The Flexible Port

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K. C. A. M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen
op dinsdag 19 maart 2013 om 12.30 uur

door

Poonam Taneja

Master of Science in Hydraulic Engineering, UNESCO-IHE, The Netherlands
geboren te New Delhi, India

Dit proefschrift is goedgekeurd door de promotoren:

Prof.ir. H. Ligteringen
Prof.dr. W.E. Walker

Samenstelling promotiecommissie:

Rector Magnificus	voorzitter
Prof.ir. H. Ligteringen	Technische Universiteit Delft, promotor
Prof.dr. W.E. Walker	Technische Universiteit Delft, promotor
Prof.dr.ir. P.M. Herder	Technische Universiteit Delft
Prof.dr.ir. C. Memos	National Technical University of Athens
Prof.dr. T.E. Notteboom	Universiteit van Antwerpen
ir. M. van Schuylenburg	Havenbedrijf Rotterdam
Prof.ir. T. Vellinga	Technische Universiteit Delft

This research has been funded by Port Research Centre Rotterdam-Delft, Next Generation Infrastructure Foundation, Water Research Centre Delft and Public Works Department Rotterdam.

ISBN 978-90-79787-47-0

Published and distributed by the Next Generation Infrastructure Foundation
P.O. Box 5015, 2600 GA Delft, The Netherlands
www.nextgenerationinfrastructure.eu

Cover: Figure "Model relating a system's life span and its flexibility" courtesy Dr. J. H. Saleh; in the background Port of Rotterdam.

Printed by Gildeprint Drukkerijen, Enschede, The Netherlands

The electronic version of this thesis can be found at http://repository.tudelft.nl

Preface

It's a bad plan that admits of no modification – Pubilius Syrus, Roman slave & poet (ca. 100 BC).

Infrastructures provide the basic services and facilities necessary for our economy to function. The many uncertainties with which they are confronted during their lifetime makes the planning and design of these infrastructures very challenging. As a practising civil engineer in a number of countries, my observation was that we limit the uncertainty considerations in infrastructure projects to the most unimportant uncertainties. Even before the objectives of a project are clearly set out, seemingly unaware of uncertainty associated with the forecasts, the planners and designers (mostly engineers) are churning out plans and designs. If they do introduce flexibility in their plans intuitively, its value is not made explicit during project appraisal. As a result, the cheapest solution is selected. In the face of uncertainty, this solution proves inadequate.

Despite the new challenges confronting our rapidly changing globalized economy, traditional engineering practices have remained largely unchanged, especially in the port sector. Therefore, this dissertation addresses the urgent question of how we can modify these practices to be able to plan and design port infrastructures that function effectively under conditions of uncertainty. The answer lies in flexibility and adaptability of the system. As the figure on the cover illustrates, the greater the flexibility, the longer is the lifetime of the system. A port planner must first identify relevant uncertainties in his plans, generate flexible strategies and solutions, and convince the decisionmaker of their long-term benefits. Therefore, the main goal of this research has been to provide him with practical and easy to use tools from fields of engineering, finance, management, and policymaking, to conduct these diverse tasks. I hope that the diverse case studies presented in this dissertation, illustrating the proposed methods and tools, will be able to convince the planners and decisionmakers of their efficacy.

In the course of four years, the relevancy of the subject (i.e. planning under uncertainty), to present times has been borne out by events such as the credit crisis, volcanic eruptions, tsunamis, and breakthroughs in science and technology. This is a very opportune time for firms to adopt new practices so that they can address new challenges and opportunities. In testimony of this, at the time of writing, the Port of Rotterdam (PoR) has approved a proposal for applying the methodology presented in

this dissertation to update the current Master Plan of the Maasvlakte 2 project.

This PhD has been a rewarding and enriching experience. I would like to thank my promoter Han Ligteringen for giving me this opportunity and support throughout, my promoter Warren Walker for the lively discussions, and Maurits van Schuylenburg, from the Port of Rotterdam (PoR) for steering me in the right direction. I am indebted to Marc Aartsen, Wim Zwakhals, and Ronald Schut (PoR) for their whole-hearted support. Also, I would like to thank Jan-Willem Koeman and Cees Klaver (PoR) for their encouraging presence at every one of my brainstorm sessions.

The Next Generations Infrastructures Foundation and Paulien Herder gave me a much needed platform to meet other researchers and introduced me to subjects and themes that a civil engineer would not normally stumble upon.

I would like to acknowledge that much of my inspiration comes from the pioneering work over flexibility being carried out at the Engineering Systems Division at MIT. Fortunately, I got the chance to thank Prof. Richard de Neuville and Michel-Alexandre Cardin personally.

Thanks to my employer Tiedo Vellinga for giving me ample room to round off my research, my roommates Kees den Heijer and Fedor Bart who harassed me into using LaTeX, and Robin Ros, Bart van Turnhout, and Esther Bijloo for their hard work and contribution to the case studies.

And finally, I am grateful to my family for allowing me to take so much time for my personal ambitions.

Summary

A port should be a masterpiece of engineering, a work of art, and it must be able to stand the test of time. It should be flexible so that later generations can adapt it for their own needs!

In today's turbulent, technology-driven, hyper-competitive, globalized economy, ports are beset with many uncertainties about their futures. They are confronted with new demands in terms of functions and scales, new external constraints, and changed expectations. The inability to adequately meet these demands can mean costly adaptations for a port, or loss of cargo and competitive position. A plausible reason is that the traditional practices of port planning have remained static in this dynamic world. We are still trying to predict the future using linear tools for complex non-linear systems, and then basing our plan on the predicted future. This plan fails when another future appears. While there is broad agreement about the need to deal with uncertainty, few have suggested a framework or a set of tools to help in doing so. Therefore, this dissertation addressed the question: *How can we plan and design our port infrastructures under conditions of uncertainty?*

A port can be seen as a dynamic, open, and complex engineering system subject to highly uncertain external influences. *Uncertainty* is as any departure from the unachievable ideal of complete determinism. An exploration into the many facets of uncertainty (its nature, levels, and location), in the context of ports shows that deep uncertainty is most significant during port planning. Defined as the situation in which multiple decisionmakers cannot agree on the system model, the prior probabilities for the uncertain parameters of the system model and/or the value function, deep uncertainty characterizes many situations. Our aim was to find a suitable uncertainty handling approach among the many that have emerged over the recent years. This requires a knowledge of the various sources of uncertainty one can encounter during port planning. We also need to comprehend the implications of prevailing and emerging trends that have direct or indirect implications for our goals, our plans, and the chosen planning approaches. Continuing globalization and containerization, changing functions of ports and magnified scales of port projects, changing actors in the port arena, breakthrough technologies, and increasing attention for the environment, are examples of such trends.

Traditional port planning, comprising elements such as masterplanning, infrastructure design, and project appraisal, focuses on short-term uncertainties. There are long

distances between the economist preparing demand forecasts (on which the plans are based), the engineer doing the planning, the investment manager who sets up the business case, and the decisionmaker. The planners do not habitually think in terms of uncertainty, and therefore propose inflexible plans and designs based on deterministic forecasts. The linear planning approach followed for most projects means that the decisionmaking cannot benefit from new information that reduces uncertainty. Investment appraisal involves a financial evaluation in a business case, and the selection among alternatives is based on expected values. Flexibility can enhance the value of a project, but cannot be valued with traditional methods. Decisionmaking for a project facing multiple uncertainties on a single monetary value is likely to be misguided. The result is inflexible port layouts and infrastructure designs that are not functional under changing requirements. Clearly, a new approach is required.

Flexibility helps a port to adapt to a wide range of exogenous developments. A flexible or adaptable port 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 (which essentially means, maintaining, or even improving service levels, with a small extra investment). An *option* is the right to carry out a strategic action, without the obligation to do so, now, or in the future, for a predetermined condition. In the context of real systems and projects, options represent a type of flexibility, and are termed as 'real options' (and can be valued through a Real Options Analysis). Flexibilities are sometimes embedded in a system; at other times they have to be created through strategic thinking. This is possible at all levels of a port infrastructure system, i.e. in its physical infrastructure, its procedures and operations, and the services it provides. It requires an understanding of the port system and the system attributes relevant to the provision of flexibility in a system. We propose a framework that can be employed by port planners to identify and incorporate flexibility.

We have proposed *Adaptive Port Planning (APP)*, an approach that bridges the gaps in the traditional practices of port planning by incorporating uncertainty and flexibility considerations. It provides a framework for the planner to generate plausible alternatives in the context of his planning objectives and his definition of succes; identify critical uncertainties (vulnerabilities and opportunities); and then, to explore, value, and incorporate flexibilities for handling these uncertainties. Subsequently, actions can be taken either in the planning stage, or actions can be prepared in advance, and taken as events occur. Next, the planner evaluates the alternatives and makes a selection – the value of flexibility is included in his evaluation. During the implementation phase, actions are taken in response to triggers from a monitoring system set up for the selected alternative (which monitors the external environment for new developments and alerts planners of the need to modify or reassess the plan).

Real-life case studies established that APP can accommodate diverse planning needs and deliver flexible and robust solutions that can better withstand the vagaries of the future. These cases dealt with critical issues such as spatial planning under uncertainty and energy transition, or served to illustrate flexibility related features (e.g. flexible infrastructure designs, flexible logistic concepts, and flexibility in decisionmaking). The illustrative cases were designed to help a port planner to apply the proposed framework and the methods it embraces.

Flexibility in (physical) infrastructures was investigated through a survey and a brainstorm session with various stakeholders in the port (related) industry. Among the favoured strategies for flexibility were: design modularity, standardization, and generic and robust designs. The session served to establish that current approaches to planning, design, and project appraisal, need to be modified to incorporate flexibility considerations. The general opinion was that four alternative design approaches to infrastructure design, i.e., design for fixed specifications and resort to ad-hoc adaptation; design for obsolescence and demolish; design for robustness through building in margins; or design for flexibility need to be considered for each project instead of opting for a client specific design.
Flexibility in infrastructures facilitates reuse, optimizes the use of natural resources, limits waste and pollution in the environment, conserves energy resources, and can result in significantly lower lifecycle costs, thereby contributing to sustainability. However, no examples of flexible structures were to be found in the Port of Rotterdam (PoR). The practices related to reuse in the port are limited to down-cycling materials into low-grade applications. Flexibility (and sustainability) considerations, which include designing for deconstruction and reuse, must be incorporated into all designs. Therefore, a framework that guides adaptation and reuse has been presented.
The importance of innovation in engineering design for dealing with the biggest challenge for the port industry is being recognized. Although many innovative logistic and infrastructural concepts have been proposed in recent times, despite intensive engineering effort and investment in pilot projects or feasibility studies, none have been implemented. An investigation into the factors underlying failed and successful innovative endeavours at PoR corroborated that innovation is shaped by the interplay of need, economic, and institutional factors. The strategies for flexibility cannot be considered in isolation from the efforts required at the institutional level to incorporate and implement flexibility. Equally important is making explicit to the management, the added value of flexible solutions, in the most recognized unit, that is money.

APP requires a *valuation method* that is able to take into account the multiple uncertainties and flexibilities in port systems, is amenable to the characteristics of port projects and applicable for the port market being considered, is transparent, and possesses the communicative power to convince management of the superiority of flexible solutions. The tools of traditional economic analysis – such as Simulation (basically a stochastic Discounted Cash Flow method) or Decision Tree Analysis (DTA) – are adequate to achieve a useful and consistent comparison of alternatives. While simulation is suitable for continuous risks, DTA is recommended in case of clear investment alternatives and contingent decisions. Simulation, applied using a simple spreadsheet model, results in a range and distribution of the possible outcomes, together with the likelihood of their occurrences. It requires practitioners to make explicit the uncertainty inherent in all estimates going into the analysis, which is a significant advantage. It employs the intricate knowledge of the port system and its processes acquired during planning and design, so that little effort is required to set up an evaluation model. We have suggested how these methods can be usefully applied to real situations at PoR, dealing with investments in innovative projects such as MultiCore, steam pipeline network, and long-term planning and expansion projects.
A real options analysis (ROA) based on financial option theory was found unsuit-

able, since many of the assumptions implicit in the method are not valid for port projects and markets, though further research in this rapidly growing field may find ways to relax these assumptions. Its inherent complexity, limited applicability, and non-transparency further limit the use of ROA. Real option thinking, however, that can reveal the value of (hidden) flexibility in a project, needs to be embedded in the standard practices of an organization. That is why we present a a qualitative framework to be used in combination with traditional quantitative methods.

APP relies on *monitoring of the external environment*. Monitoring aims at evaluation of events or developments as they occur or just after (and involves activities like measuring, analysis, assessment, and forecasting), so that timely actions can be initiated. Specifying appropriate triggers to monitor when external developments require changes in a system is far from easy. We demonstrated, using the simplest class of forecasting techniques employing statistical methods, that it is possible to monitor developments that represent major vulnerabilities for port projects. Changes in container markets can be monitored using economic indicators, such as GDP. Environmental scanning, media monitoring, and expert opinion can help to track changes in policies or to get advance warning of changes to come. Technological forecasting is still far more an art than a science. Through identifying physical limitations in a current technology (or precursor technologies), and monitoring developments that can either remove or circumvent these limitations, we can get sufficient warning of a possible breakthrough. We have presented a simple framework for monitoring breakthrough technology and illustrated this through two examples.

Adoption and successful implementation of APP by organizations involved in port planning and design faces many barriers. The conservative port industry, the nature of port projects constrained by legal procedures that limit flexibility, the traditional role assigned to an engineer doing the planning, the organizational culture that leaves little room for new techniques, the extra investments associated with flexible designs, and the fact that innovation is low priority in times of uncertainty, all represent barriers. Recent global events are already creating a new mind-set, and the importance of making visible the value of flexibility is being realized. Since the implementation of APP has to be carried out in multi-actor and multi-disciplinary setting crossing social, economic, environmental, legal, and political boundaries, we need a 'strategic planner' – a generalist who can take a holistic approach, understand the tasks of an engineer, economist, manager, and a policymaker, and is able to communicate with the many disciplines in his planning team. He/she must be able to integrate their knowledge, incorporate uncertainty considerations in standards and projects, seek innovative flexible solutions, and justify them to the authorities.

In an uncertain world, where responsible decisions for a very distant future have to be made now, tasks are set out for many. Port planners need to practice adaptive planning. Policymakers need to stimulate formulation of norms and guidelines that embrace uncertainty considerations and lead to flexible infrastructure designs and solutions. A port authority needs to initiate collaborative efforts to find innovative solutions to tomorrow's problems. Both the terminal operators (many of whom are now multinational enterprises) and the port authorities need to be pioneers (risk-takers) in implementing new solutions. The government needs to play the role of a facilitator in innovation, mostly due to the mega scale of projects and the required authority to implement institutional change accompanying (technological) innovation.

In conclusion, this dissertation "The Flexible Port" is about planning under uncertainty. Uncertainty is here to stay; we must recognize it, prepare for it, adapt to it, manage it, profit from it. We must use an adaptive approach to planning to create Master Plans and infrastructure designs that can stand the test of time. We must build in flexibility so that later generations can adapt them to their own needs.

List of Symbols & Abbreviations

km	:	kilometre
ha	:	hectare
m2	:	square meter
m	:	meter
€	:	euro
M€	:	Million euro
t	:	tonne (metric tonne)
mln	:	million
ACT	:	Amsterdam Container Terminal
ABP	:	Assumption-Based Planning
APM	:	Adaptive Policy Making
APP	:	Adaptive Port Planning
APMT	:	APM terminals
APPA	:	American Association of Port Authorities
ARRA	:	American Recovery and Reinvestment Act
BAFO	:	Best-and-final-offer
BAM	:	Koninklijke BAM Groep NV
BFT	:	Barge Feeder Terminal
CBT	:	Common Barge Terminal
CBA	:	Cost Benefit Analysis
CITG	:	Department of Civil Engineering and Geosciences
CP	:	Capitalizing Actions
CPB	:	Netherlands Bureau for Economic Policy analysis
CPI	:	Consumer Price Index
CR	:	Corrective Actions
DA	:	Defensive Actions
DCMR	:	Dienst Centraal Milieubeheer Rijnmond
	:	(Environmental agency Rijnmond area)
DCF	:	Discounted Cash Flow
DTA	:	Decision Tree Analysis
DUT	:	Delft University of Technology
DWT	:	Dead weight tonnage
ESPO	:	European Sea Ports Organization
ECT	:	Europe Container Terminals
EECV	:	Ertsoverslagbedrijf Europoort C.V. (Dutch)
ESPO	:	European Sea Port Organization

EMSA	:	European Maritime Safety Agency
FMEA	:	Failure Mode and Effect Analysis
FRP	:	Fibre Reinforced Polymer
FTA	:	Fault Tree Analysis
GBN	:	Global Business Network
GHG	:	Green House Gases
GPL	:	Gangavaram Port Limited
GSM	:	Goederen Stroom Model (Dutch)
HPH	:	Hutchison Port Holdings
IAPH	:	International Association of Ports and Harbours
IGWR	:	Ingenieursbureau Gemeentewerken Rotterdam
	:	(Department of Public Works Rotterdam)
IMO	:	International Maritime Organization
IPC	:	Israel Ports Company
IPCC	:	Intergovernmental Panel for Climate Change
IRR	:	Internal Rate of Return
JNPT	:	Jawaharlal Nehru Port Trust
KIVI	:	Royal Dutch Institution of Engineers
KPI	:	Key Performance Indicator
LOA	:	Length overall
LCA	:	Life Cycle Analysis
LCC	:	Life Cycle Costing
LPG	:	Liquefied Petroleum Gas
LNG	:	Liquefied Natural Gas
MCA	:	Multiple Criteria Analysis
MTEU	:	Million TEU (see TEU)
MTG	:	Mercator Transport Group
MV2	:	Maasvlakte 2
M	:	Mitigating action
NEA	:	NEA Transport research and training
NAP	:	Normaal Amsterdams Peil
NPV	:	Net Present Value
PIANC	:	Member World Association for Waterborne Transport Infrastructure
PMBOK	:	A Guide to the Project Management Body of Knowledge
PoRA	:	Port of Rotterdam Authority
PoR	:	Port of Rotterdam
PMR	:	Projectbureau Maasvlakte Rotterdam
	:	(Rotterdam Mainport Development Project)
ROA	:	Real Options Analysis
RDM	:	Robust Decision Making
RE	:	Reassessment
RIL	:	Risk Inventory List
RAL	:	Risk Action List
RISMAN	:	Risk management program
R & D	:	Research and Development
SH	:	Shaping action
SSK	:	Standaard Systamatiek Kostenraming (Dutch)

SZ	:	Seizing action
TEU	:	Twenty foot equivalent unit
TPM	:	(Department of) Technology, Policy and Management
UAV	:	Uniforme administratieve voorwaarden (Dutch)
UNCTAD	:	UN Conference on Trade and Development
USCAE	:	US Army Corps of Engineers (Corps)
WCM	:	World-wide Container Model
3PL	:	Third-party logistics provider
4PL	:	Fourth-party logistics provider

Contents

Chapter 1

The Flexible port: An introduction

A port should be a masterpiece of engineering, a work of art, provide tremendous service to society at large, and be able to stand the test of time.

1.1 Ports as risky businesses

1.1.1 The changing world around us

The last few years have seen a unique combination of systemic change driven by globalization, new technology and increased environmental awareness combined with a number of seismic shocks to the global economic system such as 9/11, SARS, Hurricanes Katrina and Rita, the Asian Tsunami, and the global credit crunch (Axson, 2009). This has implications for the way we live and do business. The question is: are we changing fast enough to avoid future shock[1]. If not, what must we do to keep up? In this dissertation, we will approach this issue specifically in the context of the port sector.

1.1.2 Developments in the port sector

Infrastructures, in the field of transportation, health, power, communication, water, energy etc. provide the basic services and facilities necessary for an economy to function (Sullivan and Sheffrin, 2003). Port infrastructures are essential components of the international trade and goods movement, providing services to ships and cargo. In the last 50 years, ports have evolved from being cargo loading and unloading locations to being crucial hubs in value-driven logistic-chain systems. They now are international logistic platforms acting as interfaces between production and consumption centres (Van de Voorde and Winkelmans, 2002) as well as economic complexes wherein several industries operate (de Langen, 2004a). A port is recognized as a complex set of

[1] A term coined by Toffler (1970) which describes the effect of the accelerated rate of technological and social change on individuals and society if one does not keep up.

functions that, while interacting with the life of the local community, is interwoven with national and international interests, not only with regard to traffic and trade relations, but also in terms of organization and financial matters (Moglia and Sanguineri, 2003). Seaports of today are functionally regionalized systems (Notteboom and Rodrigue, 2005) that are parts of wider transport networks and are embedded in supply chains (Robinson, 2002).

The major factors contributing towards this have been developments in information and communication technology and containerization, aided by developments in marine and construction technology. Containerisation (through unitisation) has increased handling productivity, facilitated interchange between modes leading to efficient network connections, safe delivery, lowered costs, and fostered expansion of trade, and spurred globalization. Globalisation, as a phenomenon, is defined as a substantial (exponential) 'expansion of cross-border networks and flows' (Lorthiois, 2008). It is instrumental for changes in consumption patterns and production locations as well as the shrinking cost of commercial transport, and has led to increasing world trade and cargo volumes. In short, while the Internet has revolutionized world communication, and changed the way we work and play, the invention of the container and the rise of container shipping have changed the balance of world trade, rewritten the rules of modern manufacturing, and transformed port and manufacturing cities around the world (Zuckerman, 2007).

1.1.3 Inadequate infrastructure

Many ports and their associated roads, rail, and inland waterway systems, have often suffered from years of under-investment or total neglect. Inadequate land area, inefficient layout, poor configuration of berths and terminal areas, inadequate equipment, insufficient gate facilities and road access, characterize many of the ports. The rapid growth of cargo volumes over the last few decades has led to port capacity shortage both at land and sea side. The result of the increased economic activity is congestion in existing ports and their hinterlands. Limited room for sustainable expansion, and the growing scarcity of prime locations, aggravates the problem.

Leaps in technology have led to new handling and logistic concepts requiring a very different port or terminal layout and multi-modal infrastructure. The insufficient water depth in existing ports to cater to present mega ships (requiring deeper water, bigger cranes, longer berths, bigger container yards) poses a serious problem. The increasing focus on safety and sustainability too demands innovative solutions for ports. These developments call for expansion or adaptation of existing waterfront and land-side assets, or alternatively, investments in new infrastructure. Ports which do not evolve will find themselves stranded, outside the main loops and networks (Sletmo, 1999).

Meanwhile, the changed function of the major ports into transport, industrial, distribution, and logistic nodes has changed the nature of competition, and brought forward new issues for planners and users alike. While the neighbouring ports with the same hinterland compete for the transport function, all ports with similar facilities and serving the same hinterland compete for the distribution/logistic function, and almost any location in the world with similar facilities is eligible to compete for the industrial function. Thus the industry competes on a global level (PoRA, 2010e). With increasing competition, between supply chains instead of ports, efficiency and productivity has to be improved over the entire supply chain.

The top five reasons for future competitive advantage are said to be: the geographical location, intermodal logistics, cargo handling efficiency, port facilities and multi-service port. In order to capture the potential from convergence of the global economy and competitive markets, and consolidate a port's position under changed requirements, in addition to improving overall efficiency in the port sector, there is a need to build up capacities through investment in infrastructure. Keeping up with the urgent investment requirements of modern port infrastructure has become a challenge for many ports (Rodrigue et al., 2009). As Haralambides (2002) states: "Sufficient infrastructure is required in order to provide sufficient service levels, while extra capacity is required to attract future growth." In words of the Head of Terminal Strategy at Maersk Line (Maerskline, 2011): "Today, having the right capacity and capabilities is integral to the long-term growth and success of ports. Ensuring that the nautical infrastructure, quay design, cranes and operational layout match the specifications of future vessels is essential for ports to get ahead of the curve."

1.1.4 Risky investments

Port infrastructure facilities require investments that are huge, irreversible, highly risky, and have a very long return period. As existing facilities, they may confront economic competition of an increased space demand, or other functional demands may be placed on them (Penfold, 2005). We will define some terms before discussing this aspect.

