the economy of a nation. Currently, ports worldwide are expanding capacity to accommodate trade growth. In these turbulent times, considering the long-term nature of port projects, future developments will have major implications for ports, and will be key factors in determining their success. These developments include systemic changes driven by globalization, emerging and often disruptive technologies, increased environmental constraints, energy transition and transition to sustainability, climate change impacts and resources stress, and will influence all aspects of our life in ways that are nor foreseeable. These will result in changed demands, new functions and new constraints for port infrastructures. Clearly the port must function under new (yet uncertain) conditions. Failure in anticipating the long-term future and preparing for it, will result in inadequate infrastructure and eventually lead to loss in competition with the neighboring ports.

Literature over sustainable ports advocates common sustainability guiding principles and suggests that a more sustainable port can be realized through embracing the perspectives of engineering, ecosystem services and governance in an integrated approach to port development. However it would be more apt to state that sustainable infrastructure should not only achieve economic, environmental, and social objectives, but should be robust in an uncertain future conditions (Haasnoot et al., 2011; Walker et al. 2013). And since sustainable development never reaches an ‘end-state’, the equilibrium continuously needs to be adjusted. Therefore adaptability and continued learning are of essence (Cicin-Sain, 1998).

In acknowledgement of the increasingly complex, and frequently interconnected and interdependent multidimensional issues confronting planners, there is a shift towards approaches that consider

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flexibility in their long-term plans and favor adaptation as a way of dealing with challenges in unpredictable complex systems (UNDP GCPSE, 2014).

1.2 Research gap and objective

International port-related organizations too are developing and regularly updating guidelines and codes of practice for sustainable development of ports and waterways. Guidelines over sustainable port development make a mention of uncertainty, and, adaptation and flexibility as strategies for future proofing a port. However a comprehensive planning approach that incorporates the above concepts, and systematically deal with uncertainty to result in a sustainable plan, is missing. This is a research gap.

The objectives of this paper are manifold. The first objective is to highlight that uncertainty is a dimension of sustainability, and in fact, it belongs to the overarching definition of sustainability. Therefore sustainable infrastructure should not only achieve economic, environmental, and social objectives, but should be robust, meaning that it performs satisfactorily under multiple futures and is adaptable to (unforeseen) future conditions.

Secondly, the paper suggests that is essential to understand the various dimensions of uncertainty categorize uncertainties relevant for the planning, before selecting an appropriate approach for handling it.

Thirdly it addresses the research gap discussed earlier, by proposing a systematic approach known as Adaptive Port Planning, that accounts for uncertainty in the process of port planning to result in a sustainable plan.

1.3 Outline of the paper

Section 1 identifies the research gap, and outlines the research objectives. Section 2 presents a review of current guidelines for port development to examine their handling of uncertainties. After defining uncertainty and discussing its various dimensions in Section 3, five major uncertain development confronting ports are examined to see how they are handled in practice, and what are the solutions proposes in current literature in Section 4. Section 5 proposes an approach for port planning based on planned adaptation and gives illustrative examples from three cases of port masterplanning.

2. LITERATURE REVIEW

2.1 Introduction

The world has entered a new area, a complex age of turbulence and opportunity (Rand, 2017). Terms such as strategic surprises, disruptions, wildcards, trend-breaks, structural discontinuities, and deep uncertainties have become common while talking about the future. Consequently, research on uncertainty and risk management, and flexibility and adaptability, in relation to infrastructures is growing by leaps and bounds. This section first defines flexibility and related concepts and then goes on to scrutinize the current port literature for their handing of these concepts.

2.2 Some relevant definitions from literature

In this section, we define some relevant concepts used in the paper, based on literature (Taneja, 2013).

A *flexible or adaptable system* can be altered or employed differently, with relative ease, so as to be functional under new, different, or changing requirements in a cost-effective manner.

*Resilienc*e is the degree to which a system can recover quickly from a major disruption. A resilient system can recover quickly from a major disruption while regaining - or even exceeding - its original level of performance.

A *robust system* has the ability to meet requirements under changed circumstances, without significant impact on the service level. A distinction is made between static and adaptive robustness Static robustness implies that plan that will perform well in many futures while adaptive robustness makes it possible to adapt a plan, in case conditions change (Walker et al. 2013),

2.3 Review of port guidelines

Nowadays, long-term planning of (waterborne) infrastructure is interwoven with the concept of sustainability. International organizations such as AAPA (American Association of Port Authorities), EPA (US Environmental protection Agency), ESPO (European Sea Port Organization), IAPH (International Association of Ports and Harbors), UNEP (United Nations Environment Program), UNCSD (United Nations Conference on Sustainable Development), PIANC (Member World Association for Waterborne Transport Infrastructure), USCAE (US Army Corps of Engineers), WWF (World wide fund for nature), and numerous others, are developing and regularly updating guidelines and codes of practice for sustainable development of ports and waterways.

A quick scan of literature over implementing a green port philosophy and about what this philosophy means for ports around the world was conducted. Following this, the current guidelines for port development were scrutinised to examine in how far the concepts of long-term planning, uncertainty, robustness, flexibility, adaptability etc. find a place (PIANC 2013; 2104a; 2014b; 2017).

PIANC (2014a) defines the primary objectives of a port masterplan (i.e., to communicate the vision for the port to the wide range of stakeholders and develop the port in accordance with international and national legislation and guidelines integrate economic, engineering, environmental and safety considerations in the overall plan) and indicates that orderly long-term development and growth of the port must be promoted, allowing the port to respond to changing technology, cargo trends, regulations and legislation and port competition. PIANC (2006) states that port masterplans should be flexible tools, in order to be adapted with time as the needs of the port may change, sometimes abruptly.

In addition to green design and green approaches to development at the port, guidelines for sustainable port development mention adaptation and flexibility among the fundamental principles of port planning.

PIANC (2014a) recommends making the port future proof through creating flexible port layouts and future proofing of the critical parameters such as, water depths at the quay walls, land areas and land connections. It proposes that port expansion should be phased in response to demand (p.40,41) and port masterplan must be adaptable and flexible – and able to respond to market changes and changing economic conditions in terms of potential land uses (p.171). Evaluation of alternatives should include among others, as planning flexibility as criteria (p.216). Scenario planning and robust decisionmaking are proposed as ways of dealing with uncertainty: “Since long-term forecast necessarily has a high degree of uncertainty, it is worth including different scenarios to test the various alternatives for development. Afterwards, designers can minimize risks by searching for plans that are robust under a variety of possible future traffic scenarios, or likely to be easily phased” (p.40).

WG174 (Sustainability reporting in ports; in preparation), observes that innovation is required to create knowledge and creativity so ports can adapt and anticipate on big changes and face future challenges. It also recommends adaptive port planning using open source and internet based tools as well as sharing information and best practices through worldwide operating platforms such as PIANC, IAPH and interest groups (PIANC, 2017).

Many of the design principles and recommendations in the guidelines are directed at minimising environmental impact and optimization of resources. However, long term consideration are also reflected in recommendations such as: avoid building today what you need to move tomorrow; phased development that enables progressive adaptation of the port extension to respond to demand

However a comprehensive planning approach that incorporates the above concepts, and systematically deal with uncertainty to result in a sustainable plan, is missing.

There is increasing awareness of uncertainties surrounding long-term infrastructure projects. Not all uncertainties about the future can be eliminated and ignoring uncertainty could mean end up in situations that could have been avoided; missed chances and opportunities, and lead to unsustainable plans. Therefore, a major challenge in designing sustainable plans is the requirement to accept, understand, and manage uncertainty, (Walker et al., 2013). The question of how to design such sustainable plans, accounting for uncertainty in port masterplanning, is rarely addressed in the sustainability literature.

3. UNCERTAINTY AND ITS VARIOUS DIMENSIONS

3.1 Introduction

It has been common practice, even for long-term planning, to assume a stable environment, where the future will be an extrapolation of the current state. However, future studies field has long distinguished between different types of futures (Henchey, 1978) in recognition of different uncertainties attached to them. Voros (2003, 2017) classifies potential alternative futures: possible (might happen), plausible (could happen), projected (business as usual), and probable (likely to happen) future, in addition to preferable or desired future. These alternative futures can be seen associated with different levels of uncertainty. Rather than making predictions based on extrapolation of current trends or frequency of similar past events, foresight cultivates the capacity to anticipate alternative futures and an ability to visualise multiple possible outcomes and their consequences.

It is essential to understand the concept of uncertainty, and explore its different dimensions before selecting an appropriate approach for handling uncertainty.

3.2 Dimensions of Uncertainty

Walker et al. (2013) define uncertainty as any departure from the unachievable ideal of complete determinism. They categorize uncertainties by their location, level, and nature. The first dimension of uncertainty deals with the location, i.e., where the uncertainty manifests itself in the system under consideration. These uncertainties include the external forces on the system, the system response to external forces as well as uncertainty about the valuation of outcomes.

The second dimension expresses the degree or severity of the uncertainty, which can range from deterministic knowledge to total ignorance. Level 1 indicates a fairly clear future and can be described adequately by means of a point estimate; level 2 uncertainty is said to exist if the probabilities of alternate futures are known; level 3 uncertainties can be ranked but the probabilities can't be assessed, and level 4 uncertainties represents the deepest level of recognized uncertainty. In this case, we know only that we do not know. Complete certainty, and total uncertainty acts as limiting cases. The choice of an appropriate approach for handling uncertainty, depends on its level (Lempert et al., 2003; Walker et al., 2013).

The third dimension is the nature of the uncertainty. The phenomena about which we are uncertain can either be due to our lack of knowledge about the phenomena (i.e. epistemic uncertainty) or the inherent variability in the phenomena (i.e. uncertainty inherent in their nature). Epistemic uncertainty can be partially be reduced through new information. Variability uncertainty that is attributable to natural randomness, is, however, irreducible.