Irreversible means that the changes are permanent.

The *economic lifetime* of infrastructure is the period of time during which the infrastructure can fulfil its functional requirement(s) without adaptation.

The *technical or design lifetime* of infrastructure is the period over which the infrastructure can fulfil its technical (design) requirements. Civil infrastructure such as quay walls and jetties (referred to as basic infrastructure in Table 3.1), have a design lifetime of at least 50 years, and often more.

The current trends in deregulation, with subsequent economic volatility, developments in technology, increasing dependence on information technologies, vertical integration among shipping lines, challenges in dealing with diverse stakeholder groups, and growing complex organizational structure, have made ports increasingly risky businesses (Meersman et al., 2009; Ryuji and Prianka, 2000; Notteboom and Rodrigue, 2007). In container transport, for instance, port development is very rapid, and shipping lines tend to shift large container volumes from one port to another. And on a global scale, as transport costs fall to extremely low levels, producers move from high-wage to low-wage countries. These geographic shifts can occur quickly and suddenly, leaving long-standing port infrastructure under-utilized or abandoned as economic activity moves on (Levinson, 2006). Also, changes in policies at international, European, national, or regional level may create restrictions for a project either at operational or service level, effecting its viability.

'Black Swan' events (Taleb, 2007) such as the financial crisis (2008-2010) that froze movements of money and shipments, natural disasters such as the earthquakes off the coast of Japan and Indonesia in 2011 en 2004 respectively, and the volcanic eruptions in Iceland in 2010, have given us all a reason for re-examining how we plan for an uncertain, unpredictable future. While today, a suitable substitute for ships as means of transport seems unlikely, as does a world war; black swan events seem improbable until they reveal themselves.

Clearly, ports are elements of the volatile market and as such much more affected by political factors, international trade, and overall world economic conditions than most other enterprises. The many logistical, technological, and economic uncertainties under which a port must operate, make the planning and design of these complex socio-technical infrastructures very challenging. Often, the result is a port that cannot meet future requirements, due to its physical limitations and its adequate infrastructure. Either drastic and costly adaptations are required or the infrastructure has to be demolished long before its design lifetime has been reached. The overall consequences for the port are – in the best case – inefficient use, and loss of cargo and competitive position, and – in the worst case – redundancy and obsolescence. Numerous examples of congested or obsolete ports and stories of costly adaptations can be found all over the world, which is why port planning, and large scale infrastructure planning in general, has come under heavy scrutiny. The increasingly shortened useful economic lifetime of ports in the face of uncertainty, leading to huge direct and indirect losses, has made the nature and timing of infrastructure investments a critical issue in the port sector[2].

Being currently surrounded by an environment characterized by a high degree of complexity, where activities are often carried out in a disorganized way, with high costs, inadequate customer services, lost opportunities and sub-optimisation of resources, the port industry needs to adopt a new attitude (Paixäo and Marlow, 2003). Notwithstanding, the biggest challenge for ports arises from external factors such as uncertainty in market demand, new technology, and new policies related to environmental, safety, security issues.

Brolsma (2006) aptly states: "We don't want ships to wait; we want the infrastructure to wait for the ships." Thus there is an urgent need for redevelopment of older ports and investments in port expansion to ensure sufficient infrastructure and service levels. Port infrastructures have long life expectancies and given the capital-intensive nature of the port industries, the assets are long-term. Conditions may and will change, issues and focus will change (van Binsbergen, 2004), which adds to the dilemma of

[2]It is important to mention in this context that major factors cited as being responsible for the failure of large infrastructural projects are: changes in scope or aim of project, weak project definition, interfering government, management problems, conflicting perspectives from different actors, optimistic cost and risk estimates, weak or risky contracts, and variable components in those contracts, an imbalance between process and product, and the project organization) (Verbraeck, 2009). As we will see in subsequent chapters, the most significant factors are the result of, or related to, unforeseen external developments.

a long payback time etched with uncertainty. There is an urgent need for the ports community to explore asset management strategies and practices to face and manage these challenges.

1.2 Setting the background

Before framing our problem, we will set the background by defining some terms and discussing the processes involved in port planning.

A port development project

This can refer to an entirely new port project, to a port expansion, or to a new terminal in an existing port. The project lifecycle includes the following phases: the feasibility phase, preliminary design, detailed design, implementation, and exploitation (including maintenance and adaptation). Though there are many measures of success, a port (re-)development project is, in very general terms, said to be successful if it provides returns on investments for the investors, and service quality for the users, during its design lifetime[3]. Due to an increase in private investor participation (in what was formerly undertaken by the public sector), who demand quick and larger returns, the economic pressure on ports is immense.

A port development project requires a robust design and layout, efficient land use, placing the clients at the right location, providing room for expansion, creating synergy through co-siting, and causing minimal negative impact on the environment and society, throughout the project lifecycle. It is of essence that a port is able to cope with the new demands without drastic adaptations either to the port layout or to marine, quay, terminal, or intermodal infrastructure during its planning horizon. The new requirements are not only dictated by changes in types of cargo or fluctuations in volumes of cargo, but also by changes in technology or changes in policies, at all levels – local, national, or international.

Port stakeholders

There are numerous stakeholders in the port sector, involved in design, development, maintenance and operation of these systems. Figure 1.1 (Nijdam, 2011) depicts the major stakeholders and their interrelationship including the port authority (or the governing bodies), the terminal operator, carriers, shippers, freight forwarders, and third parties such as logistic-, port- and transport service providers (sometimes the roles may be combined). The actual involvement of the stakeholders will depend on whether day-to-day operations, implementation of port development plans, business plans, or strategic planning is involved (Dooms and Verbeke, 2007). Generally, economists, planners, designers, financiers, contracting firms, and the client (who in turn depends on various market parties while formulating his requirement), are the major actors during planning.

[3]Sometimes a port project is instrumental for the welfare economy through creating jobs, and cost recovery is not an issue. In other cases, the immediate goal may be to attract a cargo segment to create a future niche market and pricing is based on other strategies than cost recovery.

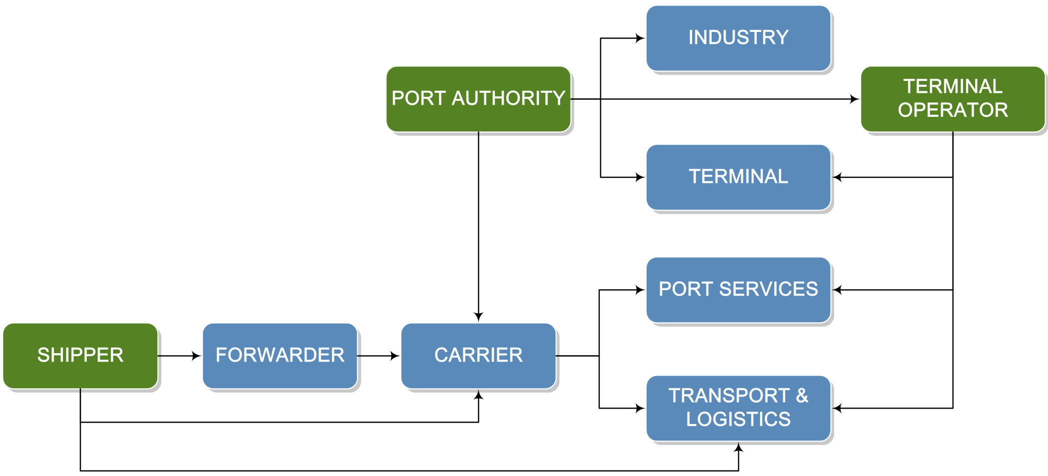


Figure 1.1: Stakeholders in the port arena

Port infrastructure system

A port infrastructure system includes physical elements (such as breakwaters, access channels, berths, equipment, roads and rail connections), in addition to the operating procedures, management practices, and development policies that interact together with societal demand and the physical world to facilitate its functions (National Research Council, 1987). The physical elements are also referred to as *civil structures* or *structures*.

In the words of Roos et al. (2004): "Large-scale engineering projects share three major features: they last a long time, which means they need to be designed with the demands of a distant future in mind, exhibit economies of scale, which motivates particularly large construction, and have highly uncertain future requirements, since forecasts of the distant future are typically wrong". Port infrastructures are large-scale, complex, indivisible, highly capital intensive systems. Alternative use of (port- or non port) land, especially in a densely populated area, is difficult to implement. The indivisible character requires that they be built in quantum chunks (World Bank, 2007), in accordance with demand for peak and off peak periods, as well as any sudden rise in future demand, since they cannot be built up in a short period of time with low investments (Gaur, 2005).

Port planning process

An element of port planning and design is necessary for any port development. A Master Plan of a port includes a layout of the port wherein land is allocated to the various uses, describes the phases needed to implement the plan, and gives an indicative implementation scheme per development phase (Ligteringen and Velsink, 2012). It incorporates preliminary designs of the major port infrastructure works – e.g.: breakwater layout, dredging areas and depths, entrance channel and turning circles, plans and cross-section of quays, terminal areas, and pavements. These designs provide the basis for cost estimates, and are worked out later in a detailed design phase. A Master Plan simultaneously reflects the strategic objectives of government, port authority and other stakeholders, the requirements of port users and operators, and the needs of local

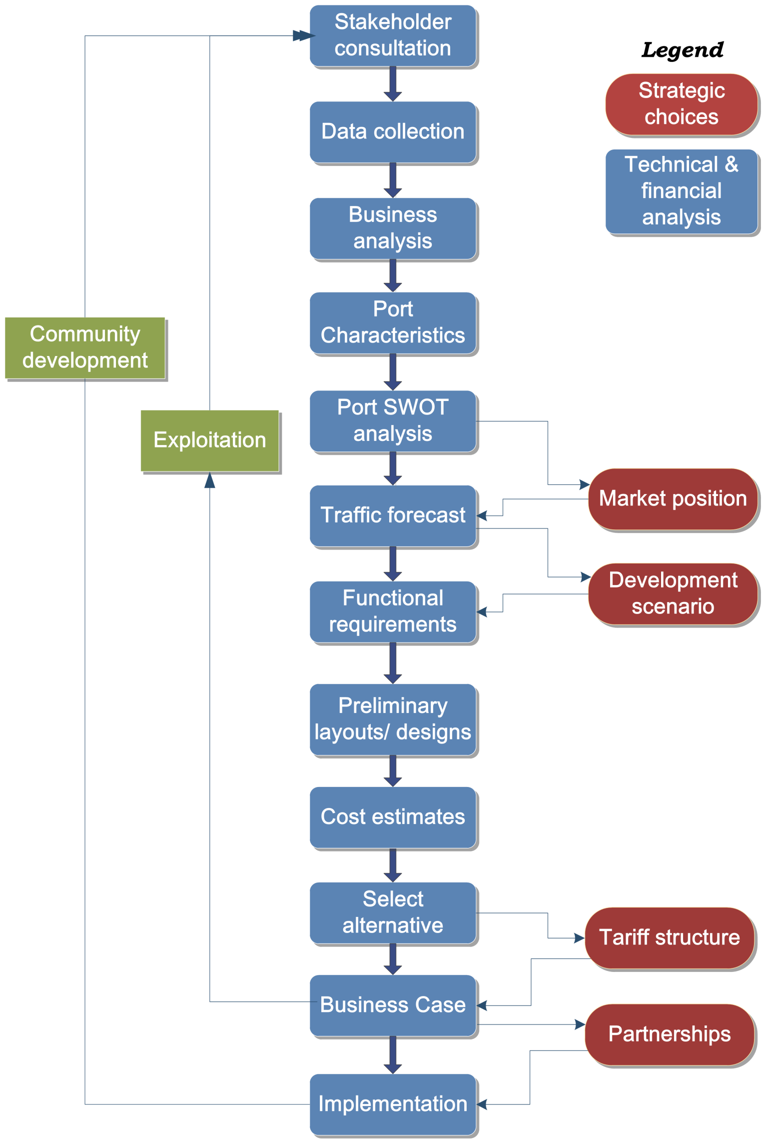


Figure 1.2: Port Planning Process

communities (which are in turn determined by myriad global forces). Masterplanning, depending upon the country, port, and the port management model, is carried out by the Port Authority or specialist consultant assigned to the job.

The planning of a port is carried out by a multidisciplinary team, and involves many stakeholders. Figure 1.2 (source: PoR) shows the various steps in the planning of a new port. After consultations with the stakeholders and initial data collection, a business analysis is carried out. The objective of such an analysis is to identify the specific requirements posed by port users in their working environments that can influence the port development strategy. Port characteristics, such as location, geometry, and hinterland connections determine its position in the competitive landscape. These can be placed in a SWOT (strength, weaknesses, opportunity, and threat) framework to highlight market opportunities in terms of cargo types and sectors likely to attract potential investors. This analysis helps towards developing a phased and detailed port development strategy.

Once these general requirements have been established, the next step is traffic or demand forecasting based on scenarios that indicate the margins of economic growth in a country for the projection period (not including extreme conditions). The scenarios describe the hypothetical future state of the world; and a family of scenarios spans a range of plausible futures and captures some of the major uncertainties expected to be encountered in these multiple futures. These scenarios – which generally include a ‘trend’ or ‘business as usual’ scenario, an optimistic scenario, and a pessimistic scenario, attempt to capture a reasonable bandwidth based on historical trends. The infrastructure requirements needed to meet the forecast demand (more often than not based on the trend scenario) are determined and developed into a detailed Master Plan including preliminary design of basic infrastructure. Thus, the general approach is simplistic: study the market and ‘predict and provide’.

The subsequent step involves working out a commercial strategy based on the market analysis and the SWOT analysis. It includes determining the tariff structure for various services offered by the port. The expected revenues are calculated based on the cargo forecasts and the tariffs. The costs of the selected design alternative are set up in a business case in order to determine the feasibility of a project. The possibility of attracting private and public investments is examined based on the ownership model of the port (private, landlord, service or tool). The organizational set-up and the division of responsibilities among private and public parties is optimized, and the various contracts evaluated.

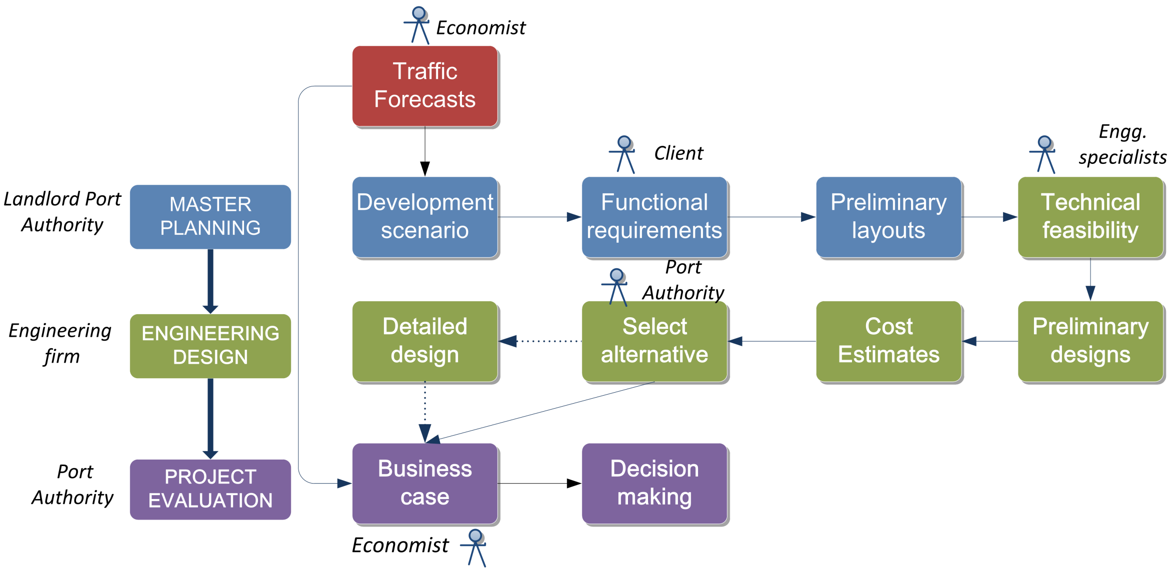


Figure 1.3: Elements of port planning

Figure 1.3 depicts various elements of port planning along with the actors involved, beginning with the traffic forecasting.

Project evaluation

Project evaluation refers to the process of assessing, in a structured way, the viability of a project, and often involves comparing alternatives through use of financial or other techniques. The process of economic evaluation to support decisionmaking falls generally to economists. A business case, which includes the investments and future revenues is set up and decisionmaking is generally based on a financial criterion using the Discounted Cash Flow (DCF) method. Whenever we mention *port planning* in this thesis, we refer to all the procedures depicted in this figure – namely, Masterplanning, Engineering Design, and Project Evaluation. Port planning is irrevocably related to port operations, management, and governance.

Having set the background, we will frame our problem in the next section.

1.3 Framing the problem

Our infrastructures constitute the physical framework within which our economy and society operate (Hansman et al., 2005). Traditional designs of infrastructure projects usually bear all the weight and costs of the bad side of uncertainty, without profiting from the potential of the good side (Ramirez, 2002). The realization of the importance of dealing with uncertainty during planning of infrastructure is on the rise as we face the consequences of ignoring it.

Therefore for every port development project and before an investment decision, port planners are looking for answers to the following questions: Should the port owner invest immediately in facilities to accommodate future demand throughput or wait until more definite information becomes available? Should the port infrastructure be a durable structure with a technical lifetime (or design lifetime) at least equal to the expected economic lifetime, including possible future upgrading, or should a cheaper structure with a shorter technical lifetime be opted for? Can the technical lifetime of infrastructure span multiple economic lifetimes, through adaptation and reuse, so as to maximize the return on investment?

Nevertheless, the standard practice is to model uncertainties as trends from historic data. As can be seen in Figure 1.3, the typical decisionmaking process related to a port project involves engineering design based on scenario forecasts, followed by a project evaluation generally carried out by economists.

The current practice of scenario-based planning acknowledges that the long term future may be very different from the present. Even so, decisionmaking is usually carried out based on the scenario that possesses the most benefit and is the most cost effective, with minimum risks and impacts. Thus scenario-based planning, as practised, offers a single solution for one specific future based on the most likely forecasting of traffic demand. However, which future will eventually materialize, is not known. Moreover, the process is static and follows a rigid sequential strategy, leaving no room for adaptation. That is why this approach often fails for long-term planning!

The engineering and financial disciplines have little communication, and not all information is able to be traced back in the project documentation. Due to this gap, valuable input from the engineering discipline is often missing, and decisionmaking related to capital investment can be misguided. A similar gap exists between the economists doing the forecasts and the engineers, so that the latter are unaware of the uncertainty surrounding the forecasts, and treat these as deterministic, thereby ignoring uncertainty.

The sequential nature of the procedure means that the best seeming alternative is evaluated in the detailed design stage, and the rest of the alternatives are not taken into account. The decisionmaking related to technical aspects and project investments are independent and carried out in different time frames. The decisionmaker does not see the technical alternatives, and bases his decisions mainly on the financial value of a single design (if found non viable, the costs related to this alternative are lowered through altering the design or ignoring risks). There is no scope within the standard procedures to reconsider, adapt, and re-evaluate another alternative (as to material, design, technology, or operation), if the first evaluation results in a non-viable business case.

The commonly applied financial techniques such as DCF, are adequate for a stable environment, where the projects have deterministic requirements and the management has a clear strategy. But uncertainty poses new challenges. For the majority of projects, variables such as costs and revenues are uncertain, and the assumptions underlying the determination of these variables are questionable. But in a business case they are treated as if they are certain. The DCF method also assumes that decisions are made now and will not change later, and fixes the cash flow streams for the future. Though two extreme scenarios are considered, the decision-making is based on the most likely outcome of a situation, e.g., expected value of investment and potential revenues. But with all the uncertainty involved in such projects, the chance of a single value being correct is essentially zero. The Netherlands Bureau for Economic Policy Analysis (CPB, 2003) states: "Due to (often) large uncertainties, concerning the project itself, as well as the environment in which the project will function, it is neither possible, nor desirable to express the project value with one deterministic number, and use it as a basis for investment decisions."

Each investment project is considered in isolation, with its own approval procedure, and credit/loan application. A business case does not include all the effects of a project. Societal impacts of a port development plan, although sometimes stated separately in the business case, remain outside cost-benefit calculations. This involves a risk that societal impacts are represented less prominently than financial items, so the business case is not balanced.

It is being increasingly acknowledged that the most important uncertainty management concept for large projects is that of flexibility. Flexibility and its related concepts such as adaptability and robustness, represent the ability of a system to respond to new, different, or changing requirements, and can be instrumental in avoiding downside consequences of uncertainty or exploit its upside opportunities. Flexibility in decisionmaking or flexibility in design and operations enhances the value of a project, but cannot be included in the project evaluation with standard DCF methods. The lack of suitable analytical and evaluation techniques has been a barrier against investments in flexibility in the past. New techniques have recently been developed, but their use is not common.

In conclusion, the traditional planning approaches fail to adequately account for high levels of uncertainty. Thus, we need new perspectives on planning and design of ports.

We need to define our objectives and functional requirements more carefully, we need to incorporate flexibility and adaptability into port planning and design processes, and we need to come up with flexible design solutions. As stated by de Neufville (2004); Hansman et al. (2005); Roos et al. (2004): "Engineering systems face the tremendous challenge of meeting the changing demands while ensuring functionality, capacity and service quality. Thus, planning is needed to anticipate future developments and to ascertain that the infrastructure, once built, functions well."

In the next section we will frame our research question(s) and present our research approach and strategies.

1.4 Research design

In this section we present the research design, i.e. the research questions, approach and strategies.

1.4.1 Research questions

The previous sections established that planning and design of ports to satisfy both present and future needs requires a new approach. Therefore, in this dissertation we set forward the following hypothesis:

The port industry is in a state of radical change and the biggest challenge confronting it is uncertainty. Since uncertainty is here to stay, we need to recognize it, manage it, and even try to profit from it. This requires approaches for port planning and design that emphasize the importance of flexibility and adaptability in coping with uncertainties.

Against this backdrop, we formulate the research question as follows:
How can we plan and design our port infrastructures under conditions of uncertainty?

The main research question, which belongs to the how? category, requires an exploratory research method, where typically historical research, literature surveys, brainstorm sessions and case studies will be combined to provide the answer. In order to answer this question, we need to address the following sub-questions:

1. What is one of the major challenges facing ports?
2. What are the drawbacks in the traditional methods of port planning with respect to handling uncertainties?
3. What is a good manner to deal with the uncertainties in port planning?
4. Which planning method(s) can remove the drawbacks identified in the traditional methods?
5. Where can we incorporate flexibility in port infrastructure?
6. How can we value flexibility in a project appraisal (and justify its extra costs)?
7. How can we monitor major uncertainties in order to initiate timely action?

8. How can we stimulate the adoption and successful implementation of the proposed planning method?

1.4.2 Research approach and strategies

Our research objective is to devise frameworks and methodologies for port planning and design that result in robust Masterplans and flexible/adaptive designs, so that a port is able to adapt to changing requirements, and provide functionality, capacity, and service quality over a longer time horizon. The prolonged economic lifetime of port infrastructure will ensure that the payback on the investments can be realized.

Our research approach is to pursue the logical sequence of steps discussed below. These steps are directly linked to the eight sub-questions. The research strategies applied at every step are also briefly mentioned. Each research strategy requires tools or instruments, the choice of which is based on a combination of research objective, interest, expertise, disciplinary tradition, and availability of resources (Verschuren et al., 1999; Creswell, 2003).

After setting the background and describing the motivation for this research, we introduce the main research question and sub-questions, and present briefly the research approach and strategies (Chapter 1).

Next, we examine the present and future challenges facing ports (Chapter 2). Ports and the shipping industry have been evolving at a rapid rate and we need to have an understanding of the plausible future changes in the world. This requires us to relate the past to the present and the present to the possible futures through historical review and desk research. Not surprisingly, a frequent reassessment of many relevant trends was required during the research period.

We investigate the adequacy of the traditional methods of port planning, design, and project evaluation for dealing with the major ,challenge – uncertainty (Chapter 3). A literature survey and desk research and interviews at the offices of Port of Rotterdam Authority, various engineering firms, and design consultants are essential in order to examine the current practices, especially for their handling of uncertainty.

Next, we carry out a literature study encompassing various infrastructure domains, to uphold the supposition that flexibility and adaptability are indeed the appropriate strategies to deal with uncertainty. Subsequently, we propose incorporation of these concepts in the port planning and design methods, and discuss them at length in the context of the port industry (Chapter 4).

We present a planning approach called Adaptive Port Planning (APP) which incorporates flexibility and adaptability during planning, and removes the drawbacks of the traditional methods of port planning. The application of the method is illustrated through a case involving an ongoing project in the Netherlands (Chapter 5).

Next, we found it useful to conduct a survey to get a perspective about flexibility from various port stakeholders, followed by a brainstorm session to discuss flexible solutions for (physical) infrastructure (Chapter 6). We examine the existing port infrastructure in Rotterdam for its robustness, flexibility, and adaptability. We also investigate innovative infrastructural concepts that have been proposed in recent times and the reasons why they have not been implemented.

Thereafter, we assess the existing financial evaluation methods for evaluating the costs and benefits of flexibility with the objective of selecting an appropriate method for port projects. The application of this method is illustrated through two cases (Chapter 7).

We analyse if we can monitor major uncertainties for port planning and design through application of simple tools, so that we can initiate timely actions to protect our plan (Chapter 8).

Though the generic idea of adaptive planning is brought up in literature (lately more frequently), examples of adaptive planning are not to be found. We carry out various case studies dealing with port planning, each illustrating a different application of APP and the methods and techniques it employs (Chapter 9). These cases have been selected because they either deal with a significant issue in the port sector, or illustrate some aspect of flexibility. The majority of these cases are from the Port of Rotterdam.

In Chapter 10, we discuss the many barriers to implementations of APP and suggest how we can possibly surmount them.

Finally, Chapter 11 presents the conclusions and reflections on the research.

1.5 Outline of the thesis

The outline of the thesis follows the structure outlined in Section 1.4.2 and shown in Figure 1.4 on the next page. The research sub-question answered in each chapter is stated alongside the chapter number and title.
As can be seen, we have placed the chapters into six categories:

- Background and problem definition
- Investigating flexibility and adaptability
- Valuing flexibility
- Monitoring the environment
- Implementing flexibility
- Reflections

Figure 1.4: Outline of the thesis

1.6 Contributions and limitations of the research

In this section we summarize the contributions of this research, i.e. its scientific value and its relevance to the society. We also mention the assumptions and constraints.

1.6.1 Contributions

The importance of infrastructure to society is similar to the foundation the human skeleton plays in the overall structuring, functioning and health of the body (Dale and Hamilton, 2007). Nowadays, uncertainty and flexibility considerations are required to play a large role during their planning. These subjects have only recently received attention in the port sector due to developments such as the downward turn in throughput due to the financial crisis, and technological breakthroughs such as Maersk's Triple-E container mega vessels and APM Terminal's FASTNET cranes. Though sporadic research is being carried out, resulting in innovations in products and processes, the issues why, how and where with respect to uncertainty and flexibility have not been dealt with in an integrated manner. As a result, concepts and methodology for port planners in times of uncertainty, is missing.

Therefore, this thesis addresses the highly topical issue of infrastructure planning under uncertainty. It proposes an adaptive approach to planning or APP that guides a planner to first identify and then systematically deal with uncertainties that appears over the lifetime of a project, and results in Master Plans and infrastructure design that can better stand the vagaries of the future. This research frames the issues of flexibility and adaptability, gives a better understanding of how these concepts can be integrated into port planning, and suggests how the added value of flexibility can be included during port evaluation.

APP has been well documented and tested in four case studies from the port sector. These case studies demonstrate that the value of APP lies in the creation of an awareness of uncertainty for the planner at every step, so that his focus does not shift from flexibility and robustness, whether it is during the selection of a logistic concept, a design approach, or a a design alternative. The many advantages of APP and its efficacy in addressing different type of planning problems will provide aid to port planners.

Port planning is a multidisciplinary effort, which is why the proposed planning method embraces proven methods and techniques from the diverse fields of engineering, finance, and management. To be able to communicate with several disciplines at many levels, the language has to be broadly understandable, and the approach not too complex. Therefore, our focus has been on methods that build upon standard practices, are easy to understand and apply, and ultimately provide decision support, instead of on precise (but complex and expensive) tools. The results can be presented to the decisionmaker in a format that he understands, so that he can draw conclusions, select solutions, and justify these to stakeholders in a transparent manner.

The dissertation is written for the practitioner, i.e. a strategic planner who can give shape to next generation infrastructures. We think that through applying the approach proposed herein, he will spread its message of flexibility and adaptability among the decisionmakers and the policymakers.

1.6.2 Some limitations

Planning is preparing a strategy (representing a sequence of actions) to achieve a predefined goal. Simply put, planning is deciding in advance what to do, how to do it, and who is to do it (Koontz and O' Donnell, 1972). Planning can be aimed at annual budget allocation or training of personnel (short-term planning), investment in superstructure (middle-term planning), or new investments, spatial planning, restructuring, upgrading (long-term planning). In this dissertation, our focus will be on middle to long-term planning.

The problems related to port planning maybe be due to reasons such as the absence of a central planning organization, or the constraints embodied in the institutional framework of the organization (Frankel, 1987). We think that the biggest challenge for port planners arises from exogenous factors such as uncertainty in market demand, new technology, and new policies related to environmental, safety, and security issues. The difficulty of reaching a common understanding of goals and expectations among the numerous stakeholders and disciplines involved in the planning and design of ports adds to this challenge. In this dissertation, we will primarily address this type of uncertainty.

Since the last four decades, the container market sector has been the most dynamic of all cargo sectors. Containers are seen as 'stars' by the port authorities, due to their high potential for growth and earnings. Therefore, they are willing to invest in the container sector to foster this growth[4]. Container shipping companies are not loyal to ports, which means that a port must constantly compete with its neighbouring ports for contestable hinterlands. The developments related to handling, logistic, and transport of containers have made, and are still making explosive leaps. Therefore, in this dissertation, the focus will be on container ports. However, spatial planning, which needs to incorporate long-term considerations while confirming to the norms of safety and sustainability, and has been given due attention.

Considering the port as a system, one can identify numerous layers representing degrees of freedom in the system that can be manipulated to reach a specific objective. Broadly, these can be distinguished into the physical infrastructure, operation and management layer, and the product and services offered. The operational aspects (though more amenable to incorporation of flexibility than physical infrastructure), are outside the scope of this research and left to the experts in this field.

Port planning is a task and responsibility of the port authority (World Bank, 2007), therefore in this dissertation, the perspective of analysis is that of a port authority, and more specifically of a landlord port. The landlord function combines the development, management, and control of the port area, including nautical access and port

[4]The market sectors are classified as as dogs, cash cows, wild cats, and stars in a model known as BCG portfolio matrix. A detailed description can be found in Stern and Stalk (1998).

infrastructure, taking into account safety and environmental issues[5]. As Saundry and Turnbull (1997) state: "It is no coincidence that the majority of the world's most successful ports conform to the landlord model, with public sector involvement in the administration of the port as both land owner and regulator. This allows the benefits of private sector management in the efficient handling of cargo to be combined with the public and (common) user interests of both customers and other important stakeholders".

[5]Some landlord ports such as Port of Rotterdam assume the role of a strategic port manager and include the functions such as stakeholder management and account management in their duties.

Chapter 2

Uncertainty surrounding ports

Science and technology cannot change the future's fundamental unpredictability - S. W. Popper, R. J. Lempert, and S. Bankes, 2005

Uncertainty has become so great as to render futile the kind of planning most companies still practice - Peter Drucker, 1992

2.1 Introduction

One of the few certainties in the modern world is uncertainty. The term uncertainty with reference to planning and design of port infrastructure system emphasises that the choice of decision making must be made on the basis of incomplete knowledge about projects that do not yet physically exist, and whose projected consequences will occur–if at all–in an unknown future (Walker, 1994; Walker et al., 2003). In the introduction we suggested that inadequate uncertainty consideration during port planning and design is by far the most significant reason for the 'not so successful' port development projects. We present some cases from the port sector to highlight the implications of uncertainty (Taneja et al., 2010b,c). Next, we depict ports as engineering systems subject to external forces. Then we go on to explore the different facets of uncertainty in general, and in the context of ports. Awareness of the prevailing trends in the port and shipping sectors is essential, since these can have direct or indirect impacts on the planning and design of ports. Therefore, we discuss some of these existing and emerging trends.

2.2 Implications of uncertainty for ports

The year 2008 saw the beginning of a global economic downturn, and international trade took a hit as credit markets froze and demand slumped. The results were visible everywhere. The number of vessels calling at Singapore, the biggest container port in the world, dropped from 1,712 to 1,466 in April 2009, compared to the year before, and throughput fell by 17.7% (PSA, 2009). The estimated number of idle container vessels at seaports worldwide soared by March 2009 to a record high of more than 450 ships with a total carrying capacity of 1.4 million TEU. The consequences of this decline in container throughput at the seaports reaches beyond marine ports and terminals, affecting container ship fleet capacity, railroads, the commercial trucks that service the seaports, and the inland warehouses and distribution centres that provide logistical support for the entire multimodal freight supply chain[1](RITA, 2009).

Not only is the ports and shipping sector vulnerable to external developments, but a port infrastructure project can also have an impact on the trade patterns and give a cause for uncertainty. The Panama Canal project, to be completed by 2014, involves creating new navigational channels, widening and deepening the existing canal, and creating a new set of locks capable of handling 12,600 TEU ships, in addition to Suezmax liquid-bulk tankers, LNG, and other vessels. The Panama Canal, with a capacity for ships of about 52,500 tonnes on the Panama Canal draft (Lloyds Register, 2012), will allow two or three times more tonnage on a vessel. It will launch new all-water routes between Asia and Gulf coasts of the USA (Labrut, 2009) and probably divert freight from the neighbouring ports. Many shipping lines are exploring alternative westward routes in anticipation of rising tolls to fund the expansion. All these developments are expected to give a new definition to post-panamax shipping and change the existing patterns of world trade.

The port sector has always been volatile, and new demands have forced the ports to evolve. For instance, in the Port of Rotterdam (PoR), the extent of new harbour area and the water-depth have continued to increase over the years, while the period of time between the successive expansion projects (e.g., Rotterdam city terminals, Botlek, Europort, Maasvlakte, and Maasvlakte 2) has become shorter. Whereas in the city area, Leuvehaven sufficed for more than 200 years and the Waalhaven for 40 years, the much larger Botlek area was too small after only two years, and Europoort was almost full before construction was complete. Surprises can happen in the other direction as well. The planned activities for Maasvlakte, i.e., ship building and steel factories had moved to Asia before the reclamation project was finished. So, ever growing volatility in the port sector, stimulated by the global trends of liberalization, economic expansion of Europe, and changes in producer and consumer markets (China, India, Brazil, Eastern Europe), is adding to the uncertainty surrounding port development projects.

Some examples from the port sector, which serve to highlight the uncertainty in the port sector, and the enormity of its impact, are given in the following sub-sections according to the following three impact-categories:

- Failure of the Master Plan or obsolescence
- Very costly adaptations
- Less costly adaptations

[1] An analysis of the current situation and the prospects for the container and shipping industry till 2015 can be found in Podevins (2009).

2.2.1 Obsolete ports

From 1960's onwards container ships replaced the traditional types of ocean-going vessels and caused the abandonment of old ports all over the globe, leaving industrial wastelands that cut city centres off from their historical birthplaces at the harbour. In cities like Baltimore, Sydney, and Rotterdam, the port's decline was accelerated by the flight of residents and businesses from the central city, due to the availability of post-war suburban housing and accessibility on a regional highway system. Fortunately, the abandonment of the old ports was seen as an opportunity to redefine city centres, utilizing the central location and symbolic nature of the waterfront to make a place to gather and celebrate cultures and history. This happened worldwide, including cities such as Sydney, Rotterdam, Barcelona, Osaka, Belfast, and Capetown, as well as U.S. cities such as Norfolk, Long Beach, Honolulu, Pittsburgh and San Diego (Global Harbours, 2008).

2.2.2 Very costly adaptations

The essence of a Master Plan is that you should not do today what you will have to undo tomorrow. This section gives some examples of where this is exactly what happened, sometimes at a considerable expense.

Changing markets: Waalhaven, Port of Rotterdam

Figure 2.1: Waalhaven entrance, PoR, The Netherlands

In 2001, the biggest clients of container stevedores Hanno en Uniport based at piers 5, 6, and 7 in the Waalhaven were China Shipping, K-Line and Yang Ming. They expressed the intention of putting in use the new generation container ships of 5500 TEU. At that time, only third or fourth generation ships, with a draft of about 11.0 m, were being handled in Waal-Eemhaven. The Port of Rotterdam Authority (PoRA) decided to broaden and deepen the entrance to the Waalhaven port at a cost of 13.6 million Euro in order to receive these ships. This involved demolishing the sheds and their foundations, the existing quay walls and jetties, decontamination of the soil, and construction of a new quay wall at a distance of 78 m behind the original wall, thereby widening the entrance channel (Figure 2.1). In addition, the depth of new waterway was increased to NAP-15.0 m and the depth of Waalhaven basin from 13.50 m to 14.5 m, giving access to vessels with a draught of up to 14.0 m at high tide.

Hanno was taken over by ECT (Europe Container Terminals) in 2004 to be used as overflow for their home terminal in the Eemhaven and, barely five years later, the two terminals were taken over by Steinweg, to be partially used for storage of empty containers. No 5500 TEU ships are expected to call at this terminal anymore. This is a prime example of the uncertainty prevailing in the port sector!

Changing networks: Ceres Terminal, Port of Amsterdam

The port of Amsterdam realised a brand new container terminal known as the Ceres Paragon Terminal, for a throughput upto 1 million TEU. The planning began in 1996, and the terminal was operable in 2002. Characterised by a revolutionary concept known as an indented berth, with nine ultra modern post-Panamax gantry cranes, productivity levels could be raised to over 250 moves an hour, making it the fastest terminal in Europe. Three years after it became operable, the terminal had not served a single client. One of the main shareholders of the Ceres Paragon Terminal, NYK, in 2002 was in Grand Alliance with P& O Nedlloyd which had interests in another terminal in Rotterdam (currently known as the Euromax terminal). Lobbying attempts by NYK, to draw attention to the Amsterdam based terminal, were tempered by P& O Nedlloyd veto rights. After Maersk took over P& O Nedlloyd, Ceres received the first ship in 2005. In 2008 the credit crisis took place and hardly any ships were handled.

Ceres was taken over from NYK by Hutchison Port Holdings (HPH) under the name Amsterdam Container Terminal (ACT). HPH was also not successful in attracting clients, and ACT is now concentrating on inland shipping and barge services. Meanwhile the throughput in Rotterdam has continued to grow while ACT was recently closed (2012). The drawbacks such as the lock complex and the North Sea canal having its effect on the port's nautical access, and the port's intermodal linkage influence on hinterland connectivity, do not give sufficient account for the failure of the terminal (Kroon et al., 2005). Was it because the terminal did not fit into the maritime network with its alliances and loyalties, among others to PoR? Could such a development have been predicted?

Changing demand: Jawaharlal Nehru Port, India

The Port of Nhava Sheva currently known as Jawaharlal Nehru Port (Figure 2.2) is India's biggest port and handles almost half of the country's maritime traffic. It was constructed in 1989-90, about 20 km from the existing overcrowded Mumbai port. The port, operated by Jawaharlal Nehru Port Trust (JNPT) handles 55 to 60% of the total containerized import and export cargo of India. The port originally had three operational terminals; two for containers and one for bulk cargo. In its second year of operation, the container throughput had increased from 33,880 to 54,643 TEU and the port authorities announced an extra investment in portal cranes and transtainers

Figure 2.2: Nhava Sheva Port, Mumbai, India

and an expansion of the container freight station.

However, the containerized cargo continued to grow at an exponential rate and in year 2004-2005, amounted to over 2.5 million TEU. In order to relieve congestion on the two container terminals, the Port Trust decided in 2006 to turn the bulk terminal into a container terminal. This terminal is now operated by Gateway Terminals India Pvt Ltd, a consortium of A.P. Moller-Maersk A/S Group and CONCOR, and has a capacity of 1.3 million TEU. Since the container throughput is projected to grow considerably in the coming years, JNPT is ready with a feasibility study of a fourth container terminal with a 2,000 m long container quay and a planned capacity of 4.5 million TEU. This is an example of unanticipated developments requiring costly 'ad hoc' adaptations.

Changing technology: Bigger ships

The advancements in marine technology, and the accelerating trend towards bigger vessels in order to utilise economies of scale, have made forecasts with respect to ship size difficult. This uncertainty has implications for port planning. An example can be found at the Delta peninsula in the Amazonehaven basin in PoR (Figure 2.3). The present layout was given shape in the early 1990s. A nautical simulation study had established that, in order to receive 9,000 TEU ships, the width of the Amazonehaven should be at least 305 m with a minimum depth of NAP-16.65 m. But the terminal operating company had a need for larger terminal area, and not anticipating the drastic developments in container shipping, accepted a width of 255 m and a depth of NAP-13.65 m. Barely ten years later, the company was forced to reconsider. The costly modification, in order to receive larger ships by providing a width of 310 m and a depth of NAP -17.65 m, commenced in 2010.

Meanwhile, the container vessel sizes continue to grow. A recent survey by the UN Conference on Trade and Development (UNCTAD) showed that between July 2004

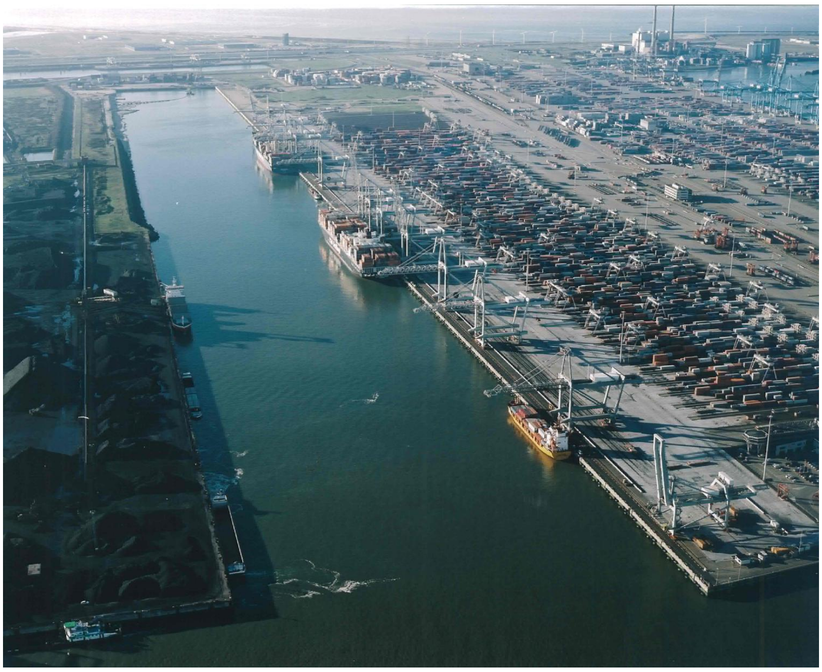


Figure 2.3: Amazonehaven at Maasvlakte, PoR

Figure 2.4: Emma Maersk, Triple E class Maersk vessel, future vessel of STX (from top to bottom)

Figure 2.5: Vorstenbosch bunker tanker

and July 2010 the average vessel size grew by 65 per cent. The world had just got over the shock of Emma Maersk and her sister ships which appeared on the scene in 2006, when on 21 February 2011, Maersk ordered a family of 10 even larger container ships from Daewoo, the Triple E class[2] with a capacity of 18,000 TEU. The first is to be delivered in 2014, and there is an option of 20 more ships. Meanwhile on December 14, 2012, CMA CGM Group has a new 16,000 TEU container ship Marco Polo built for Asia-Europe sailing by Daewoo Shipbuilding & Marine Engineering Co. Ltd (Vesselfinder, 2012). South Korea's STX Shipbuilding Co. Ltd. states in the June 2008 edition of STX news that they have succeeded in the development of a 22,000 TEU class container ship (Schuler, 2009), though till now no illustrations have been seen (Figure 2.4). Can the existing ports receive Triple E class ships? Are the basins wide and deep enough? Are the quay walls strong enough?

The inland ship also responds to the increase in scale in container shipping. The sea vessels with capacities of up to 15,000 TEU have larger fuel tanks that need to be filled in the same short time in the port as the smaller vessels. Figure 2.5 shows the largest tanker barge in the world the 'Vorstenbosch'. The construction was completed around its China-built hull in the Netherlands. It measures 147 x 22.80 x 6.36 metres (the largest tanker barge to date was 135 metres). The vessel, owned by VT Minerals, has a capacity of 12,000 tonnes. The Vorstenbosch transports bunker oil in Rotterdam and the other ARA ports.

Changing functional requirements: Filling in harbour basins Waal-Eemhaven

Another example of ongoing port evolution in response to exogenous developments is the Waal-Eemhaven region in Rotterdam, which was in 1950 the biggest port complex in Europe. When Waalhaven began running out of space, many of the basins were filled up to acquire extra land and restructure existing companies and set up new ones. These included filling up space between pier 6 and 7 in 1993 and south of pier 9 in 1996. Filling up Prinses Margriethaven in 1997, the turning basin of the Johan

[2]The name 'Triple E' is derived from the three design principles: Economy of scale, Energy efficient and Environmentally improved.