The last characterize many of the real world uncertainties. However in the current approaches to infrastructure planning, uncertainties are usually treated as either level 1 (small margins around deterministic figures) or level 2 (by expressing uncertainties about variables or underlying functional relationships among key variables in the form of a probability distribution). This results in plans that prove inadequate under changing requirements.

3.3 Handling of different levels of uncertainty

During long-term planning, we can prepare for the uncertainties through extensive research (not always effective, since not all uncertainties are reducible) or postponing decisions till uncertainty clears up. Delaying action until there is perceived to be more certainty is not always feasible. The level of uncertainty determines the most suitable for treating it.

- Level 1 uncertainty represents a fairly clear future, one can predict and aim for an optimal plan.

- In case of Level 2 uncertainty, long term probabilistic projections are made. Level 1 or Level 2 uncertainty (where the probabilities of alternate futures are known) are rare. Level 1 or Level 2 uncertainty (where the probabilities of alternate futures are known) are rare.

- Level 3 uncertainty usually calls for a static robust solution along a range of plausible scenarios in which one identifies plausible futures. Scenarios explore the joint impact of various uncertainties. Next, assessment of alternative plans (solutions) can be carried out for each scenario. The chosen solution should be robust under all these scenarios. A possibility exists that not all scenarios (or key variables in these scenarios) have been accounted for during the scenario planning. For this reason, flexible solutions should be opted for that can be adapted as conditions change (Taneja, 2013).

- Under deep uncertainty (level 4), predictive approaches will result in inadequate plans. In international development, there is a shift towards a complexity-aware approach that favours adaptation as a way of dealing with challenges in unpredictable, complex systems (UNDP GCPSE, 2014). Haasnoot et al. (2011) and Walker et al. (2013) state that an adaptive policy approach is considered most appropriate for level 4 uncertainty.

Adaptive policy-making is often a way of dealing with deep uncertainty that falls between too much precaution and acting too late. Walker et al. (2010) add that while the need for adaptation is increasingly acknowledged, it is still a developing concept, and requires the further development of specific tools and methods for its operationalization.

In view of the above, port planning needs to move from optimal designs to flexible designs, from anticipating risks to monitoring the environment, from operative m to directive planning, from strategic planning (aided by risk management) to integrated, adaptive planning methods. Adaptive approaches for port planning and design will result in flexible and robust solutions that can better deal with the challenge of uncertainty (Taneja, 2013).

4. UNCERTAINTY CONSIDERATIONS IN PORT PLANNING

4.1 Uncertainties in port planning

The world stands at the brink of a (green) energy transition as the sources of fossil fuels diminish and concern for the adverse environmental impacts increases. There is a global focus on energy efficiency, optimized use of fossil fuels, and development of alternative renewable sources of energy to meet future energy demands. Sustainability and climate change goals are (or at least, should be), driving our actions. Digitization and artificial intelligence are converging to give rise to new technologies that though disruptive, offer new opportunities for increased efficiency, productivity, or safety. Ship evolution from manned ships to remote, automated, and eventually autonomous ships is underway[3].

Uncertainties, when they appear, can affect the performance of the port and the overall implications relate to service levels, costs, revenues, the competitive position and image of the port. In some cases they can even lead to obsoletion of the port. The many sources of uncertainty in port planning can be placed in a project, corporate, market or political/regulatory context. The major exogenous uncertainties are related to market aspects such as the developments in global trade, trends in the shipping market, and structural change in shipping services. Land and energy prices, the continuing threat of a new entrant, potential for global substitutes, the presence of powerful customers and powerful suppliers are exogenous factors which contribute to the uncertainty in port competition. The emerging economies, the expansion of EU, the present trends of deregulation and privatization, international security policies, and safety and environmental regulations have an immense impact on the port industry. Such forces cannot be accurately predicted or their influence quantified. The planner

[3] http://www.unmanned-ship.org/munin/about/the-autonomus-ship/

has little control over this form of uncertainty, but are of particular importance to him, especially if they are likely to produce large changes in the outcomes of interest.

In addition to cargo and ship traffic forecasts, which are determinants of myriad uncertain external developments that can disrupt existing trade patterns and cargo flows, emerging technology, energy transition, sustainability requirements, and climate change represent major uncertainties for most ports.

We examine each uncertainty, categorize it, and examine the appropriate method of handling it.

4.2 A discussion over some major uncertainties in port projects

a) *Cargo and Traffic Forecasting*

Choice of (profitable) cargos, followed by accurate forecasting of traffic and throughput is of crucial importance for long-term planning of a port. Port infrastructures require huge (irreversible) investments and the capacity cannot be increased in response to seasonal variation in demand. Therefore cargo and traffic forecasting and modelling is carried out at a macro as well as micro level. A wide range of methods for forecasting including economic modelling of hinterlands, cargo origin and destination surveys and statistical trend analysis are used in practice. The uncertainty associated with long-term forecasts (level 3 uncertainty) is often captured in the form of a few trend-based scenarios based on alternative assumptions about the external factors.

Containerization plays an important role in the rapid growth of international trade and it is common practice worldwide to carry out container demand forecast (TEU'S) based on different assumptions about GDP growth. (TEU represents an inexact unit of container capacity). However, even while organization such as Mckinsey[4] issue low-case and high-case forecasts for global TEU growth[5], they mention that uncertain developments such as power rivalry between China and the USA that would encourage a new wave of on-shoring or increase in degree of containerization in various sectors, could influence the forecasts.

As shipping lines, logistic operators and terminal operators are increasingly joining forces and setting up alliances, trade patterns can change abruptly and forecasts can become meaningless. In view of such developments, this uncertainty belongs to level 4 to be handled as proposed in Section 3.3, through strategies of flexibility and adaptability.

b) Mega Ships and Autonomous Ships

Ensuring that the nautical infrastructure, quay design, cranes and operational layout of a port match the specifications of (future) vessels is essential for the success of a port. In the last decade, container ships have grown to giant proportions. Technology and geographical factors have been constraining the upper limit on container ship capacity so that the most current designs for 24,000-TEU vessels have a depth of 16 meters, allowing them to transit the Strait of Malacca (min. depth: 25 m) and the Suez Canal (min. depth: 24 m).

McKinsey[6] suggests future fuel costs, which affect the efficiency advantages enjoyed by ever-larger container ships, may influence ship size evolution so that we could see orders for 30,000-TEU ships within 10 years, or delayed for up to 20 years if prices remain low.

Speculations that 42,000 TEU[7] 1.0 km long ships sizes may not be inconceivable in the future, continue, while increasingly, ports are discussing the downsides to investing in infrastructure designed to service mega ships[8]. Many believe that the port industry is going to transition from a

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[4] https://www.freightwaves.com/news/2017/10/26/mckinsey-forecasts-the-next-50-years-of-container-shipping.

[5] In the low-case scenario, container capacity grows from 182M TEUs in 2016 to 464M TEUs by 2066, representing a conservative growth rate of 1.9% per annum. In the high-case scenario, container capacity grows to 858M TEUs by 2066, representing an optimistic growth rate of 3.2% per annum.

[6] https://www.freightwaves.com/news/2017/10/26/mckinsey-forecasts-the-next-50-years-of-container-shipping

[7] http://www.gatewaycontainersales.com.au/will-container-ships-keep-growing-in-size-forever/

[8] https://www.inform-software.com/blog/post/automation-and-technological-innovation-is-crucial-to-the-future-of-ports-part-2

point-to-point shipping model to a hub model, where there are only a few major ports servicing mega ships. Therefore, ship size remains an uncertain factor during port planning, as do the policies and strategies adopted by specific ports.

Added to this is the uncertainty surrounding developments of autonomous ships: when will they appear, and what will the implications be for a port, e.g., changed requirements in terms of manoeuvring areas and quay or storage capacity (in case of increased efficiency). Research efforts and innovation, monitoring related developments and investment in flexibility are required to deal with what is, at this point in time, a level 4 uncertainty.

c) New Technology

In the present era of fourth industrial revolution, technologies with a potential to be disruptive are unfolding at a very rapid rate. Some of these include: mobile internet, the Internet of Things, cloud technology, advanced robotics, autonomous and near-autonomous vehicles, energy storage, 3D printing, advanced materials, advanced oil and gas exploration and recovery, renewable energy, drones, hyperloop transport.

The impact of new technology on ports is many-fold. New equipment configurations, new logistic concepts, new cargo handling methods, and advanced information systems offer the means to increase terminal efficiency and productivity. The advancements in construction materials and technology, is expanding the choice of designs and construction methods. However, new technology introduces new challenges for infrastructure planning by creating new functional, spatial, organizational, and procedural requirements. Since precise lifetimes of technologies are not known, expected values are used in planning decisions.

Many types and methods for technology foresight have been developed in the last three decades (a comprehensive review can be found in Mishra et al. (2002). In case of technology forecasting, exclusive reliance on historical data inevitably leads to an overemphasis on evolutionary innovation and leaves the user vulnerable to surprise from rapid or nonlinear developments. Trying to trace the (typically non-linear) development path of potentially disruptive technology requires guesses of the potential performance characteristics of the new technology, as well as its adoption by potential users. Therefore, scenarios have often been used to explore both the development paths of technologies and how they will play out in the real world. However, during strategic long-term planning, the paradigm shifts brought by new technologies are generally not considered in the core scenarios of organizations, because they cannot be anticipated in full.