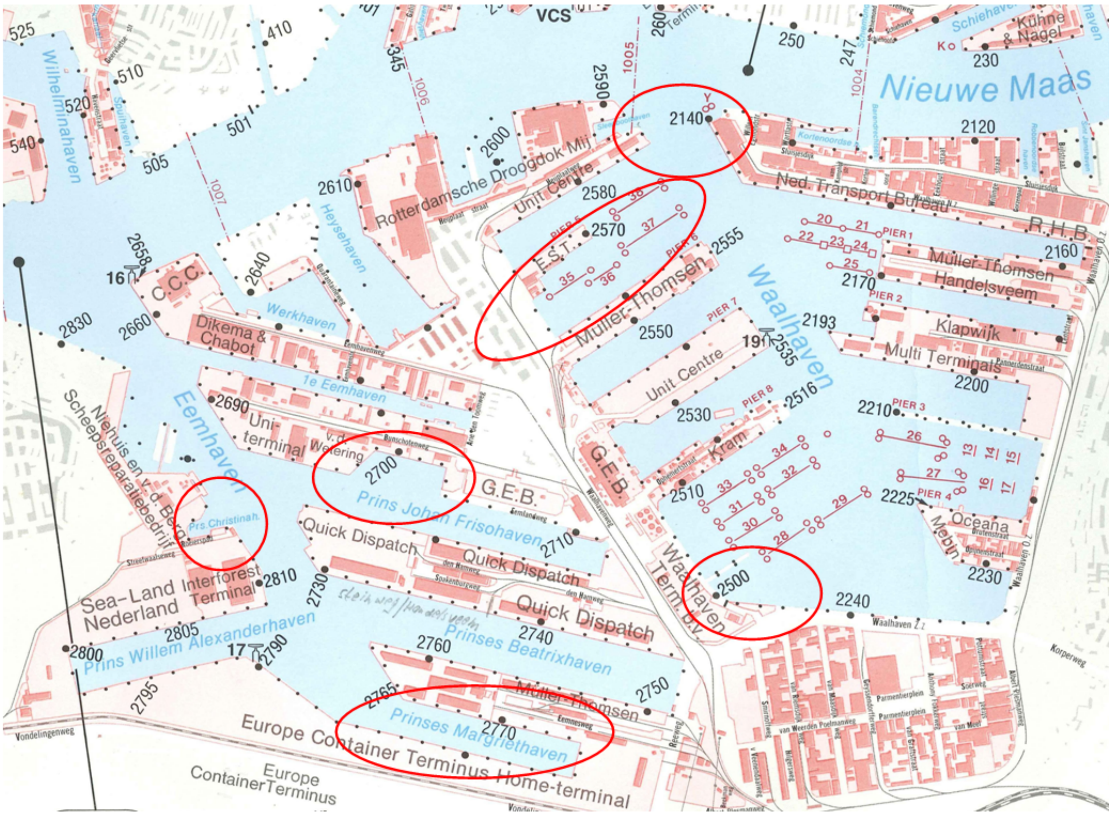


Figure 2.6: Waal-Eemhaven in 1970, PoR (source: PoR)

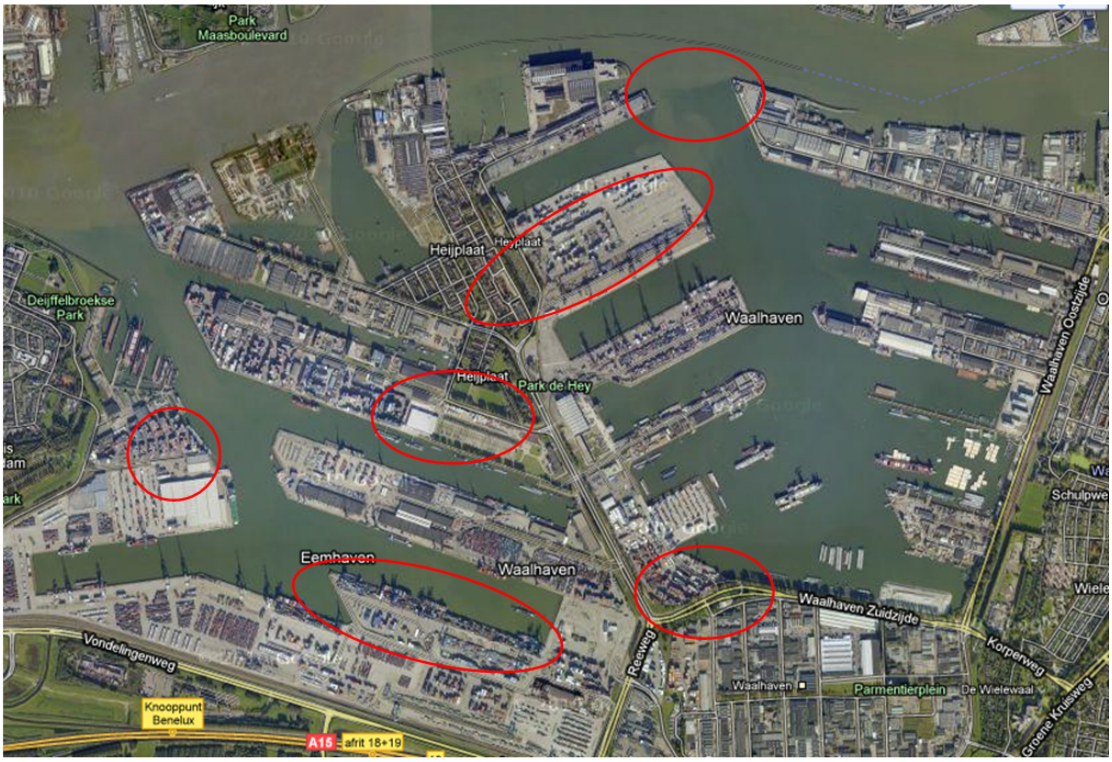


Figure 2.7: Waal-Eemhaven in 2010, PoR (source: PoR)

Frisohaven in 1999, and Prinses Christinahaven in 2001 followed. Figures 2.6 and 2.7 show Waal- Eemhaven region in 1970 and 2010, after these modifications (encircled on the figures).

2.2.3 Less costly adaptations

New clients, new legislations, upgrading equipment and efficiency improvements can all require adaptations of infrastructure. We give here some examples from the port sector.

Changing technology: Argos, Port of Rotterdam

Figure 2.8: Jetty for liquid bulk (source: PoR)

The liquid bulk storage company Argos decided to place extra loading arms on an existing jetty in order to increase the handling capacity (Figure 2.8). This was a deviation from terms of reference employed for designing the structure. Fortunately, due to margins in design, the structural strength of the concrete deck and the pile foundation proved adequate to carry the extra loads. Otherwise it could have meant extensive adaptation during which time the jetty could not be used for handling ships, or even required replacement of the structure.

Changing technology: EECV

Europoort C.V. (EECV), situated in the Europoort area of PoR, operates one of the biggest bulk terminals in Europe for handling ore for the hinterland transport to the German customers in the Ruhr area. In 2008, EECV imported the largest unloader in the world – with a maximum unloading capacity 2000 t/hr for coal and 2600 t/hr for ore (Figure 2.9). The quay wall which was built in 1960 had to adapted at an enormous cost to carry the extra loads imposed by heavier equipment with greater lifting capacity and outreach.

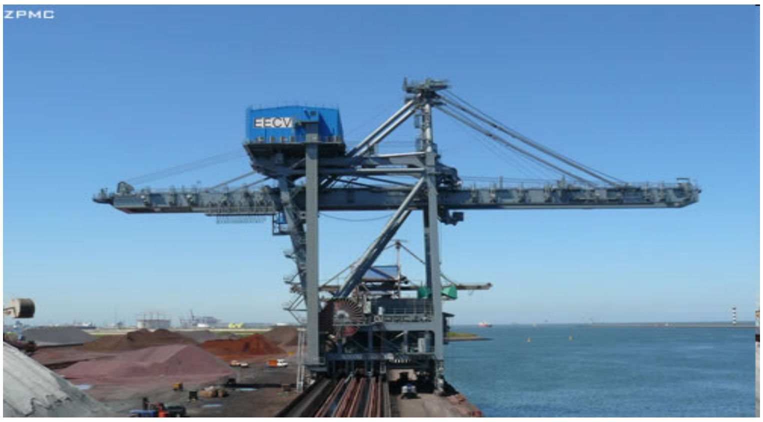


Figure 2.9: Bulk unloader EECV (www.EECV.com)

Changing clients and inflexible contracts: Abengoa, Port of Rotterdam

Figure 2.10: Facilities of Caldic and Abengoa in Europoort (source: PoR)

Abengoa Bio-energy Netherlands B.V. had plans to set up a bio-ethanol factory on the site of Caldic Chemie Europoort B.V. at Rotterdam-Europoort, which was originally to be returned to the port after the contract expiry. In order to supply the factory with required raw material (grain) and the products of the production process such as ethanol en DDGS (distillers dried grain with solubles or fodder), a berth for sea ships and another berth for inland ships was required at the nearby Weserhaven. In order to create these facilities for Abengoa, the berth for inland ships at the south-eastern arm of the Caldic jetty had to be demolished. As compensation, PoRA had to invest in lengthening the north west arm of the Caldic jetty and create an extra berth for inland ships (Figure 2.10).

Change in legislation: Inland jetties

A new EU legislation was passed in 2003 concerning the transport of dangerous goods over the Rijn. In accordance to this, all berthing facilities for barges with dangerous goods were required to have escape routes at the bow and the stern of the vessel. The reason was a fire on a tankship in Germany in 1999 during the loading operations.

Figure 2.11: Escape routes barge terminals (source: PoR)

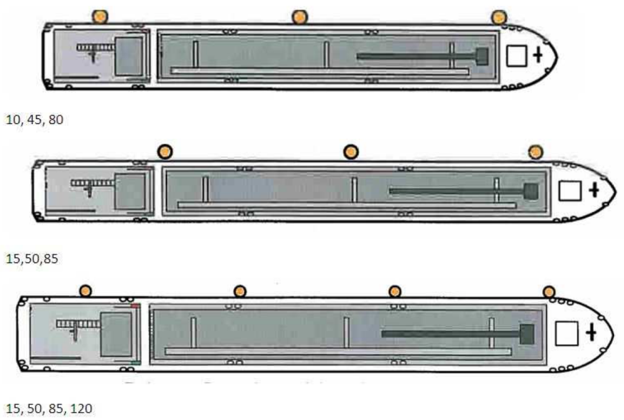


Figure 2.12: Pile configuration for ships of 90, 110, 135 m length (source: PoR)

As a result, all barge berthing facilities in the ports were required to be modified (Figure 2.11). To add to the problem, many of the existing facilities in PoR were based on barge lengths of 100 m while 135 m barges were already in use. As can be seen in (Figure 2.12) the pile configuration for berthing barges of different lengths is very different. Consquently, considerable adaptations were required.

Changing functional requirements: upgrading quay walls

Most ports need to upgrade their existing quay walls in response to bigger ships and increasing drafts. This requires a structural analyses to guarantee the structural strength and stability of the quay. The measures for deepening basins include the following (Reiter, 2008):

- leaving the existing structure in place and installing a secondary retaining system carrying the additional loads in front of the existing quaywall. Some examples are Berths 65 and 66 in Port Kaoshiung, Taiwan and many quay walls in Merwehaven in PoR.

- placing an underwater cut-off toe wall installed in front of the existing structure. Some examples are Berths 82 through 98 in Port Elizabeth, South Africa and Waalhaven entrance in the Port of Rotterdam.
- new retaining system incorporating an existing quay wall. Some examples are Berths 102 and 103 in Sao Francisco do Sul, Brazil and Oosterkade in the Port of Rotterdam.

Continuous pumping to lower the ground water level and soil stabilization by injecting the soil behind the quay wall with grout are also possible solutions.
Even the less costly adaptations result in a period during which the facility is unavailable for ships, resulting in additional losses. Through the examples in this section we have highlighted that developments unanticipated at the time of planning can have major implications for ports in terms of costs, and ultimately even mean the loss of its competitive position.

In the next section we will define uncertainty and examine its various dimensions.

2.3 Uncertainty and its dimensions

2.3.1 Definition of uncertainty

Many definitions of uncertainty exist in literature. According to Kikuchi and Perincherry (2008), uncertainty is the state of the plea for information: information about the structure and causalities of the system, information about the input to the systems, information about the goals and objectives, and interpretations of the outcomes of the analysis. Complete certainty is the situation in which we know everything precisely. It is not attainable, but acts as a limiting characteristic at one end of the spectrum of the uncertainty scale. Total ignorance is the other extreme and also acts as a limiting case. Walker et al. (2003) define uncertainty as any departure from the unachievable ideal of complete determinism. They categorize uncertainties by their location, level, and nature. The three dimensions are relevant when selecting an appropriate approach for handling uncertainty. These are discussed below in context of an engineering system. The capacity for some uncertainties to be resolved in the future is a characteristic that allows it to generate value (Ramirez, 2002).

2.3.2 Location of uncertainty

The first dimension of uncertainty deals with the location, i.e., where the uncertainty manifests itself in the systems under consideration. Three primary locations can be identified:

- Uncertainty about the external forces: This has been dealt with in the previous section in the context of ports.

- Uncertainty about the system response to external forces: This can be attributed to either the model structure uncertainty, or parameter uncertainty. The former arises from a lack of sufficient understanding of the system under consideration. In case of a port system, the relationships between inputs and variables, among variables, and between variables and output is (at least qualitatively) relatively well understood. Therefore, a system model which is an adequate representation of the real system can be set up. Three types of parameters can be distinguished: fixed, a priori chosen, and calibrated parameters. Fixed parameters are considered 'exact', while calibrated parameters are 'caliberated' through use of historical data, and thereafter treated as constants.

  A priori chosen parameters are of two types: decision variables and value parameters (Rodger and Petch, 1999). Decision variables are quantities over which the decision maker exercises direct control. Value parameters represent aspects of the preferences of the decision makers or people they represent. These parameters have no 'true' value, but are rather a reflection of a value that is selected as appropriate for the situation. Both decision variables and value parameters can be varied as a part of the uncertainty analysis. In terms of location, our focus will be on uncertainty in the external forces, the system response to these forces, and how to deal with these during planning.

- Uncertainty about the valuation of outcomes: This deals with the (relative) importance given to the outcomes by stakeholders, i.e. the weights assigned to our outcomes. This depends on the current and future stakeholders configuration and values which may change over time in unpredictable ways, leading to different valuations of future outcomes than those made in the present.

2.3.3 Level of uncertainty

The second dimension is an expression of the degree or severity of the uncertainty, which can range from deterministic knowledge to total ignorance. Walker et al. (2012) present the 5-level uncertainty typology shown in Figure 2.13, which shows the progressive transition of levels of uncertainty from complete certainty to total ignorance.

Level 1 uncertainty represents the situation in which one admits that one is not absolutely certain, but one is not willing or able to measure the degree of uncertainty in any explicit way (Hillier and Lieberman, 2001). Level 1 uncertainty is often treated through a simple sensitivity analysis of model parameters, where the impacts of small perturbations of model input parameters on the outcomes of a model are assessed.

Level 2 uncertainty, or statistical uncertainty is when probabilities can be used to specify the likelihood or plausibility of the uncertain alternatives.

In case of Level 3 uncertainty, or scenario uncertainty, multiple alternatives can be enumerated and rank ordered in terms of their likelihood, but how much more or less likely cannot be specified. Level 3 uncertainty about the future world is often captured in the form of a few trend-based scenarios based on alternative assumptions about the driving forces.

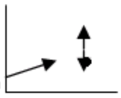
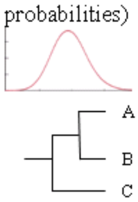
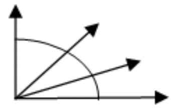
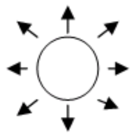
Complete Certainty		Level 1	Level 2	Level 3	Level 4	Level 5	Total ignorance
	Context	A clear enough future (with sensitivity) 	Alternate futures (with probabilities) 	Alternate future (with ranking) 	A multiplicity of plausible futures (unranked) 	Unknown future 	
	System model	A single system model	A single system model with a probabilistic parameterization	Several system models, one of which is most likely	Several system models, with different structures	Unknown system model; know we don't know	
	System outcomes	Point estimates with sensitivity	Several sets of point estimates with confidence intervals, with a probability attached to each set	Several sets of point estimates, ranked according to their perceived likelihood	A known range of outcomes	Unknown outcomes; know we don't know	
	Weights on outcomes	A single estimate of the weights	Several sets of weights, with a probability attached to each set	Several sets of weights, ranked according to their perceived likelihood	A known range of weights	Unknown weights; know we don't know	

Figure 2.13: Levels of uncertainty (Source: Walker et al., 2002)

In case of Level 4 uncertainty, a rank ordering of alternatives is ruled out. Analysts struggle to specify the appropriate models to describe interactions among the system variables, to select the probability distributions to represent uncertainty about key parameters in the models, and/or how to value the desirability of alternative outcomes (Lempert et al., 2003).

The strongest form of uncertainty is Level 5 uncertainty, recognised ignorance, deep uncertainty (Lempert et al., 2003) or severe uncertainty (Ben-Haim, 2001). As Walker et al. (2012) state: "Recognized ignorance is increasingly becoming a common feature of our existence, because catastrophic, unpredicted, surprising, but painful events seem to be occurring more often." However, even when alternatives cannot be enumerated, merely keeping open the possibility of being wrong or of being surprised can be useful.

Level 1 uncertainty (a fairly clear future) and Level 2 uncertainty (where the probabilities of alternate futures are known) are rare. Level 3, and often Level 4 uncertainty, are usually treated as Level 2 by expressing uncertainties about variables or underlying functional relationships among key variables in the form of a probability distribution, even though this may not always be appropriate. This is why probability is the most widely used formal language of uncertainty by far (Morgan, 2009). In Chapter 5, we will distinguish among three categories of planning (short, medium, and long-term), based on their treatment of uncertainty.

2.3.4 Nature of uncertainty

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 arises from technical and scientific uncertainty (such as limited and inaccurate data, measurement error, incomplete knowledge, imperfect models, subjective judgement etc.). It can be at least partially reduced through additional research. Variability uncertainty that is attributable to natural randomness, is, however, irreducible.

Uncertainty has a bad side known as risk, and good side known as opportunity. Knight (1921) contrasted risk with uncertainty, using *risk* to refer to random processes whose statistics were well known and *uncertainty* to describe unknown factors poorly described by quantifiable probabilities. Economies evolve over time and are subject to intermittent and sometimes large unanticipated shocks. Economic evolution has its sources in discoveries and inventions, which lead to technical progress. Structural breaks may also be precipitated by changes in legislation, sudden switches in economic policy, or political turmoil. Unpredictable events with low probability and high impact (also known as trend-breaks, black swans, or wild cards) will take place. Therefore, a model that will have captured past events quite well may not be able to capture the events that will drive the future.

2.4 Ports as engineering systems

2.4.1 Engineering systems

An engineering system (Blanchard and Fabrycky, 2011) is a man-made system designed to meet functional purposes or objectives in response to identified needs. It is composed of a harmonized combination of resources, such as physical infrastructure, facilities, equipment, materials, people, information, software and money. These elements represent subsystems (or components) that interact with each other to produce a desired system response. By definition, an engineering system is embedded into the natural world and interacts with it in desirable and undesirable ways.

A port represent a dynamic, complex, open engineering system. It is dynamic because it combines physical components with operating components. Complex indicates that multiple interactions between different components (or variables) are possible, as is emergent and non-linear behavior (Bettis and Hitt, 1995). Non-linearity obscures relationships, making cause and effect difficult to replicate and/or identify (which is why, employing linear tools and thinking to such a system is ineffective). Even if relationships can be identified, they are difficult to interpret (Lei et al., 1995). Emergent means that some variables that are not important at the time of planning, possess the capacity of evolving and becoming very influential in some distant futures. Some of the components of a port system are themselves complex systems. The many influences that a port is subject to originate from remote sources, and the geographic boundaries of a port are not easy to specify (Byl, 2002).

2.4.2 External influences

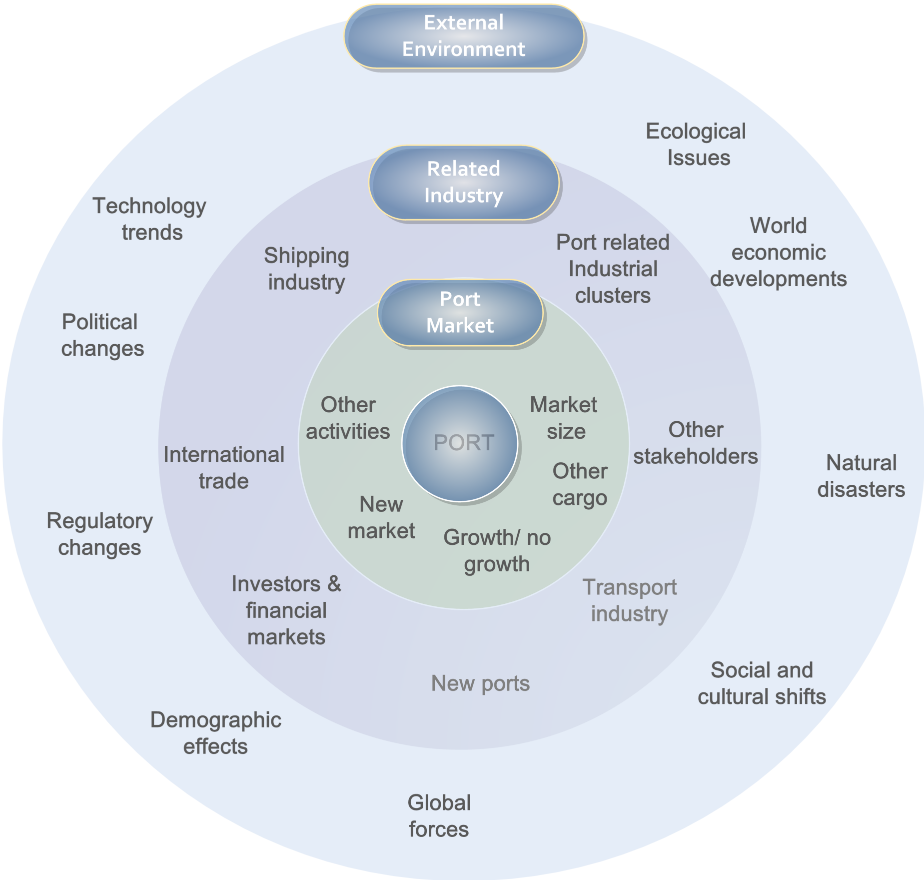


Figure 2.14: Port system and external forces

Figure 2.14 shows the physical boundaries of the port together with the various external influences. The *port environment* can be seen as a combination of technological, economic, social and political factors. It includes variables such as social and cultural shifts, inflation, exchange rates, political instability, demographic effects, and natural disasters. The *industry* refers to the port and shipping industry that affect markets including stakeholder relations, developments in the shipping industry such as vertical integration of shipping lines, consolidation of terminal operators, advancements in marine and transport technology, and trends such as focus on sustainability and safety.

The port *market* is determined by factors such as the size of its hinterlands, competition with the neighbouring ports, port policies, its strategic vision, etc. Within these spheres of influence is the port. A comprehensive understanding of the (uncertain) variables within these 'spheres of influence' as well as the correlations among them, is essential for understanding the dynamics of a port system. Each of these variables has a different evolution pattern, and the future values remain uncertain. While planning for a port development project, it is essential to take into account the uncertainties in the environment, the industry, and the market. In Figure 2.15, based on de Weck and

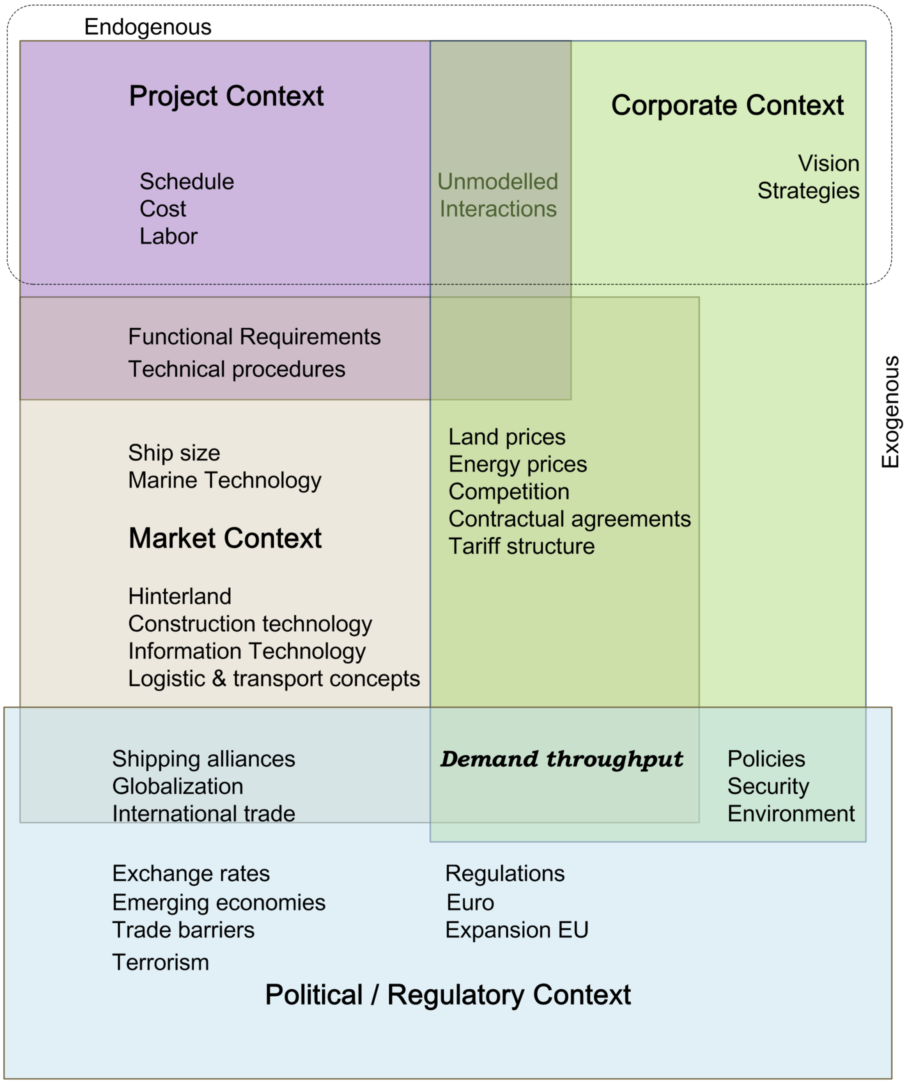


Figure 2.15: Sources of uncertainty in port planning

Eckert (2007), the major sources of uncertainty in port planning have been placed in a project, corporate, market or political/regulatory context to highlight the difference between endogenous and exogenous uncertainties. (The external driving forces that are not under the control of the planner or the decisionmaker are said to be exogenous, while endogenous uncertainty is inside the system boundary or sphere of influence.) Any infrastructure development project has an element of technical uncertainty related to costs, construction schedules, estimated quantities of material, material prices, and labor issues. With sufficient expertise, a reasonable estimate of the degree of uncertainty can be provided by the planner. Management tactics used by ports to win market share, e.g. pricing decisions, marketing, service improvement and other traffic-generating strategies (such as volume discounts, guaranteed vessel turnaround times, and berthing windows) also fall into this category.

The major uncertainties associated with planning and design of port infrastructure systems are related to market aspects such as the developments in global trade, trends in the shipping market, and structural change in shipping services (UNCTAD, 2005; HWWI and Berenberg Bank, 2007; Pinder and Slack, 2004; Selkou and Roe, 2004). 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 has little control over this form of uncertainty, but these are of particular importance to him, especially if they are likely to produce large changes in the outcomes of interest.

2.4.3 System model

The decisionmaking related to different aspects of planning of an engineering system requires an analysis of the system. The analysis could be aimed at determining the physical performance of the system, its financial or economic value, or its external impacts. A common approach is to create a model of the system of interest. Such a model defines the boundaries of the system and describes its structure and operations – i.e., the elements, and the links, flows, and relationships among these elements. In this case the analysis is referred to as being model based. An engineering system model is more often than not a mathematical model where the relationships among the various components of the system are expressed as functions. A simulation is the implementation of the model which permits manipulation to gain understanding about a particular entity or process in the system, or even the entire system being represented.

In addition to the goals and objectives and preferences expressed by the various stakeholders, the external forces are a part of the framework which needs to be analysed. The resulting system model generally represents a compromise between desired functionality, plausibility, and tractability, given the resources at hand (data, time, money, expertise, etc.) (Walker et al., 2012).

The results of these interactions (the system outputs) are called outcomes of interest. The valuation of outcomes refers to the (relative) importance given to the outcomes by crucial stakeholders, i.e., landowner, investor, manager, operator and client, reflecting their goals, objectives, and preferences. These involve the trade-offs stakeholders make among the different outcomes of interest and are often represented by assigning weights to them. In case there is a gap between (some of) the system outcomes and the goals, changes are implemented to influence the behaviour of the system in order to help achieve the goals. Multi-criteria analysis (MCA) and cost-benefit analysis (CBA) are among well-known techniques for selecting among the resulting alternatives.

Figure 2.16 shows a model of the port system with various elements and their interrelationships. In this figure, a 'plan' can refer to a Master Plan, (infrastructure) design, an operational policy, a management procedure or even a workforce schedule plan. Similarly, 'planner' refers to the entity carrying out the processes which result in

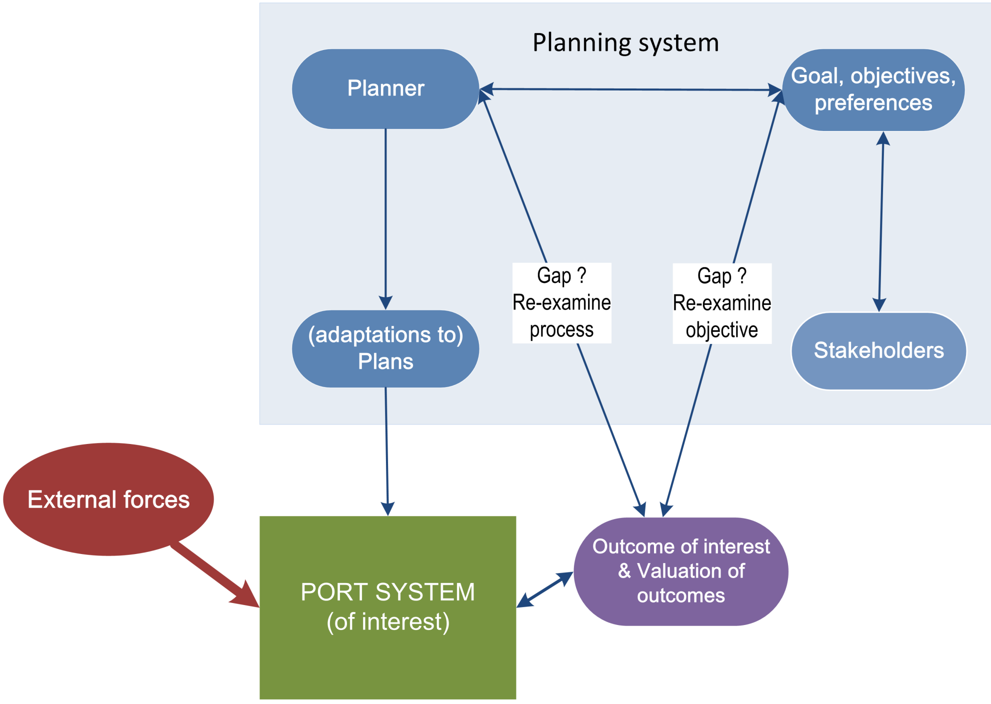


Figure 2.16: A model of the Port System (of interest)

plans, designs, operations, or policies. The port system (of interest) and its scope will be determined by other elements in the system. The model that has come to dominate engineering design is the mathematical model – often combined in computers to model the whole system. Throughout our research, we will be constructing and working with simple models of the port system. These will mostly be cost-revenue models which can be analysed using a spreadsheet. However, these too require an understanding of the processes and the relationships between parameters.

2.5 Recent trends and impacts on port planning

2.5.1 Introduction

Planning constitutes three essential elements:

1) the functional goals (and the related constraints),
2) the processes or activities towards realization of the goals, and
3) the resulting plans or designs.

All these elements are interrelated and equally significant during planning. We need to examine the environment surrounding ports for the trends which have a direct or indirect impact on our goals, on the plans and designs, or on the processes related to planning and design. According to Winkelmans and Notteboom (2007), ports develop in a world full of change. Hence, port development needs also to comprehend the implications of some basic structural changes or shifts. Some may lead to new external constraints, some others can change our value expectations, while yet others are changing the way we work and live. Some mega trends are:

- continuing globalization and containerization which is the driving force behind the need for infrastructural investment, also in emerging economies;
- changing functions of a port which imply attention for the entire supply chain instead of a terminal or a port;
- changing actors and networks resulting in changed distribution of power, and new demands related to port services;
- changing technology, which influences transportation costs on one hand and can necessitate drastic infrastructural adaptations on the other hand, and
- an increasing awareness for the environment and society.

A bit further into the future, energy transition will be added to this list.
These factors influence the goals we define, the way we approach planning and design, and the solutions we choose.

2.5.2 Continuing globalization and containerization

Global container trade has witnessed tremendous growth in the last 50 years, with an accelerated growth since the mid-1990s. Containerization is now the preferred form of transport for nearly all imports and exports (UNESCAP, 2012). As Notteboom and Rodrigue (2008b) state, the expectations about the future growth of containerized traffic will have to be matched by a physical reality of transport infrastructure. The provision of capacity alone is not sufficient, and future developments for container terminals and their infrastructure will be focused more on throughput than capacity. This will require a holistic approach to design of the supply chain.

While infrastructural investment in container ports needs to continue, the competition may also drive wasteful investment in unnecessary infrastructure by competing ports (Blank and Brooks, 2006). A trend of locating production centres close to consumption centres may develop, either in response to reduced difference in costs between Asia and Europe, or driven by the onset of energy-transition and stricter growing environmental regulations. This might also result in underutilized investments, not only in ports, but also in shipping (Ligteringen, 2010).

Another impact of globalization is that the fragility has intensified in today's extended and complex trading network, and a significant disturbance in one location will have an almost immediate effect on the rest of the network (Blank and Brooks, 2006). This underlines the importance of continually examining the environment around us in order to reassess our strategies.

2.5.3 Changing functions and scales

Ports have moved from performing nautical, cargo handling, stacking, and distribution functions to being multimodal nodes in the logistic chain (Heaver et al., 2001; Olivier and Slack, 2006; Meersman et al., 2009).

Today, investment in a large mainline container ship is in the region of US$ 60 million and the cost of developing an individual container terminal can easily exceed US$ 70 million. To be successful in making decisions on such important long-term investments within a highly competitive and rapidly changing environment, planning must include a comprehensive view of competing and complimentary regional developments (UNESCAP, 2012).

The enormous scales and complexity of (port) project also mean greater risks (Dempsey et al., 1997). A larger stakeholder involvement adds to the problem. Shipping companies, especially in the container sector, demand increasingly higher levels of efficiency and service level (for the same price). Currently, the new motto, also in the port sector, seems to be 'Supply the customers with what they want, to standards and specification they want, and at a price that suits their needs' (Verbraeck, 2009).

Verhoeven (2009) specifies three dimensions in a fourth generation port – operational (including core, value added, and industrial activities), spatial (signifying a network of ports/terminals extending into supply chains and port-city interactions), and societal (with a focus on a wider eco-system and a sustainable existence). These dimensions need to be duly acknowledged during the complex, multidisciplinary endeavour of port planning.

2.5.4 Changing actors

Today, the landlord port is the dominant port model in larger and medium sized ports. The infrastructure provided by the landlord port is leased to private operating companies or to industries while a single entity (the private sector) owns and operates the cargo handling equipment, in addition to providing and maintaining its own superstructure. Port planning is often initiated by existing clients and their immediate needs.

Concession agreements are the most common approach in infrastructure projects. This approach is used by ports in order to facilitate the involvement of private sectors in port activities (Baird, 2002). Their adoption is driven by the belief that the participation of the private sector in the operation and management of port services of a terminal will lead to greater flexibility and efficiency in the market and better responses to consumer demand (Notteboom and Rodrigue, 2007). The private sector is financing the construction of entire terminals, including quay walls, land reclamation, dredging, superstructure, and equipment.

This port model has an impact on port planning, since it can result in overcapacity due to pressure from various private operators, as well as misjudging the proper timing of capacity additions (World Bank, 2007). This has also given rise to a large variety of financing contract forms. (The increasing role of private enterprise also means a greater stress on budget and schedule. since the horizon in which the private investors want to earn money is much shorter. For instance, once a project is awarded, the speed of realization is of essence to achieve a realistic capital cost profile, so extreme pressure is put on the designer to confirm his conceptual designs via data collection, small scale model testing, and computer simulations leading to frozen project specifications that can be used for actual tendering of engineering procurement and construction contracts (Huisman and de Waal, 1999). The time available for pre-engineering (concept and specification development), as well as the realization times are reduced. This reduced front-end time creates challenges for design engineers, specialized consultants, and project managers.

In today's global trade network, various actors may have quite different goals in a broader cultural and geopolitical context. That is, what they seek to accomplish or to gain from their efforts may differ. Global shipping lines have grown their base of power, and ports have less market power in the emerging trading dynamic. Financiers who own equity in ports or shipping lines may be interested mainly in short-term profits (seeing the port essentially as a financial asset), while environmentalists may be willing to sacrifice port operations, for example, to reduce emissions or preserve water or air quality (Blank and Brooks, 2006). Powerful market players step to the foreground as direct interlocutors not only on the operational level of port activity, but also in strategic matters related to port planning and port policy (Winkelmans and Notteboom, 2007).

2.5.5 Changing technology

New technology is being implemented within the maritime industry to address a whole variety of issues, related to operational efficiencies, environmental conditions, safety and security (Johansen, 2007). The impact of new technology on ports is many-fold; on one hand it offers solutions, and on the other hand it introduces new functional, organizational, and procedural requirements. While new equipment configurations, new logistic concepts, new cargo handling concepts, and advanced information systems increase terminal productivity (and efficiency), they also present new challenges for infrastructure planning and design. For instance, the rapid increase in the operational scale and scope leading to increasing space requirements has been responsible for ports close to city centres (e.g., Antwerp, Rotterdam, Los Angeles) to shift operations further away. The increase in ship size has resulted in intense pressures in terms of infrastructure designs and layouts, and the associated investments. Limited space for expansion is creating a need for innovative solutions such as spatial bundling, underground infrastructure, and transport corridors. On another front, the advancements in construction materials and technology, aided by globalization which allows access to worldwide developments and best practices, is expanding the choice of designs and construction methods.

We cannot handle new challenges with technology at hand, we need to innovate. Innovation is more than new technology – it involves how business processes are integrated and managed, how services are delivered, how public policies are formulated, and how markets and more broadly society benefit (Lynn and Salzman, 2006). We will elaborate on this vital link between planning and innovation at a later stage.

2.5.6 Increasing attention for environment and safety

Depleting energy sources, degradation of the environment, and implications of climate change are leading to new trends. An emerging trend concerns the increasing attention, protection of the environment and safety. Any development related to a new port or an existing commercial port, will have to be environmentally sustainable and conform to the norms, standards and regulations of national and provincial environmental policies and legislation (Flyvbjerg et al., 2003; Winkelmans, 2007; Verhoeven, 2009; Ligteringen, 2010; Vellinga, 2012; Vellinga and de Jong, 2012). Nowadays, a port development needs to be based on a balanced view of numerous rationalities. It needs to ensure economic development (return on investment), social progress (employment) and protection of the environment (viable territory) (Dagnet, 2010).

'Green' concerns, for example threatened the progress of the Maasvlakte 2 project in Rotterdam. In the UK, port projects were rejected on the basis of environmental constraints (Southampton), whereas others (the London Gateway Port; Felixstowe expansion) were allowed to progress only following the agreement between port promoters and authorities that the impact on the local area is adequately catered via conditions to mitigate the large-scale impacts (Rynikiewicz, 2011). In Belgium almost every new port project is currently hampered by the application of environmental regulations such as the EU Habitat and Bird Directives, even in cases where it concerns port areas which have been reserved for port extension 'in tempore non suspecto', i.e. long ago (Winkelmans and Notteboom, 2007).

Previously, port projects were seen as engineering projects requiring a hard systems approach that dictates a single perception of problems, objectives, methods, criteria, and solutions. The performance measures are generally time, cost, and quality. However, as ports seek to strike a balance between social, ecological, and business needs and objectives, it is being realized that 'soft' issues are equally important. This is because a network of multiple heterogeneous stakeholder groups with divergent perceptions, values, and interests are involved, and soft issues such as community perception, safety, environmental impacts, legal acceptability, and political and social impacts, need to be addressed at the beginning of the project. Change management and stakeholder management (Dooms et al., 2004) are becoming well known in ports. The role of economists, environmentalists, lawyers, and managers is gaining importance. Engineers (i.e., port planners, designers) are challenged with having to design around numerous constraints.

According to Toor and Ogunlana (2009), the traditional measures of the iron triangle (on-time, in-budget and according to specifications) are no longer sufficient for measuring performance on large public sector development projects. Other performance indicators such as safety, efficient use of resources, effectiveness, satisfaction of stakeholders, and reduced conflicts and disputes are being added to the list. This implies a shift from the traditional quantitative performance measurement to a mix of both quantitative and qualitative performance measurements.

This shift has major impact on our goals, planning approaches and selected solutions. A consequence of 'cradle-to cradle' thinking is that the functional goals have been expanded to include lifecycle considerations. The fact that ports must have a social 'license to operate' directly influences their choice of economic and logistic principles, design alternatives, construction practices, as well as operational methods. Which is why (as we will discuss later), sustainability and flexibility need to become overarching principles of development.

However, margins have diminished in a much more competitive environment. Nowadays, from a capital investment, operating, and maintenance point of view, the approach to infrastructure design is changing. The structures are designed keeping in mind future maintenance activities. Pre-investment for the future is a point of many hefty debates. Pre-fabricated, assembled modules are preferred in order to reduce construction times. Structure designs take into account the local construction practices rather than relying on large equipment mobilized by international contractors. Lifecycle costs are scrutinized critically, and each step of capital expenditure is balanced against expected revenues (Huisman and de Waal, 1999).

2.6 Treatment of uncertainty during planning

Over the years, many methods have emerged in attempts to deal with uncertainties and support decisionmaking in our day to day activities, businesses or projects. Figure 2.17 shows an overview of uncertainty handling methods mentioned in the literature.

At its simplest, uncertainty analysis is a qualitative procedure that establishes the risk picture for an activity or a project using expert opinion through literature studies, brainstorming sessions, and group discussions (Aven, 2008). Morphological analysis (Zwicky, 1969; Ritchey, 1998) is a form of non-quantified modelling relying on judgemental processes and internal consistency, rather than causality, and applied frequently in policy analysis and futures studies. These methods are particularly useful while developing and analyzing futures scenarios which involve factors that are too complex, or contain strong social-political dimensions, and are thus non-quantifiable.

Model-based uncertainty analysis is primarily quantitative and makes use of formalized techniques such as detailed modelling, event tree or decision tree analysis, simulations (using either deterministic or stochastic approaches), Real Options Analysis, and Exploratory Modelling and Analysis. Mixed qualitative and quantitative methods have also resulted in structured approaches such as multi-criteria analysis, (the history of which is traced by Koksalan et al. (2011); what-if analysis and scenario analysis (developed by RAND and their use pioneered by Royal Shell (Cornelius et al., 2005)); forecasting, backcasting (a term coined by Robinson (1982)) and bounce-casting (developed by RAND), which combines the two methods (Liu, 2005)); Assumption-Based Planning (Dewar, 2002); Dynamic Strategic Planning (de Neufville, 2000); Adaptive Policy Making (Walker et al., 2001); Robust Decision Making (Lempert et al., 2003), and Agent Based Modelling.

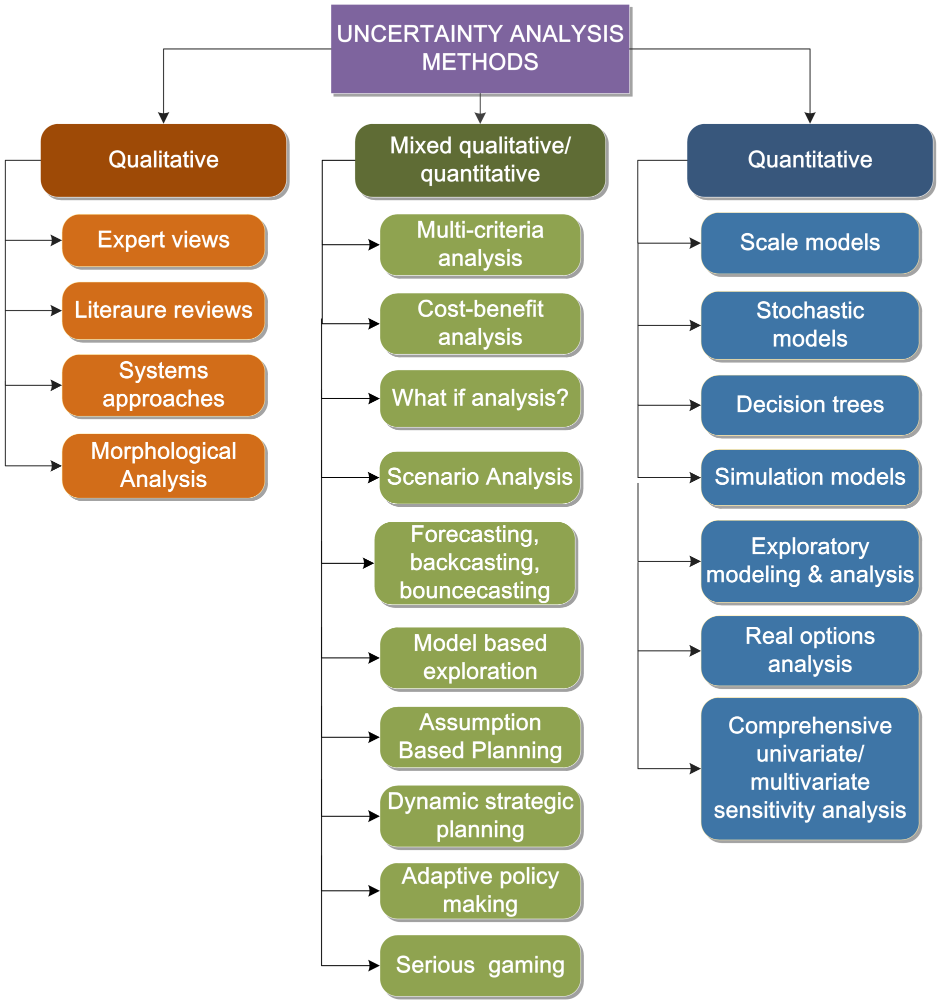


Figure 2.17: Uncertainty Analysis Methods

Serious gaming is a useful tool to simulate complex, socio-technical infrastructure systems and support policymakers and designers in understanding the complexity of planning and design of these systems (Bekebrede, 2010) (the term was coined by Abt (1970)).

Many methods of analysis, mostly derived from methods described in literature, are being applied to different business or market areas. For example, in the field of engineering, FMEA and FTA methods are being widely used. FMEA (Failure Mode and Effect Analysis) is a structured method for evaluating the risks associated with potential failures of a system through evaluating the severity and likelihood of the failures. FTA (Fault Tree Analysis), originally developed by Bell Laboratories in 1962, attempts to model and analyze failure processes of engineering and biological systems.

Of course, an uncertainty analysis delivers a lot of information; but its value lies in putting this information to good use, in order to manage uncertainty throughout the entire project lifecycle. Consequently numerous 'risk management' techniques have been developed, mostly by project owners and business consultants, for specific use.

However, most approaches utilizing these methods in practice, suffer from the drawback that they focus on those uncertainties that are among the least of our worries; their effects are swamped by uncertainties about the state of the world and human factors for which we know absolutely nothing about probability distributions and little more about the possible outcomes (Quade, 1982). As Popper (2009) states, the traditional methods 'all founder on the same shoals: an inability to grapple with the long term multiplicity of plausible futures.' When planning complex infrastructure involving a long lifetime, multiple uncertainties, and numerous stakeholders, these approaches prove to be inadequate.

A few of the above methods focus on deep uncertainty and the problems it creates for decisionmaking (Ben-Haim, 2001; Walker et al., 2001; de Neufville, 2003b; Dewar, 2002; Lempert et al., 2003). They emphasize the need to acknowledge and embrace uncertainties, and suggest that flexibility and adaptability are of central importance in coping with the uncertainties.

2.7 Conclusions

The long lifetime of (mostly) indivisible port infrastructure and the irreversible character of the huge capital investments that require a long payback period, makes the task of port planners very challenging. The consequences of an 'unsuccessful' port project are enormous and far reaching. If port infrastructure or layouts have to undergo drastic adaptations long before their design lifetime has been reached, it not only means loss of investment or costly adaptations, but also a loss of cargo and revenue in the period that the facilities cannot be used. Container shipping companies (especially with transshipment cargo) do not display loyalty and can easily move on to other ports that provide adequate capacity and service levels. Loss of clients and a tarnished image are the ultimate results. We think that the major challenge is presented by the uncertainty in the external environment. In order to support our statement, we presented some illustrative cases from the port sector highlighting the implications of uncertainty.

Next, we depicted ports as open and complex engineering systems subject to external forces; this model will be useful for the remainder of the research for analysing the port system. We have defined uncertainty, and explored its different facets in the context of ports. We found it essential to explore the different dimensions of uncertainty, (i.e. its nature, its location, and its level), in the context of ports, before finding ways to deal with it. Deep uncertainty is the most significant during infrastructure planning, and can be defined as the situation in which the decisionmaker does not know, or multiple decisionmakers cannot agree on, the system model, the prior probabilities for the uncertain parameters of the system model, and/or the value function.