According to National Research Council (2009), new forecasting methods must be developed if disruptive technology forecasts are to be effective. Though it is impossible to predict the future accurately, it is possible to minimize surprises by:

- Monitoring key enablers (e.g. precursor technologies) and inhibitors of new technologies.
- Assessing the impact of potential disruptions
- Postulating potential alternative futures
- Increasing the lead-time of awareness to prepare for the future

Identifying new potentially disruptive technologies and/or new disruptive trends and applications is a challenge due to the emergent behavior of new technologies. Moreover, identifying and monitoring precursor signals of disruptive technologies is not always easy. Therefore, uncertainty due to new technology needs to be handled through research[9] into potential impacts and innovative solutions based on incorporating adaptability, flexibility and resilience in port infrastructure systems.

d) Energy Transition and Sustainability Regulations

Energy transition is characterized by changing pattern of supply driven by new energy sources, and changed patterns of energy demand due to newly emerging economies. In addition to finding methods of generating sustainable energy, and taking measures towards becoming carbon neutral, ports are confronted with changed or new cargo flows and new activities related to bio-fuels, offshore wind, solar and nuclear energy among others. In order for any infrastructure planning effort to be

[9] An example is Port of Rotterdam preparing for a digital transformation with IBM's cloud-based IoT technologies https://www.iottechnews.com/news/2018/feb/02/port-rotterdam-prepares-digital-transformation-ibm-iot/

successful, future plans must take into account that the energy system will have changed considerably during the planning horizon[10].

Transition of the energy system toward sustainability depends on the developments related to new technologies. As stated earlier, these are non-linear and highly uncertain, but need be taken into account when analyzing the dynamics of energy transitions (Hamarat, 2013).

In addition to technological uncertainty, socio-political and economic uncertainties play a role, therefore, adequate handling of uncertainty is of prime importance. Energy transition and climate change belong to 'tragedy of the horizon', wherein the impacts of a risk occur outside of traditional decision-making cycles, and may prevent decision makers from taking preventative or early action which may be more efficient (Kruitwagen, 2016)

Literature proposes that Adaptive Robust Design approach can be employed for shaping and steering transitions toward more sustainable energy systems (Hamarat, 2013). Numerous ongoing future-oriented technology analysis (FTA) projects aim at developing long-term, adaptive, and robust policies for socio-economic and technological changes such as energy transitions (NRC, 2009).

Incorporating flexibility in port systems to enable diversification into new cargo and new activities when required, research into yet unexplored methods of generating sustainable energy, to be followed by innovation, are required. Ports can serve the function of creating sustainable energy hubs with renewable fuels and energy relevant to the new economy.

e) Climate change

There is increasing awareness that given the long lifespan of infrastructure, understanding and addressing the potential impacts of climate change and the related effects on port infrastructure and operations as well as possible disruptions to the supply chain is essential. Climate change impacts for ports include sea level rise, storms, flooding, wave and wind impacts, environmental regulations and possibly shifts in markets.

Many studies attempt to characterize the causes and predict the rate of change of various aspects of climate change, however, the scientific modelling of future extreme events remains uncertain. Integrating climate and non-climate scenarios is difficult partly as a result of their respective time horizons and partly due to the uncertainties around development of associated developments. When it comes to dealing with climate change, some of the imaginable impacts can be hedged against, others can be dealt with robustness, but most others require adaptability (Rahman et al., 2008; Haasnoot et al. 2013; Hallegatte et al., 2012). PIANC (2014b) states that the recognition of the likelihood of climate change and associated impacts – both anticipated and unanticipated - provides an opportunity for the navigation community to shape polices, adaptation strategies and mitigation measures. Adaptation, here refers to strategies to change current systems and infrastructure to account for changing climate, and preparation to respond to new opportunities. The reference to the strategy of adaptation is indicative of recognising level 4 parameter uncertainty.

Literature also advocates a coordinated approach to long-term planning of land use, factoring in flexibility, i.e. room to move for ports transport supply chain routes. Extreme climate change effects such as storms which can lead to navigational hazards and a large down time of cargo handling operations require resilience to be built into the system.

On a global scale, many ports are in the beginning stages in considering adaptations to climate change (Becker et al., 2012), however, few have specific policies in place. Adapting to climate change requires informed planning and a better understanding of when ports should begin implementing proactive adaptation strategies.

[10] http://portesbjerg.dk/en/about/news/future-energy-policy-must-ensure-green-energy-transition-and-economic-growth

5. PLANNED ADAPTATION

5.1 Ad hoc adaptation versus planned adaptation

For a long time, the planning and design of port infrastructures catered to short term functional requirements. The same old conceptual designs, suited to immediate needs and local situations, using traditional approaches and methods were implemented. Traditional approaches often tended to deal with uncertainties as certainties, purely due to a lack of common understanding regarding the definition of uncertainty (as well as a lack of suitable tools). Often the long-term uncertainty impacts were outside the planning horizon, and the decisionmaker had little incentive to address them. Ad hoc solutions were applied to deal with changed functional requirements during the operational phase, interrupting cargo handling and incurring enormous costs. Long term future considerations were missing and environmental and social aspects generally neglected.

With growing attention for people, planet and profit, additional requirements as to sustainability and safety came into picture. Due to the growing awareness about the need for handling uncertainty, various theoretical planning approaches took root. These moved from trying to reduce uncertainties, towards accepting and anticipating them, and from finding an optimal plan to developing a robust plan. In acceptance of the fact that that planning is beset by uncertainties of the future, and adaptation is inevitable, they propose a shift from ad hoc adaptation to planned adaptation as a more efficient strategy. “Planned adaptation” is the result of deliberate decisions, based on an awareness that future might change and that action is required to return to, maintain, or achieve a desired state (Walker et al., 2013). Planners accept the irreducible character of (most) uncertainties about the future and focus on reducing uncertainty about the expected performance of their plans to ensure a sustainable port system in the future. Such a “monitor and planned adaptation approach” is more suitable for the present uncertain times, than a traditional “predict and act approach”.

5.2 Adaptive Port Planning

The above concepts have been incorporated in an approach for port planning known as APP or Adaptive Port Planning (Taneja, 2013). APP requires the planner to first anticipate on the future and thereafter explore possible adaptation strategies that can be applied directly, or in the future, in case the monitoring system signals that an uncertain development is on the horizon. This approach of ‘planned adaptation’ focusses on the expected performance of a plan through exploring possible adaptation strategies, and preparing a framework which includes a monitoring system and contingency plan to guides future actions. It employs strategies for shaping uncertainties or dealing with them through incorporating flexibility and adaptability in the plans, to ensure a sustainable port system in the future. APP is based on the following guiding principles:

- *explicitly define short-term goals and long-term objectives* by studying the objectives of the organization and the needs of the stakeholders and try to connect them during the planning process;
- *explore and categorize relevant uncertainties*, varying from a global to local scale, and from short-term to long-term, and analyse whether the uncertainties present an opportunity or vulnerability for the plan;
- *commit to short-term actions while keeping options open* and preparing appropriate actions to meet objectives in plausible future scenarios;
- *continuously monitor the external environment* and take actions if an uncertainty appears or a scenario materializes

APP makes use of a variety of tools and techniques in the context of a generic framework (see Taneja, 2013, p. 106). It guides the planner to categorize multiple uncertainties (with various levels and requiring different time for response), in a single framework, and select appropriate tools for addressing them. These tools can range from extrapolation and sensitivity analysis for level 1 uncertainty, simulation for probabilistic uncertainty, multistage decision analysis for uncertainties that reduced over time with additional information, and scenario discovery, exploratory modelling and analysis (EMA), and robust decision making (RDM) among others, for deep uncertainties.

APP employs a typology for various type of actions depending on the nature of a development, i.e. whether it is fairly certain or uncertain, whether it offers an opportunity or presents a vulnerability for the plan, and the time at which it appears during the planning horizon. For instance, a *shaping action* aims at reducing changing its nature of vulnerability to prevent a (threatening) development from taking place, or to steer events towards a preferred scenario. A *mitigating action* is taken to reduce the certain adverse effects of a plan while a hedging action spreads or reduce the risk of highly uncertain adverse effects of a plan; both make the plan more robust. A *seizing action* is directed at seizing available opportunities that are fairly certain. Contingency planning (for the implementation phase of a project) distinguishes between *defensive actions, corrective actions, and capitalizing actions.*

Thus the APP framework guides the planner from strategies of anticipation to pro-active actions by suggesting tools and actions based on the level of uncertainty identified. It combines risk analysis and strategic planning into a single activity carried out in the same time frame over the entire planning horizon. This means that the management is not taken by surprise: it has a contingency plan and reserves. Monitoring and updating are a part of the cycle, so that a clear and complete picture of the status and the viability of the project is available at any given time. Reassessment and proactive stopping of the project are also a part of the planning cycle.

5.3 APP applied to port projects

The proposed adaptive planning approach is applied to the following case studies pertaining to port planning projects at very different locations in the world, namely Indonesia, The Netherlands and Colombia, aimed at developing adaptable and robust masterplans. These ports are:

- Port of Kuala Tanjung, Indonesia
- Europoort, Port of Rotterdam, The Netherlands
- Port of Barranquilla, Colombia

Over short-term, local conditions, local and national regulations, port organization structure, and international standards play a role during planning. Uncertainties about the future investments in hinterland connections or in sustainability measures by the authorities, are faced by most port projects. Over the long term, the ports are confronted by uncertainties discussed in Section 4.2, which belong to level 3 or 4.

The objective of presenting these case studies is to illustrate the handling of uncertainties within APP and only some aspects are discussed in the paper. The details of various steps in the structured approach of APP, can be found in Prakoso et al. (2017), Arreco et al. (2015) and Soto Reyes et al. (2018) respectively.

Port of Kuala Tanjung (PoKT) is located in North Sumatera, Indonesia. It is strategically situated at the Malacca strait and is planned to be Indonesia's international hub port, together with Port of Bitung in Sulawesi Island. The development of PoKT is being carried out by Pelindo 1 an Indonesian state owned port company, together with Port of Rotterdam Authority (PoRA) in the form of a Joint Venture. The APP framework is applied to develop a sustainable and robust masterplan for the first phase of the project (Prakoso, 2017). A short description of the findings follows.

Timely land acquisition and the success of the joint venture between state-owned port operator Pelindo and the Netherlands based Port of Rotterdam (PoR) in view of the cultural differences, is also essential for the project. Such internal uncertainties can be managed.