We have also discussed some prevailing trends in the port and shipping sector that can influence port planning and design (either through influencing the planning objectives, the approaches, or the solution space). These trends include: continuing globalization and containerization, changing functions of ports and scales of port projects, changing actors in the port arena, changing technology, and increasing attention for the environment. Many uncertainty handling methods have emerged over the recent years to address different types of uncertainties; an overview has been included.

In the next chapter we will focus on current port planning approaches and examine their treatment of uncertainty and flexibility.

Chapter 3

Traditional approaches for port planning

The methods used for yesterday's solutions are what cause the problems of today. We must make sure that they do not cause the problems of tomorrow as well. - R.W. Flint, 2005

3.1 Introduction

The previous chapter suggested that the uncertain environment was responsible for the inefficacy of traditional practices for port planning and development. In this chapter, we will examine these standard practices in order to validate this supposition. Before seeking methods more suitable for an uncertain environment, we will familiarize ourselves with the state of art of research related to various aspects of port planning and development. Since this dissertation is about flexibility, it is interesting to investigate if a mention of flexibility can be found in the documentation related to port projects. An examination of Master Plans from various regions of the world e.g., the Master Plan of ports in Israel; Gangavaram Port in India; Maasvlakte 2 port expansion in the Netherlands, and the Port of Portland in the USA, are expected to provide valuable information over standard practices.

Similarly, an investigation into recent concepts for infrastructure design, and the reasons as to why they have not been implemented, can offer valuable insights over the causes, and into the general perceptions about flexibility. Perhaps these causes need to be addressed and the perceptions need to be altered.

3.2 Research related to port planning

According to Woo et al. (2010), the scale of research across the spectrum of issues related to ports has increased during the recent decades, and port research has become a dominant theme in the area of maritime studies. We will establish if this is indeed so for our area of interest.

In the context of ports, the research categories shown in Figure 3.1 can be distinguished. These are: spatial studies, port management and strategy, port performance, ports in supply chains, port policy, and port operations. The subcategories have been listed under each category. Here, we will limit ourselves to research in the category 'port planning and development'. The research related to planning and development

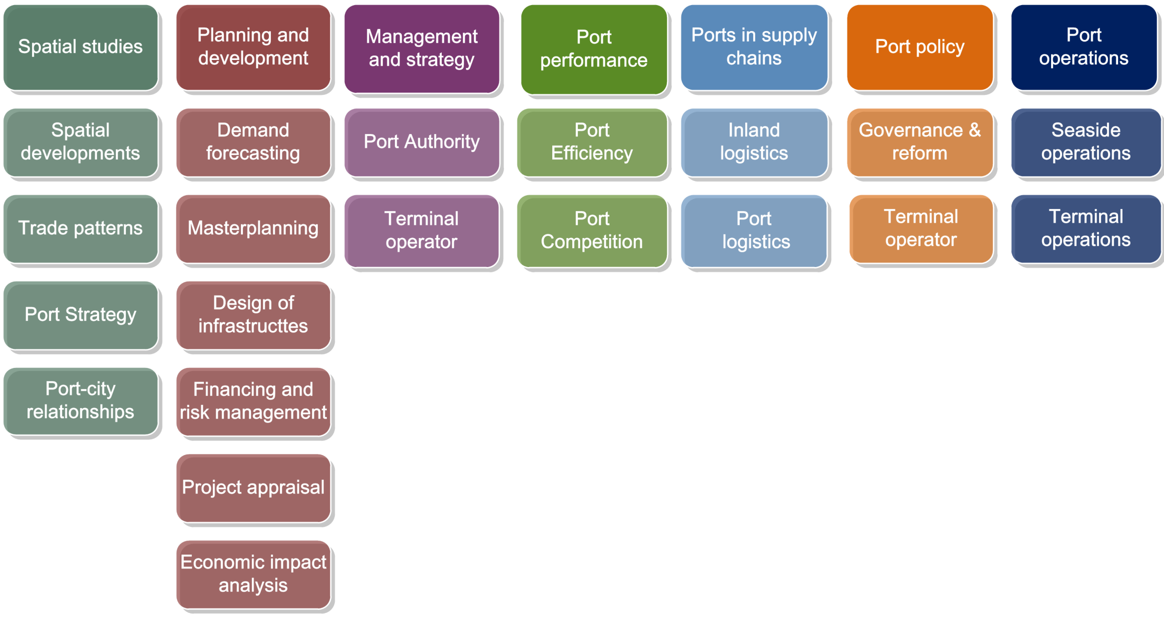


Figure 3.1: Port research themes

of port infrastructure includes the following subjects: demand forecasting and capacity planning, masterplanning, design and construction of (elements of) infrastructure; financing, uncertainty analysis and risk management; project appraisal methods, and economic impact analysis. Standard texts on port planning are abundant (Agerschou, 1983; Frankel, 1987, 1989; Bruun, 1989; Thoresen, 2004; Tsinker, 2004; Ligteringen and Velsink, 2012). These texts cover the aspects mentioned above extensively, of course within the state of art at the time of publication. We proceed to give concise descriptions of the current research on these subjects.

a) Demand forecasting and capacity planning

Demand forecasting is basically the forecasting of traffic or cargo throughput, while capacity analyses are primarily concerned with determining the optimum size of terminals and ports. The forecasts invariably involve extrapolation of historical trends, and neither the forecasts nor the applied methods are made public by the institutions carrying out the forecasts. The applied statistical methods use regression (Zohil and Prijon, 1999), time series analysis (Chatfield, 2001; Clements and Hendry, 2000), error-correction methods (Hui et al., 2004), and mathematical modelling, such as linear programming (Jones et al., 1995), mixed integer modelling (Kim et al., 2008), and simulation (Luo and Grigalunas, 2003). Exploratory approach (Walker, 1985) and logit modelling (Tavasszy et al., 2011; Anderson et al., 2009; Veldman and Buckmann,

2003) have also been applied for forecasting demand through analysing port selection behaviour.

The research is exhaustive, but in view of the prevailing volatility, the utility of the forecasts for port planning remains questionable.

b) Masterplanning

Masterplanning is focussed on matching capacity with demand and creating a robust port layout. As cities encroach upon the ports, and accessibility is endangered, space use, reserves for future expansion, and land use studies have gained importance (Rahman et al., 1999; van Schuylenburg, 2002; Werkgroep Strategische Reserve Maasvlakte 2, 1997). Port planning is dealt with in standard texts, but has not been a major subject for research in the last decades. The research related to planning and design methodologies is also limited. The increasing acknowledgement of risk and uncertainty owing to the long planning horizon for ports has stimulated the use of 'strategic planning' and 'adaptive planning' methods. In the last few years, the use of term 'strategic' planning as applied to port masterplanning has become more frequent (APAA, 1988; Dowd, 1992; UNCTAD, 1993; Zauner, 2008; Nourse, 2009). The use of the term 'adaptive' applied to planning and management, has increased over the years (Strangert, 1977; Sachdeva, 1984; RAND, 1997a; Lessard, 1998; Alterman, 2000; Walker et al., 2001; Gregory et al., 2006; Kwakkel et al., 2010), although only recently has it been applied to ports (Dongen, 2003; Taneja et al., 2010c, 2011b).

c) Design of infrastructure

Organizations such as PIANC (The World Association for Waterborne Transport Infrastructure), APAA (American Association of Port Authorities), and USACE (US Army Corps of Engineers), have established guidelines related to the planning and design of port infrastructure, and continue to update these to incorporate new developments such as radical growth in ship sizes. Increasing attention for safety issues demands a re-examination of standards and guidelines (Johansen, 2007; Lorthiois, 2008). Meanwhile, nearly every country has set up its own standards and codes to suit its local conditions and indigenous practices, which is why it has been a tedious path to arrive at unified European standards after establishment of the European Union. Such unified standards related to ports do not exist, but some standards such as CUR (2005a,b); EAU (2004); BS 6349 (2007); OCDI (2009), have found wide application in many countries.

Though many studies deal with innovative solutions for quay walls (Reiter, 2008; van Breugel, 2003; Spijkstra, 2006; de Rooij, 2006; Bonte, 2007) and construction under challenging local conditions, few studies have dealt with alternative approaches to infrastructure design. Wijnants et al. (2000) and de Gijt and van der Toorn (2007) are two studies from the Netherlands that re-examine the traditional approaches to design. The importance of sustainability (Maas, 2011; Luijten et al., 2010) and lifecycle considerations (Sletmo, 1999; Vrijling, 2005; PIANC, 2008; Maas, 2011) in port design is being acknowledged and a focus of attention.

d) Project appraisal

Increasing infrastructural scales and escalating risks and uncertainty have made port financing and investment a critical issue in the present world (UNCTAD, 1985; Saundry and Turnbull, 1997; Dixit and Pindyck, 1994; Cardin et al., 2007; Kikuchi and Perincherry, 2008). Many standard texts (Brealey and Myers, 2003) and studies (Cullinane and Panayides, 2000) deal extensively with capital budgeting methods, while Bendall and Stent (2003) investigate investment strategies under market uncertainty.

The importance of economic impact studies to provide a rationale for the capital budgeting decisionmaking of ports has always been recognized. Therefore, researchers continue their struggle to find a unified approach for measuring indirect local and global benefits of a port development project (Musso et al., 2000; Grant-Muller, 2001; CPB, 2003; Annema et al., 2007; Hall, 2009; Almodovar and Chang, 2010).

e) Risk and uncertainty analysis

The research on uncertainty analysis and risk management has grown by leaps and bounds in the last two decades (de Neufville, 2004; Ryuji and Prianka, 2000; Flyvbjerg et al., 2003; Hastings and McManus, 2004; Alessandri et al., 2004; de Weck and Eckert, 2007). The research on flexibility in relation to infrastructure has also not lagged behind (Egyedi, 2002; Olsson, 2003; Zhao and Tseng, 2003; Saleh et al., 2003; Dreyer and Gronhaug, 2004; Greden, 2005; de Neufville and Scholtes, 2011).

f) Environmental Impact Analysis

Environmental concerns over pollution as a consequence of port development projects (e.g., emissions, noise, disposal of dredged materials) have attracted attention. Alternatives to reclamation, which disturbs the flora and fauna, are being sought. Nautical safety (driven by congestion in ports and increasing transport of dangerous cargo such as LNG) and security (in light of rising piracy and terrorism), are on top of the research agenda of European Seaports Organization (ESPO) and leading port authorities.

The importance of realizing sustainable engineering systems, and the role played by uncertainty and flexibility considerations in achieving this objective, is being increasingly acknowledged. However, research into alternative approaches to infrastructure design, and integrated tools for lifecycle designs is still in its infancy. Armed with this knowledge, we proceed to examine the traditional methods of port planning and design.

3.3 Port Masterplanning

3.3.1 Port Master Plan

The basic function of a port is to provide facilities to receive, dispatch and handle efficiently the projected cargo from and to the vessels of different sizes that will be calling at the port now and in the future. Equally important are the industrial, logistic, and distribution functions that generate the value added for the port. The physical elements in a port infrastructure system include the elements listed in Table 3.1 (World Bank, 2007). The planning and design of a port begins with the development of a Master Plan.

Table 3.1: Port infrastructure

Port basic infrastructure	Port operational infrastructure
Maritime access channel	Inner channels, port basins, turning areas
Port entrance	roads, tunnels, bridges, locks in the port area
Breakwaters and shore protection works	Quay walls, jetties and finger piers
Sea locks	Aids to navigation, buoys and beacons
Rail connections between hinterlands and port	Vessel traffic management system
Inland Waterways within port area	Access roads, rail connections, marshalling yards
Port superstructures	**Port equipments**
Paving, surfacing	Cargo handling equipment (apron and terminal)
Terminal lighting	Tugs
Parking areas	Dredging equipment
Offices	Line handling vessels
Repair shops	Ship/shore handling equipment
Other buildings for terminal operations	

The Master Plan of a port includes a layout wherein land is allocated to the various uses required, describes the phases needed to implement the plan, and gives an indicative implementation scheme per development phase. It incorporates preliminary designs of major infrastructure works, such as dredging or reclamation works, approach channels and basins, breakwaters, quays, terminal areas and roads. The dimensioning of these structures is carried out in the preliminary design phase. Port masterplanning plays a key role in determining a port's position in the maritime hierarchy, not only because it identifies the port areas that need to be developed and defines their functions, but also because it is the instrument by which the port's expansion strategy in the marketplace will be shaped (Frankel, 1989). In short, a Master Plan is seen as a blueprint for future development, outlining the objectives of the port and how they are expected to be achieved in the framework of market, regulatory, social, and environmental requirements.

Normally, a Master Plan is developed for a time horizon of 20-25 years. It needs regular reviewing and updating. In practice, the updating is mostly ad-hoc, and short-term measures are more often than not unrelated to the Master Plan. By nature, port planning is a multi-disciplinary activity requiring expertise in the fields of engineering, transport, economics, shipping, nautical matters, safety, and logistics. The port planners play a central role in the team, integrating the work done by these experts into a balanced layout of the port (Ligteringen and Velsink, 2012). Nevertheless, the planning of a port is concerned not only with simply demand and supply of throughput, but with application of technology, marketing strategy and ultimately economic impact analysis for the development and implementation of a project. This intricate and complex process can be seen in Figure 3.2, which illustrates the port masterlanning process.

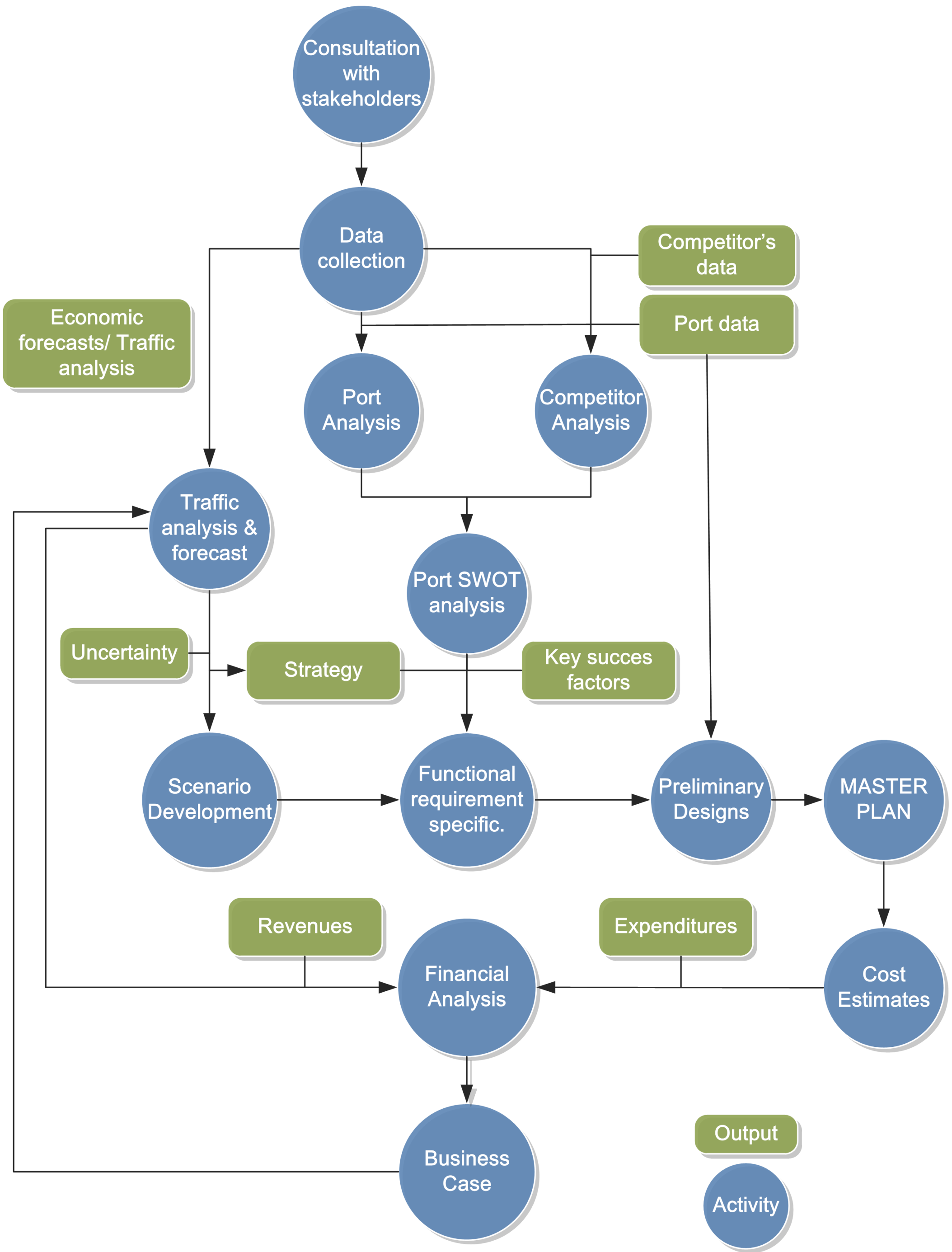


Figure 3.2: Masterplanning Process (adapted from PoR)

3.3.2 Layout and capacity of infrastructure

As stated in the previous section, during masterplanning, the requirements of the total system must be quantified and translated into alternative layouts with rough dimensions for the basic infrastructure, before going onto the evaluation of alternatives. Simulation models such as Harborsim, Flexsim, and Trafalquar are being increasingly used to analyse layouts and estimate the capacity of the basic wet infrastructure by simulating the vessel movements in a detailed model of the port. The models include the physical infrastructure, such as approach channels, turning areas, basins, terminals, and berthing facilities, as well as various ship types. The simulation output includes ship waiting times presented with statistical characteristics, necessary dimensions of the approach channel with respect to the required capacity, required number of berths, quay lengths, (un)loading capacities, storage area capacities etc. to meet the design requirements (Groenveld, 2004).

Any method, however simple or complicated, applied for capacity calculations, requires the demand forecasts as input. The following section will discuss how forecasting is traditionally carried out in order to lay down the requirements for masterplanning.

3.3.3 Forecasting demand

Forecasts are fundamental to planning, and forecasting demand is an essential element of port masterplanning. Forecasting involves the use of information at hand – hunches, formal models, data, etc. - to make statements about the likely course of future events (Geweke and Whitman, 2006). Ports attach a lot of importance, and invest a lot of effort, in obtaining detailed cargo forecasts based on analysis by commodity derived from historical trends, and adjusted for international, national and local developments, as well as the port's own competitive position. Thus, the future is seen as an extrapolation and multiplication of existing trends and technologies, and the projection of port demand is carried out using trend extrapolation based on macro-economic relationships with a more or less fixed market share for the particular port.

In the Israel Strategic port development plan, the relationship between GDP growth rate and cargo flows was employed for the long-term projections for the ports of Haifa and Ashdod (IPC, 2005). This is based on the assumption that traffic through ports is a derivative of the import/export trade activities, and thus the economic development in a region. It does, however, acknowledge that a relationship based strictly on historical developments could have a limited reliability.

In case of the multi-purpose Port of Portland situated on the east coast of USA, the lower Columbia river trade forecast served as a basis for the cargo forecasts (Port of Portland Authority, 2008). A variety of specific factors was used in order to estimate the volumes from the regional forecasts such as the historical market shares, the relative competitive position, and individual facility considerations. Specific assumptions were made about each cargo to make low and high forecasts. The possibility of unexpected developments[1], such as increase in intermodal traffic (which is at present limited) in the event that a carrier chooses Portland as an intermodal gateway, was mentioned but not included in the forecast.

The GSM cargo flow model (Goederen Stroom Model) that was used in the late 1990s for long-term projections of the cargo passing through the Rijnmond area of Rotterdam (GHR, 1998) based on CPB scenarios, applied a similar approach. The long-term

[1] In 2011, the port had to deal with the complete closure of the Columbia river for the barge system while the river locks were under reparation, and the disaster in Japan which impacted the auto volumes.

estimates made in year 2000 for the deep sea container handling for MV2 were based on two scenarios: Global Competition (GC) and Strong Europe (SE), reflecting different growth rates for container handling in Rotterdam. The estimates of the cargo flows to and from Europe in 2020 and 2040 were supplied by CPB. Subsequently, the maritime tonnages for the Hamburg-LeHavre range and Rotterdam were derived using factors derived from historical data (FAMAS.MV2, 2000).

As illustrated through above examples and summarized by de Langen et al. (2012): "The current state of the art in forecasting models mostly rests on cyclical and linear trend analyses. As models are validated on time series or cross-sectional data from the past, the capability of these models to take into account the effects of disruptions is limited." They apply a European transport network model that translates the social economic developments at the European level, and the developments in the transport sector into cargo flows for producing forecasts for PoR up to 2030. After estimating the cargo flows for all the market segments, the model results are tested on basis of the segment specific knowledge in PoR based on expert opinion, and if required, modified (PoRA, 2010d).

Tavasszy et al. (2011) stress that a model-based analysis is needed to inform planners about future freight flows which depend on spatial shifts due to factors such as availability, user price and quality of the port and hinterland infrastructure. They propose a World-wide Container Model (WCM) that models worldwide container flows by analyzing freight transport chains, while taking into account port selection criteria. They introduce the use of scenario analysis to understand the impact of future developments on container throughput. This model allows a comparison between scenarios, however, the authors rightly acknowledge that it is the differences between the scenario results which is more relevant than the absolute figures. van Diepen et al. (2012) and van Diepen (2012) have extended the WCM model by introducing a detailed multi-modal European hinterland, and integrating the modules into a single platform. They apply this model to assess the effects of future developments on PoR, through developing scenarios, and estimating the hinterland flows for Rotterdam in each of the scenarios.

Nevertheless, demand is a function of multiple exogenous uncertainties in the system and varies with time (and to complicate matters, these uncertainties are also interrelated so that a change in one can affect many others). Therefore, in a dynamic system, despite elaborate forecasting exercises, 'demand' remains a major uncertainty for the planner.

3.3.4 Role of scenarios in forecasting

As we have seen, the forecasting methods are becoming increasing sophisticated and planners are increasingly relying on use of scenarios[2].

Scenarios are merely a 'not-implausible descriptions of many alternate futures' (Tol,

[2]Herman Kahn introduced the word 'scenario' in the context of planning at the RAND Corporation in the 1950s. A scenario is a description of the hypothetical future state of the world; a family of scenario spans a range of plausible futures and can capture some of the major uncertainties expected to be encountered in these multiple futures.

2008). The longer the time horizon, the more we are forced to rely on certain assumptions, qualitative statements, and sometimes 'creative guesswork'. Generally, a port project has a lifecycle from 50 up to 100 years and it is not possible to attach much reliability to the demand forecasts made with this approach. One might claim that uncertainty considerations are incorporated in the scenarios around which the forecasts are built, but scenarios cannot capture trend-breaks. The traditional manner of using scenario forecasts results in static plans and strategies, which adds to the problems. These factors are discussed at length here.

Volatile environment

For large-scale infrastructure projects, there is a considerable time lag between planning, political decision, and actual realization of a project. This is certainly true for dredging and reclamation projects where both the difficulty of obtaining approval for, and the cost of undertaking them once the approval is given, has increased over the decades. The Environmental Impact Assessment for Maasvlakte 2 project was given approval in 2007, almost 10 years after project conceptualization, while the first ships will be received only in 2013. Especially in a volatile environment, the assumptions made for scenario building at the time of conceptual planning could prove erroneous when the project is realized, resulting in overcapacity or insufficient capacity.

Table 3.2: Recent port expansion projects

Project	Area (ha)	Year
Deurganckdok	330	2005
Westerschelde Containerterminal, Zeeland	90	2013
Euromax	125	2008
Maasvlakte 2, Rotterdam	620	2013-2030
Bremerhaven CTIV	90	2012
Altenweder	80	2005
Jade Weser	119	2009

Not all influences can be incorporated into a forecast. Simulation of the competitive strategies of other ports and the sensitivity of decisions on port investments for such strategies is difficult in a dynamic system (Gerrits, 2007). While Rotterdam is investing in MV2 – a new top European location for port activities and industry – the neighbouring ports are also investing in their infrastructure hoping to compete for the overseas container traffic. Dredging of river Schelde up to 13.1 m to allow for bigger container ships to enter the port of Antwerp independent of tide, construction of JadeWeserPort at Wilhelmshaven for 12,000 TEU container vessels, deepening of navigation channels in the Lower and Outer Elbe to serve new-generation super container ships in the port of Hamburg, expansion of Container Terminal 4 for mega container vessels in Bremerhaven are some examples (Table 3.2). How many of these developments (or competitive forces) could have been represented in the scenarios at the time of conceptualization of MV2 in 1997?