The major vulnerability for the port is competition from ports in Malaysia and Singapore. As a shaping action, PoKT is planned as an industrial port instead of a gateway or transhipment port. An industrial complex based on alloys, bio-based cargos, and petrochemicals will avoid direct competition with already established industry and cater to the domestic market. In addition to a steady cargo stream, it will provide significant added value in form of jobs and stimulus for regional economic growth while presenting minimum environmental impact through co-siting and shared utilization of port facilities and activities.

The choice of the client for the first phase will have significant implications for the next clients and potential investors. Therefore three alternative futures were defined on the basis of choice of first cluster, i.e., alloys, bio-based cargos, or petrochemicals, and three layouts developed. Evaluations of the alternative layouts was carried out on the basis of financial, environment and social criteria. The alloy cluster proved to be the best alternative to kick-start the development of the PoKT. A dry bulk terminal, a cement and electricity plant, together with required basic infrastructures and utilities, are minimum necessities for the port to be operational in its 1st phase of development. Actions were specified to make the selected layout robust, see Prakoso et al. (2017).

Europoort area in Port of Rotterdam is an industrial area with petrochemical refineries and storage tanks, bulk iron ore and coal handling, as well as container terminals. Over the years, the area has developed in an unstructured fashion, resulting in non-regular land lease areas, empty spaces without access to the waterfront, non-uniformly distributed services, and mixed zoning. Oil refineries, crude oil terminals, chemical and petrochemical companies represent almost half of the total throughput of PoR. Shift from fossil fuels and drive towards sustainability will have major implications for the future development of Europort. However, the nature, timing and magnitude of the impacts remains

In the view of multiple uncertainties, APP was considered an appropriate approach. The objective was to optimize the future use of available land and waterfront areas and making the existing masterplan of PoR robust under future uncertainties, was carried out.

The major uncertainties underlying the masterplan were identified, categorised as vulnerabilities and opportunities, and concrete actions to reduce the identified vulnerabilities and seize opportunities were defined included within current planning strategies. Many of these vulnerabilities relate to future policies and regulations, i.e., larger allowable distance between chemical clusters and residential areas in view of environmental considerations or the possibility of break-bulk replacing liquid and dry bulk cargoes.

Among the identified opportunities were the development of a bio-based cluster wherein PoRA takes the lead (e.g. facilitating and providing access to first or second generation feeder stock, providing logistical access, et cetera). Shared quay or jetty facilities was seen as an opportunity to increase infrastructure utilization and reduce negative impacts.

A detailed description of shaping, mitigating, hedging, and seizing actions to deal with the vulnerabilities and opportunities can be found in Arreco (2015).

The masterplan of Europort is based on strategic cargo concepts: Energy Port (biomass, coal, agribulk, mineral products); Fuel Hub (oil, bio-based oil, LNG, syngas, hydrogen, etc.), and Standardised Cargo Port (short sea containers, RoRo, Feeders). In the framework of APP (which recommends flexibility incorporation in all aspects), these were linked with flexible basic infrastructure (multi-purpose & multi-user quay walls and jetties). In the event uncertainty appears, this will allow adaptation to another function, thereby increasing the useful lifetime of the costly assets.

The result of APP is an adaptive master plan, i.e., the basic masterplan plus a set of actions for making it robust in the short-, middle- as well as long term.

The new port in Barranquilla, Colombia on the mouth of the Magdalena River is planned for handling three main cargo types, i.e., liquid bulk, dry bulk and containers. The feasibility study has been carried out in 2016, and the port concession will shortly be awarded by the river management authority Cormagdalena.

As a part of APP, a preliminary scanning of the project's uncertainties was followed by an action plan to shape, mitigate or hedge against the vulnerabilities, and seizing opportunities.
Falling trade with neighboring countries, decay of transshipment on Caribbean ports due to competition from US East Coast and Gulf ports as they deepen the ports and improve their hinterland connections influences cargo flows. The scrapping of Panamax vessels since the opening of the expanded Panama Canal in order to exploit economies of scale from Neo-Panamax vessels also represents a major uncertainty for the project due to inadequate water depth. Since the project is located in the middle of an environmentally protected area, opposition from the public and stakeholders is likely. Moreover, logistics for utilities supply from the West bank to the terminal represent a logistics issue for the construction of the terminal. Future development plans of Cormagdalena in the region, uncertainty over investment to improve hinterland connections, e.g. by developing a network of inland intermodal terminals, also impact the project.
A major opportunity is LNG import / storage / bunkering business as LNG becomes the “cleaner” fuel of the future.

The current masterplan is made adaptive by incorporating proactive actions that aim at seizing opportunities and attempt to shape the external forces as and when they appear. Details can be found in Soto Reyes et al. (2018).

6. CONCLUSIONS

The paper suggests that, in these uncertain times, the concepts of adaptability and robustness belong under the overarching definition of sustainability. Hence, sustainable infrastructures should not only achieve economic, environmental, and social objectives, but should be robust, meaning that they are robust and perform satisfactorily under multiple futures and are adaptable to (unforeseen) future conditions.

Literature over uncertainty suggests that a clear understanding of the relevant uncertainties can guide the planner to choose an appropriate approach to effectively address them. An analysis of major uncertainties confronting (most) ports, concluded that these belong to level 3 or 4, i.e. severe to deep uncertainty, which require complexity-aware approach that favours adaptation as a way of dealing with challenges. Therefore a “monitor and planned adaptation approach” such as Adaptive Port Planning (APP) is more suitable for the present uncertain times, than a traditional “predict and act approach”.

Case studies illustrating the application of APP framework to guide the planner to deal with both short- and long term vulnerabilities, and seize opportunities in order to create a port system that is sustainable, now and in the future, have been presented and will hopefully, promote the use of the framework.

7. REFERENCES

Arreco, P. (2015). Adaptive Port Masterplanning for Europoort, Port of Rotterdam, MSc thesis, Delft University of Technology, The Netherlands.

Becker, A., Inoue, S., Fischer, M. et al. (2012). Climate Change Impacts on International Seaports: Knowledge, Perceptions, and Planning Efforts Among Port Administrators, Climatic Change (2012) 110(1-2): 5–29.

Cicin-Sain, B., Knecht, R. W., Dosoo, J., & Fisk, G. W. (1998). Integrated coastal and ocean management: concepts and practices. Washington DC: Island Press.

Haasnoot, M. Middelkoop, H., van Beek, E.; van Deursen, W.P.A. (2011). A method to develop sustainable water management strategies for an uncertain future. Sust. Develop. 2011, 19, 369–381.

Haasnoot, M., J.H. Kwakkel, and W.E. Walker (2013). Dynamic Adaptive Policy Pathways: A New Method for Crafting Robust Decisions for a Deeply Uncertain World, Global Environmental Change, 23(2), 485–498.

Hallegatte, S., Shah, A., Lempert, R., Brown, C., Gill, S. (2012). Investment Decision Making Under Deep Uncertainty: Application to Climate Change,Policy Research Working Paper 6193, The World Bank.

Hamarat, C.; Kwakkel, J.H.; Pruyt, E. (2012). Adaptive robust design under deep uncertainty, Technol. Forecast. Soc. doi: 10.1016/j.techfore.2012.10.004.

Henchey, N. (1978). Making sense of futures studies, Alternatives, vol. 7, no. 2, pp. 24-28.

Kruitwagen, L. (2016). Grantham Institute Workshop on Decision Making under Risk and Uncertainty, Review and White Paper, February 2016.

Lempert, R.J., S.W. Popper, and S.C. Bankes (2003). Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis. RAND, Santa Monica.

Mishra, S., Deshmukh, S.G. and Vrat, P. (2002). Matching technological forecasting technique to a technology, Technol. Forecast. Soc. Change (TFSC) 69, pp. 1–27.

National Research Council (2009). Persistent Forecasting of Disruptive Technologies http://www.nap.edu/catalog/12557.html.

PIANC (2006), Ports of the Future, MarCom Special Session, 31st PIANC Congress May 14-18, 2006, Estoril, Portugal.

PIANC (2013) Waterway Infrastructure Asset Maintenance Management, InCom report 129 – 2013.

PIANC (2014a), Sustainable Ports - A Guide for Port Authorities, EnviCom WG 150 – 2014, Brussels.

PIANC (2014b), Masterplans for the Development of Existing Ports, MarCom WG 158 – 2014.

PIANC (2017), Sustainability Reporting for Ports (in preparation), WG 174 – Issue: April 2017.

Prakoso, A., Taneja, P., Vellinga T. & van der Plas, R. (2017). Adaptive port planning under disruptive trends: Case of Port of Kuala Tanjung, Indonesia, SIBE 2017, September 26-27, Bandung, Indonesia.

Rahman, S.A., Walker, W.E., Marchau, V. (2008). Coping with Uncertainties about Climate Change in Infrastructure Planning—An Adaptive Policymaking Approach; Ecorys: Rotterdam, The Netherlands.

RAND (2017). Strategic Choices for a Turbulent World: In Pursuit of Security and Opportunity. Published by the RAND Corporation, Santa Monica, Calif.

Soto Reyes, O.I., Taneja, P., Pielage, B.A., van Schuylenburg, M. (2018). Seizing opportunities from Panama Canal Expansion through Adaptive Port Planning, PIANC 2018, May 7-12, Panama City.

Taneja, P. (2013). The Flexible Port. PhD Dissertation, Delft University of Technology, The Netherlands, Publisher: Next Generation Infrastructure Foundation.

UNDP GCPSE (2014). Foresight as a Strategic Long-Term Planning Tool for Developing Countries, UNDP Global Centre for Public Service Excellence, Singapore.

Voros, J. (2003). A generic foresight process framework, Foresight, 5(3), 10-21.

W.E. Walker, V.A.W.J. Marchau, D. Swanson (2010). Addressing deep uncertainty using adaptive policies: introduction to section 2, Technol. Forecast. Soc. Change, 77, 917–923.

Walker, W.E , Haasnoot, M. and Jan H. Kwakkel, J.H (2013). Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty, Sustainability 2013, 5, 955-979.