New technology

Technology is the backbone of port planning, yet it is impossible to include the impact of future technology in scenario building for planning of port infrastructure. In words of

Notteboom and Rodrigue (2008a): "The paradigm shifts brought by new technologies and new economic conditions are generally not considered, because they cannot be anticipated in full. This means that forecasts are generally more of a factor for the mis-allocation of resources than a sound planning tool. Long-term predictions either overestimate, underestimate, or completely miss the point, since they typically fail to capture paradigm shifts or structural shocks to the system." In such cases, forecasts are useless. This also applies in case of breakthrough developments, as the following example illustrates. In the words of the Tobin, the former director of the Port of London Authority in 1971 (Tobin, 1975): "We knew that containerization would get a fast place but we thought that the reorientation of conventional general cargo would take long and we seriously doubted the capacity of the system to compete on very long trade routes. Our planners and economists applied a scientific method as basis of their analyses and forecasts. As we can establish afterwards, they were invariably wrong. They underestimated the developments. Their comparisons were lacking an essential factor, namely the strength of a brilliant concept."

Similarly, Lloyd's Register of Shipping predicted in *Ships for the eighties* (July 1978): "One thing seems clear. There are going to be no space-age developments in the eighties and the world fleet should look more or less as it does today at the end of the decade. The factors expected to affect the ship design in the eighties are those that have emerged in the seventies of which flexibility of use, cargo unitization and increased automation linked with a lowering of manning levels, will probably predominate (Suykens, 1979)".

Trend-breaks

Scenarios, on which the forecasts are based, are centred around the (assumptions related to) key uncertainties, thought to be significant at the time of forecasting. Trend-breaking developments can negate the entire exercise. Even if low probability, high impact events that can change long established trends are introduced in the scenarios to test the sensitivity of such analysis (Huss and Honton, 1987), it is not often that attention is paid to developing strategies for reducing potential threats or taking advantage of the opportunities presented by these improbable occurrences.

An investigation carried out on scenario practice (van Notten et al., 2005) included among others studies carried out at KPN Telecom, Port of Rotterdam (PoR), Central Planning Bureau (CPB), UK Foresight Programme, Intergovernmental Panel on Climate Change (IPCC), consultants KPMG and ICL. These organizations assumed that they operated in a stable environment and that the driving forces were not powerful enough to cause a significant deviation from the current trends. Considering extreme scenarios was thought to be an unnecessary exercise and was a reflection of the negative connotation of discontinuity in the context of scenarios. Therefore, discontinuity was not often addressed by organizations.

When structural shocks or unforeseen wildcards present themselves – such as strikes, wars, a radical change of political power in a region, or a change of technology – they can upset the pattern either on a long-term or short-term basis. These wildcards are by nature volatile and when they have occurred in last few decades, very few organizations have anticipated such changes. Past experience is no guide. However commercial success can be observed in those people or organizations who react quickly or positively to such changes and can see the potential advantages that might be offered (Alderton, 2004). It was through the recognition of future uncertainty and subsequent use of scenario planning to support decisionmaking and to develop suitable business tactics (at odds with the consensus opinions in the oil industry at that time) that Shell became so successful (Peterson et al., 2003).

Scenario selection

Planning can be related to investments in basic port infrastructure, in land reclamation for a new port area, in terminal equipment, etc. Consequently, the objective can range from capacity determination and budgeting, to policies for facing environmental challenges. The current practice of scenario-based planning acknowledges that the long term future may be very different from the present. Even so, decision making is subsequently carried out based on the scenario that possesses the most benefit and is the most cost effective, with minimum risks and impacts. In the words of Don (2001): "Policymakers have a strong tendency to choose a single scenario or a single point forecast and use it for planning, rather than use different scenarios as a test of the robustness and flexibility of policy choices."

Static use of scenarios

In acknowledgement of uncertainty, nowadays, we are investing considerable effort in developing scenarios while designing port infrastructure. However, forecasts are accepted as coming from a black box, and not understood in terms of the underlying economic system. And without flexible (adaptive) plans, designs, procedures, and policies that can deal with a wide range of exogenous developments, these efforts tend to be futile. Static plans fail if an alternate future materializes.

To summarize, uncertainties can not always be modelled as trends from historic data. Yet, uncertain factors such as the competitive environment of the port and potential trade shifts, future policies, and technology trends are difficult to take into account. And, when periods of 25-50 years are considered, the estimation is likely to be far from accurate. In container transport, for instance, port development is very rapid and shipping lines tend to shift large volumes from one port to another. And on a global scale, as transport costs fall to extremely low levels, producers move from high-wage to low-wage countries, eventually causing wage levels in all countries to converge. These geographic shifts can occur quickly and suddenly, leaving long-standing port infrastructure underutilized or abandoned as economic activity moves on (Levinson, 2006).

Thus scenario based planning, as practised in the context of port planning, offers one solution for one specific expectation of future based on the most likely forecasting of traffic demand. It relies on the assumption of system stability, which is a questionable assumption in long term forecasts. However, which future will eventually materialize, is not known. Also, the existing masterplanning approach is static. As a result, it is poorly equipped to deal with the many future uncertainties in the port and shipping industry.

That is why this approach often fails for long-term planning. A planning framework that addresses uncertainty is required!

3.3.5 Examining flexibility in some Master Plans

Next we examine the projects introduced in Section 3.1 for their incorporation of flexibility in the Master Plans. The Marine Terminals Master Plan 2020 of the port of Portland (Port of Portland Authority, 2000) explicitly states that a comprehensive approach was used to prepare and refine a series of facility alternatives through an interactive process involving all stakeholders in order to arrive at a road map for investment decisions by the port. It is a flexible plan with a sustainable balance for the port, and the facility development is dependent upon market-driven conditions. As far as possible, existing marine terminal facilities will be exploited through flexible use for various cargo. Thus, the increasing importance of stakeholder participation and flexibility in port development projects is duly acknowledged.

The Gangavaram port, located on the east coast of India has the deepest draft of all the ports in India, and is one of the few greenfield ports. The port Master Plan was prepared in 2005 following the methodology followed by most modern ports, which includes forecasting traffic considering the likely economic growth for three growth scenarios (pessimistic, moderate, and optimistic) and a detailed Master Plan prepared for the optimistic scenario. The alternative 'multi-purpose port handling all cargoes' is selected out of five alternatives, with an eye on flexibility. The harbour and the port layouts are planned for short, medium, and long term developments (2006, 2012, and 2020), but the plans are prepared to accommodate further facilities to handle any additional cargo traffic beyond what is forecast for 2020. Adequate water area, waterfront, and back up area is reserved for expansion in the layout.

The Israel Strategic Port Development Plan 2055 deals with the ports of Ashdod and Haifa, Israel's two major ports on the Mediterranean coast (IPC, 2005). It examines the long-term demand for port facilities and the alternatives available for meeting those demands. Future demand, future vessel size, long term space requirements for port expansion, and future operational requirements have been identified as the major uncertainties for the port Master Plan. Though the 50-year forecast has been used as the basis of the planning, it is rightly observed that economic forecasts covering such a long time period are likely to carry a significant margin of error and the figures should be treated with caution.

Further, flexibility has been defined as the ability of the plan to cope with variations and to allow adjustments to the lay-out of the plan. The following strategies have been suggested in order to cope with the uncertainties: spacious marine layout; terminal areas with sufficient depth and length; long quays to improve the flexibility for operations and vessel berthing, as well as the flexibility with regard to allocating terminal concessions; the possibility to extend quays and terminals when necessary without serious constraints created by the need for disproportionately expensive construction, and infrastructure designed in such way that it can cope with technical changes of the superstructure, equipment, etc. The plan recommends that quantification of the effects of the various uncertainties be carried out through constructing scenarios, estimating the probability of each scenario, and determining the investment required for later adaptations. Flexibility is one of the criteria in the multi-criteria analysis for evaluating various development choices. Phasing development has also been proposed, and the advantages of postponing large investments and saving capital cost have been included in project evaluation.

Flexibility has been a major goal in the masterplanning of the MV2 (PMR, 2008). The motto of the Master Plan is *Create your own future*, that is, the client should be given the maximum flexibility in the planning of his terminal on MV2. Having acknowledged that the only manner to deal with future uncertainty is to make flexible and robust designs that are adequate for different futures, a Master Plan cycle has been set up whereby every year the Master Plan is adapted to the newest insights. The Master Plan gets more detailed in every cycle as more information comes available. The design and construction contract with the building consortium gives it an enormous amount of freedom in how it carries out the project, as long as it satisfies the schedule of requirements.

Moreover, flexibility in time is achieved by adapting the development of MV2 to the actual market demand. To avoid the creation of capital-intensive sites that would later prove unprofitable, port areas are created only when contracts with clients have been signed. In fact, the motto is 'build on the basis of demand, with respect for nature' (Kamperlaan, 2005). The following phase will be developed in due time, when newer information provides a better insight into the future (another motto: *Client in sight, land in view*). The terminals (meant for containers at present) are of modular size and can be readily adapted for other cargo. The marine infrastructure is planned for future vessels, keeping in mind future flexibility.

During the FAMAS study 'Maasvlakte Integral Container Logistics' (van Schuylenburg, 2004), a new generation of container terminals and service centres with connecting Inter Terminal Transportation was studied. During the evaluation, the alternative offering flexibility regarding the terminal layout was most favoured.

These examples illustrate that uncertainty and flexibility considerations are playing an increasing role in masterplanning.

3.4 Design of port infrastructure

3.4.1 Approach to design

In an existing port, or in a new port once the basic infrastructure is in place, clients can lease space for their terminals. A landlord port authority is then responsible for locating the client in the port, creating suitable infrastructure facilities to match his needs, and maintaining these infrastructures over the entire lifetime. Or alternatively, a client may wish to expand or modify his facilities. In both cases, the provision of these facilities involves numerous multi-disciplinary activities. External agencies, such as consulting engineering firms are often engaged to carry these out. The activities have a wide scope and include feasibility studies, detailed designs, selection of a contractor, supervision during execution, selection of a port developer-operator to implement the project on a commercial format, assistance in formulation of concession agreement, and start up of project implementation (not forgetting an assessment of the environmental and social aspects of the project). These firms, in turn, engage research institutes and specialist sub-consultants to carry out some of the tasks. In the case of private landlord ports with their own engineering division, the tasks of consulting engineers may be limited to carrying out feasibility studies, detailed design, and supervision during construction.

If we consider the costs of civil infrastructures (a quay wall cost as much as €50,000/meter or 15-20 M€ for a single berth, and 1000 meter of breakwater can cost 50 M€, then a suitable infrastructure design is on the top of the list of activities listed above. This entails development of alternative designs that serve the desired function and provide adequate capacity to satisfy the need of the client and the user. The basis for the design is a 'terms of reference' (or program of requirements) document. This document includes the functional needs of the client, and the requirements imposed by the office of the Harbourmaster in the interest of safety, as well as the requirements of the maintenance department that evaluates the maintainability aspects of infrastructure.

The engineers proceed to design the elements of an infrastructure system by first translating these functional requirements into technical specifications. In addition to stating the capacity requirements, these technical specifications also give guidelines for design through specifying design norms and standards. The deterministic figures in these technical specifications form the basis for design. The designers often do not recognize that input for their designs is based on very uncertain forecasts of future demands and services. These figures remain fixed, even when relevant developments are taking place.

The practice in engineering of designing to fixed specifications is deeply entrenched in the overall process for developing technological projects (de Neufville, 2000). Uncertain factors in design generally refer to material properties and loads on structures. This is taken into account through (minimum) compliance with the requisite norms and standards wherein safety factors to be incorporated in designs are prescribed. This essentially means conservative assumptions expressed in terms of large(r) safety factors. Some uncertainties, generally at the project level, are handled in a risk analysis. The remaining uncertainties are ignored, so that the resulting designs may be unsuitable and inadequate for the longer term. There is also no scope for the contractor to incorporate flexibility since he is supplied with a fixed contract.

3.4.2 Design concepts

In the preliminary design phase of a project, alternative design choices are investigated. For a quay wall project it is usual to consider alternatives such as combi-wall, diaphragm wall, concrete block-wall, non-reinforced concrete gravity wall, cell wall, jetties on piles, caissons and L-wall (see CUR (2005a) for a description). Some of these alternatives are more flexible than others, which means that either they are robust under changed requirements, or can be adapted for reuse.

- At least in theory, a caisson can be floated to another location

- A jetty of modular construction, comprising of a deck on steel piles, can be relocated and reused, as can a quay wall built of blocks

- A massive gravity wall or a concrete diaphragm wall are fixed structures, but through incorporating margins in their designs (larger dimensions and more material), it is possible to use them even when requirements change. Such a quay wall can be extended easily subject to provision of space, and require only small infrastructural adaptations in the construction that facilitate connection of the old quay with the new

- Similarly, it is easier to create additional area with a jetty construction through driving additional piles and placing a deck on top

For a long time, the design of infrastructures such as quay walls, inland channels, terminals, buildings, etc. did not attract attention from the researchers. The same old conceptual designs, suited to immediate needs and local situations, were used. The only improvement was to optimize designs through use of software that utilized the heightened computing power of the machines. Ad hoc solutions were applied to deal with unforeseen problems or parameter uncertainty. Moreover, the design specifications catered to short term demand without any thought of the long term future. For a long time this approach sufficed, till the volatility in the environment escalated. Therefore, in recent years, many innovative quay wall design concepts have emerged. Some examples, discussed further in Chapter 6, which have not yet been implemented are:

- Maxisteck (PoR/IGWR)
- Containerland (PoR)
- Floating quay wall (Samsung, TRI, and crane manufacturer Gottwald)
- Frozen quay wall (IGWR)

Two other flexible concepts that have not been implemented are:

- Multi-user quay wall, which could increase berth utilization
- Multi-functional quay wall, which minimizes risk due to dual (or multi-) use, and can generate extra revenues

Nearly always, the inflexible, low priced alternatives designed to satisfy the immediate requirements of the clients are opted for. For any situation, before an alternative can be considered, technical, operational, or financial feasibility has to be established. This requires time and effort, and is understandably a bottleneck for implementation of new design concepts. Yet, even the proven designs have not been implemented despite the obvious advantages in certain situations. We will investigate the reasons for this in Chapter 6.

3.5 Project appraisal

3.5.1 Description

The next step in port planning involves the evaluation of the developed alternatives. In case of a simple project, this is mostly limited to a selection based on cost estimation (mainly because the throughput, and the revenues are deemed to be same in each case). In case of government funding, an economic analysis (from a broad perspective of societal economics) is required for evaluating investment in infrastructure. The direct and indirect effects of a project are systematically estimated and, wherever possible, given a monetary value. In case of private investments, such an economic appraisal is replaced by a purely financial appraisal.

Project appraisal for port projects is mostly carried out by economists based on preliminary plans and designs almost always prepared by a third party, (i.e. engineering consultants or advisors). The increasing popularity of various forms of Design and Construct contracts is reinforcing this trend. The work of these consultants is limited to finding an adequate and reasonably priced design alternative that meets the specifications; flexibility is usually not on the list of objectives.

The economic or financial analysis normally uses single best estimates of cost and value, and applies techniques such as discounted cash flow (DCF) analysis. Such financial tools explicitly consider only one expected outcome (e.g., expected profit or net present value). Science can provide very little guidance to decisionmakers beyond offering them simple decision rules to aid them in their analysis of uncertain situations e.g., maximax, minimax regret, and the equal probability rule (Thomas and Maurice, 2005). The application of any of these rules results in a single number. CPB/NEI (2000) rightly observes that, due to the many uncertainties surrounding the planning, implementation, and operating environment of a project, it is neither feasible, nor desirable, to express the net benefits of a large project in a single monetary value, as is currently the practice.

These financial tools do not value flexibility. Besides, the linear decisionmaking process (involving preliminary design of alternatives followed by an initial evaluation, detailed design of the chosen alternative, and final project evaluation) does not leave room for a flexible option identified in the detailed design stage to be included in the initial project evaluation. This can lead to misguided decisionmaking.

World Bank (2007) adds that, in many countries, the government is responsible for financing basic infrastructure, and an often occurring problem is that the decision to invest does not necessarily originate at the same level of government as the level having the financing responsibility. Because of this, the interest of public officials in increasing the efficiency and profitability of port assets is usually limited, since they are not held accountable for the success or failure of their investment decisions. In short, the division of responsibility among governing agencies, and the limited (if not outdated) financial tools contribute towards an inefficient process.
We will examine the investment related procedure at PoR to see if it suffers from the same limitations.

3.5.2 Project appraisal at PoR

Port of Rotterdam Authority (PoRA) is the developer and manager of the fourth largest port in the world (in 2011). It ensures that sufficient space is available for its clients in the port, and invests in infrastructure for them. It also invests in the improvement and construction of new roads, rail lines, inland waterway connections, and underground pipelines. The Port Reform Toolkit (World Bank, 2007) states that

Table 3.3: Project categories at PoR

Projects	Small	Middle	Mega
Range of investment	<€250,000	>€250,000	in order of €100 million
System boundary	port	land	land, Europe
Category of projects			
- Public	Yes	Yes	No
- Client	Yes	Yes	Yes
- Strategic internal	Yes	Yes	No
Evaluation method for client projects	none, simple cost estimation	business case	cost-benefit analysis
Evaluation method for public or strategic projects	none	none	none

port authority objectives should be the full recovery of all port-related costs, including capital costs, plus an adequate return on capital[3].

A client wanting to expand capacity in the port approaches the business manager at PoR. If a project proposed by the client satisfies the PoR criteria, and there are no better alternatives to the project, then a suitable location is sought in the port. Alternative infrastructure layouts/designs are developed and evaluated against financial criteria. PoRA, as a corporation, wants to be profitable. Consequently, it evaluates the financial viability of a new project-undertaking in a business case comprising the present and future cash flows of the project. Table 3.3 shows the three project categories – client, public, and strategic – and the applied evaluation methods in each case. A project requiring land reclamation will fall into the category of a (mega) client project, while a traffic guidance system for shipping can be categorized as a public project. Figure 3.3 shows the evaluation procedure for client projects. The DCF method is applied for projects exceeding €250,000. In general, a minimum internal rate of return of 8.5% on the investment is required (Aartsen, 2006)[4]. If a project

[3]This helps to attract outside investment and secure long-term cash flows for future investments, stimulates innovation, compete according to the rules of the market system and puts limits on cross-subsidization that can undermine financial performance, and avoid dissipation of the port authority's asset base to satisfy objectives of third parties.

[4]Instead of using a common discount rate for all projects, PoR distinguishes projects depending on their risk profile (based on risks determined by the scale of the project, market demand, chance of bankruptcy or plausible alternative use of infrastructure etc.).

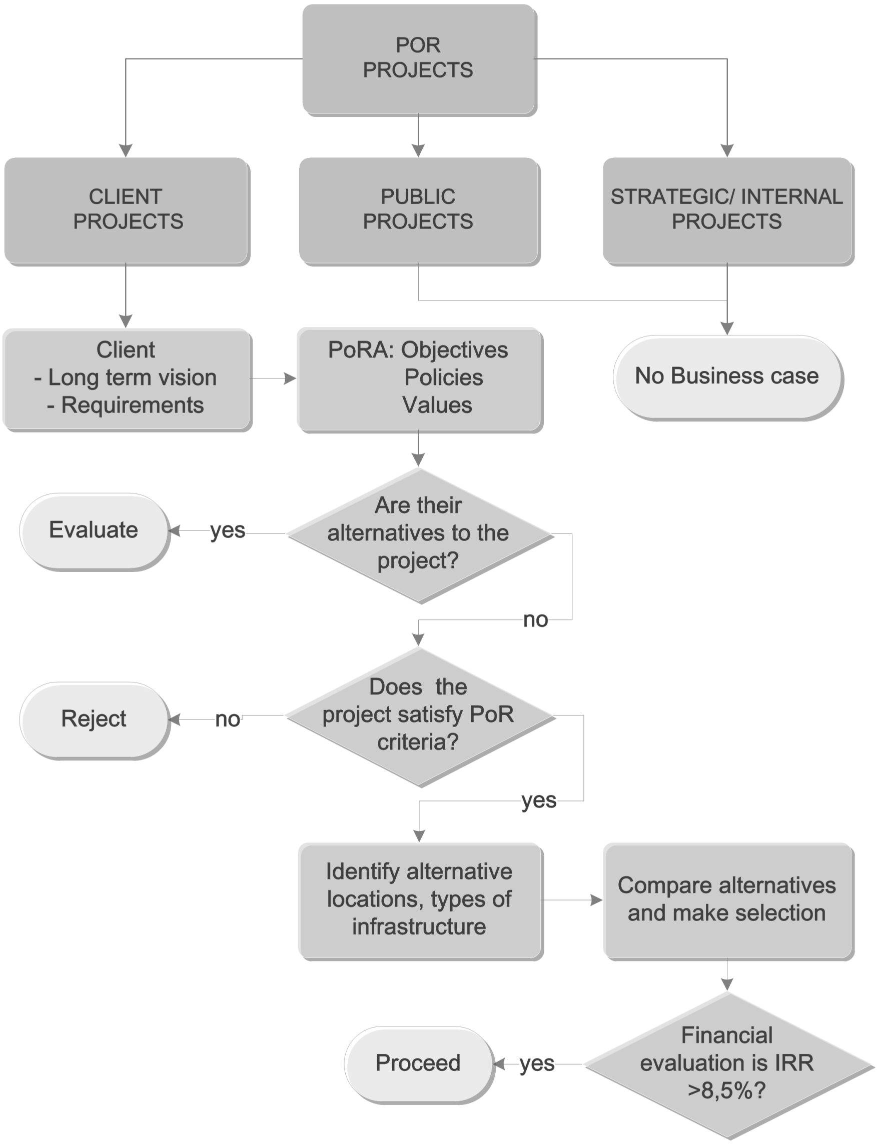


Figure 3.3: Project appraisal at PoR

seems to face greater uncertainties, a higher figure is used, or alternatively, the pay-back period, normally set to 25 years, is reduced. In case of strategic considerations, a lower figure is applied. Inflation is also included in the cash-flow model. Some costs and benefits are not quantifiable, for instance, if they contribute indirectly to efficient operations or risk mitigations; and these are not included in the project evaluation.

The uncertainty in investment costs can arise due to factors such as raw material and product prices, quantity estimates, labour costs etc. The uncertain factors such as future market share or demand, interest and exchange rates, tax and regulatory policies, all have an impact on the projected cash flow. This is taken into account by considering a certain positive and negative variation around the base case scenario, which results in an optimistic and pessimistic scenario. The decision to invest or not to invest is generally based on the base case scenario. The PoRA appraisal procedure suffers from several limitations, which are briefly discussed below (Taneja et al., 2010a):

a) The decisionmaking process precludes communication between disciplines and consideration of alternatives

A typical decisionmaking process related to engineering (involving design and evaluation) is linear and static; it is based on using scenario forecasts, and follows a rigid sequential strategy. The decisionmaking related to investments is independent of the processes related to engineering, and is carried out in a different time frame. The two processes have little communication and not all information can be traced back in the project documentation. Due to this gap, valuable input from the engineering discipline is often missing, and decisionmaking related to capital investment can be misguided.

The sequential nature of the procedures means that the best seeming alternative is evaluated in the detailed design stage, and alternatives are not taken into account after the feasibility stage. It is not useful, from an economic viewpoint, to determine the value of an investment without referring to another situation. And there is no room within the standard procedures to re-consider, adapt, and re-evaluate one of the alternatives (as to material, design, technology, or operation), if the initial evaluation results in a negative business case.

b) The business case is deterministic and does not include intangibles

Although all the variables and assumptions determining the costs and revenues in the business case are uncertain, they are treated as if they are certain. Unknown, intangible and unmeasurable costs or benefits are valued at zero in the business case. In marginal cases, if an attempt is made to subjectively quantify and include these benefits in the business case (e.g. the environmental mitigation or compensation measures), it is found unacceptable by the management, because these elements are not a part of the standard procedure of project evaluation.

c) The evaluation methods do not take uncertainty and flexibility into account

The DCF method does not incorporate the risk of uncertainty, since it treats future cash flows in a deterministic manner. It focuses only on the most likely outcome of a situation e.g. expected value of investment and potential revenues. With all the uncertainty involved in such projects, the chance of a single NPV value being correct is essentially zero. The project appraisal method assumes that decisions are made now (and will not change later), and fixes the cash flow streams for future. Flexibility in decisionmaking, design and operations, can enhance the value of a project, but cannot be included in the project evaluation with these methods.

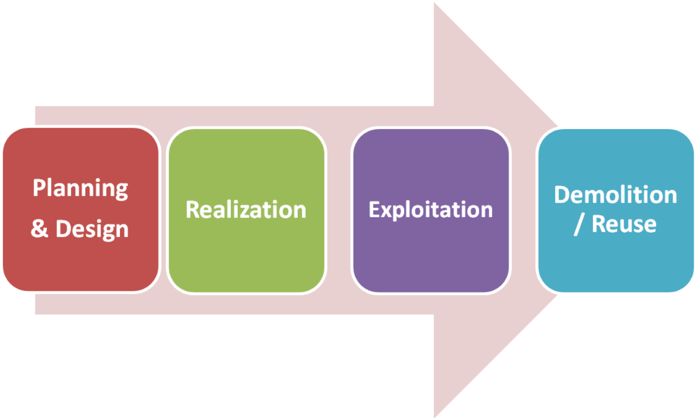


Figure 3.4: Phases in a port project

3.6 Dealing with uncertainty

3.6.1 Introduction

This section limits itself to investigating the treatment of uncertainty in civil engineering projects in the Netherlands including projects in the Port of Rotterdam. Though a detailed handling of project management is outside the scope of the dissertation, for the sake of completeness, we define terms such as project and scope management.

Project management is defined as the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stakeholder needs and expectations from a project. This involves balancing competing demands from scope, time, cost, and quality.
Project scope refers to the work that needs to be accomplished to deliver a product, service, or result with the specified features and functions (Project Management Institute, 2008).
Scope management keeps track of the end objective through defining, managing, controlling, verifying and communicating the scope to the project team and stakeholders. The risks are managed through *risk or uncertainty management*.

Four project phases as shown in Figure 3.4 can be distinguished. We will discuss the handling of uncertainty in the first three phases.

3.6.2 Design phase

During the design phase, the emphasis is on building margins around costs. SSK (Standaard Systematiek Kostenraming) (CROW, 2002) is a uniform system for making cost estimates in the civil engineering sector in the Netherlands. SSK has defined different categories to account for the unforeseen costs in an investment project. Figure 3.5 shows the different cost components. Foreseen costs refer to the costs that can be estimated based on specifications and the design (i.e the scope of the project). 'Costs object unforeseen' refer to costs due to changes in design (within the scope), new

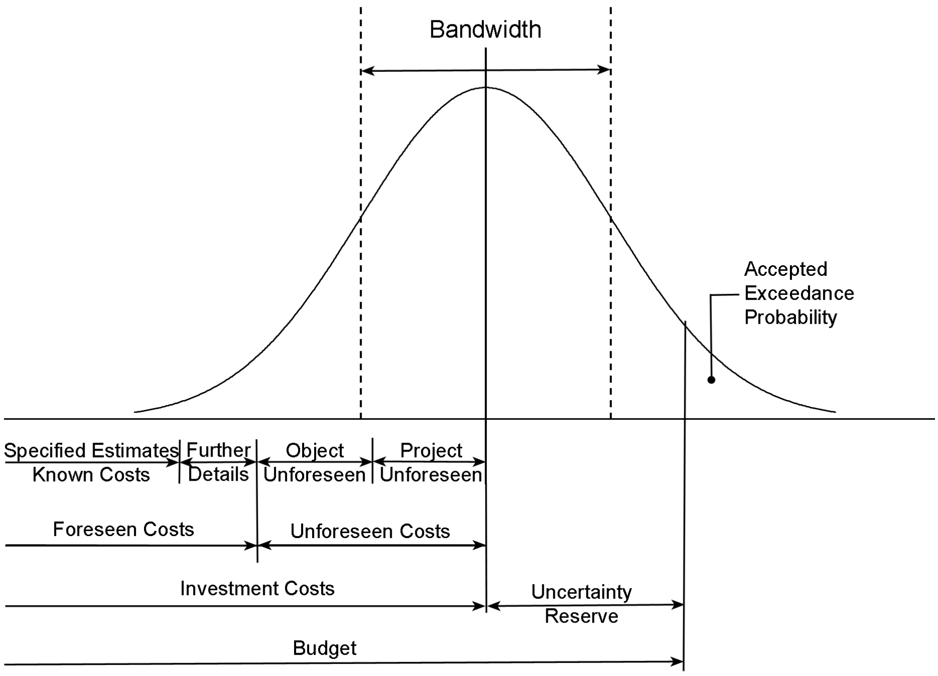


Figure 3.5: Cost components (SSK)

insights, increased complexity during realization. 'Costs project unforeseen' covers uncertainties at the project level and consist of 'foreseen unforeseen' and 'unforeseen unforeseen' (Kuiper and Vrijling, 2005). The former includes unexpected events, which further down in the project can be estimated as the product of probability of occurrence and impact. The latter are not a part of the uncertainty analysis, and no measures can be taken to reduce them. Their contribution is most significant to the bandwidth of the estimate; the bandwidth in turn depends on the chosen confidence interval.

Uncertainty reserves cover uncertainty within the scope, and management reserve (not shown in the figure) is meant to cover scope changes. The investment costs include the foreseen and unforeseen costs, while the budget for a project also includes the uncertainty reserve. The project owner (e.g. a landlord port authority) determines the budget as well as the management reserve. For 'unforeseen unforeseen' events with small probability and huge impacts, the uncertainty reserves are vastly insufficient and the project and the organization has to often incur losses.

Many firms in the civil engineering sector use cost-estimation templates based on SSK, for their projects. Thus, traditional methods take a deterministic conservative approach to project cost estimating and add a contingency factor that varies depending on the project phase, experience, and other factors, to account for the unforeseen costs. Table 3.4 shows typical margins for PoR projects during various phases (HbR, 2010b). This bandwidth representing uncertainty, is based on experience, and is, to a certain extent, subjective. A conservative estimate results in high reserves for risks (and lesser budget for other investment projects), while in an opposite extreme approach, risks might be underestimated. A misrepresentation of costs and revenues is likely to lead to the misallocation of scarce resources and funds, if it results in an unsuitable project

Table 3.4: Cost margins per project phase

Stage	Type of estimate (%)	Uncertainty margins (%)
Project initiation phase	Use of indicative figures	40
Feasibility phase	Feasibility and project definition	30
Design phase	Preliminary design	25
	Detailed design	20
	Specifications	10
	Tender	5
Realization phase	Contractor's estimate	3
Completion	Actual costs	0

or project alternative being selected.

3.6.3 Realization phase

Generally, a risk analysis is carried out by the consultant or the contractor to identify and manage risks in the realization phase. The risk analysis and management methods employed are generally a variation of the Risman method that was developed in 1995 (CROW, 2011) for the infra and the building and utility sector in the Netherlands. Risks are managed through this method by one or more of the following means:

- Creating a reliable reserve for the risks that cannot be transferred to the contractor or the insurer
- Reducing risks through implementation of risk management, so that more budget is available for other risks, changes (within scope), claims etc.
- Managing the construction process

The Risman method involves the following steps:

- Set up the goal of the risk analysis
- Identify (unforeseen) risks and set up a Risk Inventory List (RIL)
- Prioritize the risks
- Define management measures for the high priority tasks
- Select and implement the management measures, update Risk Action List (RAL)
- Evaluate the management measures
- Repeat cycle and update risk analysis

The Public Works Department of Rotterdam (IGWR), an engineering consultant for infrastructure projects at PoR for decades, is one of the developers of Risman. Most port projects engineered by them have been of a short duration, seldom exceeding a year. A detailed risk analysis is undertaken at the beginning of a project. Monitoring is carried out as standard procedure, but is limited to the physical site characteristics and the state of the civil infrastructure. Active monitoring based on the results of the risk analysis is not a common practice. And tracking exogenous developments that could form a risk for the project is not a part of the monitoring procedure. In most projects, there is no systematic risk management, and the response to deviations is mostly ad hoc.

van Schaardenburg (2009) states that the general experience is that the demand for risk management of port projects generally originates with the client (that is either the port authority or clients who sometimes build their private facilities in the port), who determine this per project. The client then allocates the necessary budget. The general opinion among many clients was that risk analysis does not deliver returns and is an extra cost-item. This forms the biggest bottleneck against investment in risk management. Generally, the consulting engineers have to convince the client of the need for risk analysis, and sometimes they even undertake such as an exercise in mutual interests, but this does not happen very often.

Even though the importance of risk management of large complex infrastructure projects is being realized, no standard practices concerning risk analysis and management have evolved in the port sector. Even in cases where (passive) risk analysis is undertaken, (active) risk management is missing. And when risk management is practised (e.g., in case of large transport infrastructure projects, such as RandstadRail), it is distinct from scope management. And neither of these takes scope changes into account[5]. The consequences of the (generally ad hoc) changes in scope, are reflected in the costs, but a detailed analysis of actual and realized scopes is not a part of the standard procedure. A study over the increase in the budgeted costs for the projects of Rijkwaterstaat and Pro-Rail in the Netherlands, revealed that in inflation contributed 50% to the increase, while scope changes and project risks each contributed 25% (PAO, 2005). Thus, even though scope changes are partly responsible for the increased investments, they do not form a part of the risk analysis in standard practice of project management,

Costs are a generally accepted indicator of a success or a failure of a project; this is especially true for mega projects under heavy public scrutiny. Sakamris and Flyvbjerg (1997) found that the cost overruns of 50-100 % above the estimated expense are found to be common in large infrastructural projects. Only when a project becomes totally unmanageable (massive cost exceedance and schedule delays for projects in the public eye, or a threat to the surroundings), is it stopped and reassessed. Proactive stopping (on the basis of signals from a monitoring system) is not a part of the risk management procedure (van Schaardenburg, 2009). It is useful to mention Maasvlakte 2, which is an exceptional project. A special project organization has been set up for this project. Due to its long duration and complexity, risk management tools, such as PRINCE, are being effectively used.

[5]Scope changes in a project can be driven by factors such as introduction of new techniques or methods, regulatory changes, requirement changes also due to incompleteness, heuristic discoveries, financial circumstances, changes in leadership, and more. These can require changes in the terms of reference, changes in design, or changes in the specifications.

Nowadays, it is common to use contract forms such as Design & Construct to avoid the direct effects of many risks during the construction phase by passing these on to the contractor. This risk transfer invariably comes at a price.

Derivatives such as swaps, futures, and options are employed to hedge against changes in price of materials that can significantly affect the business case, e.g., a commodity swap is used to reduce the risk of increase in the oil or steel prices for larger projects. Similarly, an interest rate swap is used to swap the variable interest rate to a fixed rate.

3.6.4 Exploitation phase

The exploitation phase includes the operational use, and maintenance. For dealing with the risks in this phase, mechanisms are incorporated in the contracts. A typical contract or concession will include an agreement over the time in which the investment must be earned back, the cargo guarantees with the client, as well as discounts and supplements offered. For sake of completeness we mention how the anticipated uncertainties related to costs and revenues at the project level are dealt with at PoR.

The two main sources of revenues from a project are: income from land lease, and the port or harbour dues. Clients (terminal and jetty operators) are charged for throughput (tonnes) handled, and this throughput remains uncertain. The dues paid by the clients are negotiated every year with an organisation that represents the businesses in the port area. Risks related to throughput are covered through negotiating traffic guarantees in the contracts with clients. The traffic guarantee offers a variable user fee, related to the amount of traffic. In this manner, the clients bear the responsibility of attracting shipping lines to PoR. While this assures a minimal cargo volume for PoR, it also means price discounts for the client if the cargo exceeds a certain level. A yearly indexation of rental fee, to follow the changes in the Consumer Price Index, which is subject to volatility, is also routinely implemented. For large investments in the Euro area, the inflation is fixed at 2% per year (DNB, 2011).

PoR tries to insure against default through thorough checks as a part of the tendering procedures. However, unexpected developments can result in a client becoming bankrupt. If an existing customer requires additional facilities so that PoR has to incur extra costs, the investment is covered through raising the rental fee (also known as infraplus[6] premium), or implementation of additional traffic guarantees. The tariffs and discounts on the port dues as well as on the land lease are defined in the contract, and incorporated in the business case.

Discounting plays an important role in modern investment decisionmaking. In practice, a minimum discount rate of ca. 8.5% is applied for client related projects (Aartsen, 2006). Several risks such as expiration of offers and terrains in option, are reduced in

[6]At PoR, the term basic infra refers to waterways such as approach channels, turning basins; quay walls, jetties and slopes, and roads; infra plus includes includes pavement, crane rails, sewage, cables, and pipes, and suprastructure refers to quay and terminal equipment as well as inter-terminal transport equipment.

contracts by formalisation of expectations and responsibilities. The general dissolving conditions (e.g. change of control, licences and guarantees) are also covered.

3.7 Conclusions

A port project represents a major infrastructure investment with a design life of several decades that needs to accommodate today's needs as well as tomorrow's. A port development project entails activities such as port planning, design, economic evaluation, and realization before it can start to receive ships and generate revenues. We have established in this chapter, through literature study and desk research, that the current approaches to port planning, design, and appraisal do not take uncertainty into account and result in port infrastructures that may prove inadequate under changing requirements.

Due to the lack of uncertainty considerations, the objectives and sub-objectives of a port development are often not clearly defined. There is often no clarity in the short-term and long-term visions, which often leads to conflicting performance criteria that demand paradoxical solutions. The designers do not habitually think in terms of uncertainty and do not realize that flexible designs permit multiple pathways of project evolution, according to the scenarios that develop. The decisionmaking related to engineering (technical aspects) and (financial) investments is separated. The linear approach followed for most port development projects means that the decisionmaking cannot benefit from new information that reduces uncertainty.

The traditional methods of investment appraisal are based on a financial evaluation in a business case, using standard DCF methods. This is adequate for a stable environment, where the projects have deterministic requirements and the management has a clear strategy. For the majority of long-term projects, this is not the case. The decisionmaking is based on the most likely outcome of a situation, e.g., expected value of investment and potential revenues which present serious drawbacks. These techniques do not value flexibility in projects in order to justify its extra cost.

Project management literature assumes an environment in which the range of issues facing is more or less constant, and current quantitative trends can be extrapolated into the future. Project managers, in order to curb the negative effects of risks, often implement a risk management program, in addition to project management. Even so, these are treated as independent activities, and practised in different time frames. Moreover, traditional risk management often tends 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). Scope changes in a project contribute significantly to failure of a project, yet are not a part of standard practice of risk management.

The traditional methods leave no room for including flexibility in the front-end phase of the project, which, especially for infrastructures, can prove to be very cost-effective. A systematic and integrated approach to planning of a (port) project is missing. A lack of integrated approach leads to many parallel initiatives and processes so that there is an overlap or neglect of responsibilities. When ad-hoc risk reduction measures are applied at a later stage, and lead to extra budget and time, it often comes as a source of surprise. This clearly demonstrates the need to revise best practices. Complex infrastructure engineering projects require flexibility to be able to deal with uncertainty. Therefore, port planning needs to move from optimal designs to flexible designs, from anticipating risks to monitoring the environment, from operative Master Plans to directive planning, from strategic planning (aided by risk management) to integrated, adaptive planning methods. Project evaluation needs to shift from traditional techniques to methods valuing flexibility.

Since uncertainty is here to stay, we have to recognize it, prepare for it, adapt to it, manage it and finally, try to profit from it. Flexibility and adaptability will enable a port to develop strategies to adapt to current and future needs. The remainder of the thesis will be devoted to exploring how we can best do this.

Chapter 4

Flexibility concepts in ports

We need to develop the flexibility to react to events, to take advantage of new opportunities, and to exit from unproductive pathways - Richard de Neufville, 2007

4.1 Introduction

In recent times, various new planning approaches have been put forward (Holling, 1978; Dewar et al., 1993; Lempert et al., 2002, 2003; Walker et al., 2001; de Neufville, 2000, 2003b; Taneja et al., 2010c). These approaches emphasize the need for a more thorough analysis of uncertainties, and suggest that flexibility and adaptability are of central importance in coping with the uncertainties. Therefore, in this chapter we begin by building a common understanding of flexibility and its related concepts. We also present some typologies that reveal various facets of flexibility, and we illustrate these with examples and situations from the port sector. We depict the port as a multi-layered infrastructure system, and discuss the incorporation of flexibility in various layers.

4.2 Flexibility as a solution

4.2.1 A perspective on uncertainty and flexibility in infrastructures

In planning situations there is always a gap between what is known and what should be known. Under this uncertainty, taking decisions becomes difficult: the certainty that the payoff will justify the investment decreases, while the importance of acquiring strategic advantage over the competition becomes increasingly important. Flexibility has long been cited as a key goal for dealing with uncertainty in the planning and design of complex engineering systems (Faludi and Hamnett, 1977; Porter, 1985; Ahmed et al., 1996; Volberda, 1998; Collingridge and James, 1991; Floricel and Miller, 2001; Ramirez, 2002; Saleh, 2002; Ross, 2006; Shah et al., 2008; Wilds, 2008; Yang, 2009;

Taneja et al., 2012a). Large infrastructure projects also belong to this category, and without the capability to adapt to changing conditions, these projects turn out to be white elephants.

Among others, Moses (2004); Scholtes (2007); de Neufville et al. (2007) go a step further and state that rather than reducing uncertainty to manageable levels in standard practices, we should aim to benefit from uncertainty. Managers should integrate flexible reaction capacity into the project, so that new schemes can be developed during the course of the project if a wholly unanticipated event occurs. They must become aware that flexibility is at the heart of uncertainty management for large-scale projects and value management of the delivered systems.

In the words of de Neufville et al. (2007): "We need a paradigm for planning and design of large-scale engineering systems that deals effectively with the reality that the actual future so regularly differs substantially from the forecast. We need concepts and procedures that enable us to anticipate possible uncertainties, and enable us to deal with them efficiently as they arise. In one word, we need to develop the flexibility to react to events, to take advantage of new opportunities, and to exit from unproductive pathways. We need this because the value that can be expected from a flexible system can be vastly greater than the value derived from a system designed around a specific expected future. Designers of large-scale systems need 'real options', that is, the flexibility to alter development trajectories as needed."

With reference to the port sector, Bellis (1990) points out that the limitation on the ability to modernise a port mainly because of its lack of flexibility has meant the end of many ports or at best a limit to their expansion. Therefore, it is of paramount importance to provide adaptability and flexibility in all new developments in ports and harbours. FAMAS.MV2 (2000) stresses that due to the presence of strong external influences or exogenous uncertainties, a port should aim to remain highly flexible in coping with changing market developments.

Cardin and de Neufville (2008) cite numerous case studies from mining, management, real estate, aerospace, engineering, manufacturing, energy production, automotive, and hydroelectric industries which have shown that flexible engineering design can improve value significantly.

Having supported our conjecture that flexibility and adaptability are much needed attributes in infrastructures, we can now proceed to examine flexibility-like concepts, and seek a suitable definition of flexibility in the context of ports.

4.2.2 Flexibility and adaptability

Intuitively, flexibility is understood as the ability to respond to change. However, it is a complex, multidimensional concept which is difficult to define satisfactorily.

In the present context, we use the two terms flexibility and adaptability synonymously. A *flexible or adaptable port* 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 (which essentially means, to maintain, or even improve service levels, with little or no extra investment).

4.2.3 Some flexibility-related concepts

In this subsection, we define these concepts related to provision of flexibility in an infrastructure system. These definitions have been borrowed from various sources.

Accessibility (of an infrastructure, equipment, product, or service) refers to the ease of approach and the degree of availability for operations and maintenance.

Compatibility is the capability to efficiently integrate and operate with other elements in a system without modification.

Constructability is the extent to which a design of a system provides for ease of construction while meeting the overall requirements.

Deconstructability is the characteristic of design that allows for the disassembly or dismantling of elements and components of the system easily, rapidly, and economically without causing environmental degradation.

Disposability is the characteristic of design that allows for the disposal of elements and components of the system easily, rapidly, and economically without causing environmental degradation.

Durability is a measure of the ability of materials or structures to continue to be useful after an extended period of time and usage.

Interchangeability is capability of an element to replace another element (in the same or another system) to fulfil the same requirement.

Interoperability is the ability of a system to work with other systems or an element of the system to work with another element within the same system.

Maintainability is the characteristic of design that reflects the ease, accuracy, safety, and economy of performing maintenance actions.

Modularity (-in-design) refers to use of standardized units or dimensions, facilitating interoperability, interchangeability, and scalability.

Producibility is a measure of the relative ease and economy of producing an item.

Quality is a measure of how well the requirements (of the client or customer) are met.

Recyclability is the characteristic of design that allows reuse after processing.

Reliability is the characteristic of design that ensures that a system will meet its performance requirements throughout its lifecycle.

Resilience is the degree to which a system can recover quickly from a major disruption while regaining – or even exceeding – its original level of performance.

A *robust port* has the ability to meet requirements under changed circumstances, without significant impact on the service level.

Safety refers to minimizing risk to human elements in operation, maintenance and use of a system.

Scalability is the characteristic of design that enables the system to be scaled (up or down).

Security refers to the degree of protection against danger, damage, loss, and crime.

Separability used in the context of materials, refers to segregation for reuse, ease of extraction and sorting. In case of components it requires realistic tolerances, non-monolithic joints, determinate designs, and appropriate detailing.

Standardization refers the degree to which designs achieve interchangeability in use.

Usability refers to the easy use of designs, procedures, equipment, services, and infrastructure.

Versatility is the capability of a system to carry out other functions than included in the original requirements.

4.3 Flexibility, actions, and real options

4.3.1 Some relevant terms

In Chapter 5 we will refer to many types of actions, while in Chapter 7, we will investigate real option methods for valuing flexibility. Therefore we begin here by discussing the inter-related terms action, strategy, and real options.

Table 4.1: Option and action

Goal	Option	Action
Deal with uncertainty in cargo volumes	Modular construction	Adapt quay wall if volumes increase
Deal with uncertainty in cargo volumes	Reserve quay crane and equipment	Employ reserve equipment

An *action* is a single thing to change a system.

A *strategy* refers to a combination of actions designed to achieve a particular goal.

An *option* is the right to carry out a strategic action, without the obligation to do so. The owner of an option has the right, but not the obligation, to take some action, now, or in the future, for a predetermined condition. When applied to real systems and projects, options represent (a type of) flexibility in the system and are termed as 'real options', a term coined by Myers (1984). (Thus an option in the context of 'real options' is not a synonym for 'alternative' as it is in ordinary language.) The word 'exercising' is implicit in the classical definition of an option. Options can in principle be created for any type of valuable asset. Through incorporating options in an infrastructure system, the owner can adapt the system according to the future that unfolds. Through either managerial flexibility to change paths, or creating the ability to adjust a design of a system in significant ways, system managers can either avoid downside consequences or exploits upside opportunities (de Neufville, 2003b; de Neufville et al., 2006a, 2007).

Value is increased through the creation of options for subsequent sequential choices and exercising these options in a timely fashion (Miller and Lessard, 2001; de Neufville, 2003b). An option has a cost, but can prove to be very valuable in case of unexpected events. For example, a client in PoR pays a premium amounting to 20-25% of the land-rent for holding on to a parcel of land that is not generating revenue, so that it has the flexibility to use the land for commercial purposes when it is advantageous. The client can exercise this option in the future; the period after which the option expires is set out in the contract.

We make clear the relationship between these terms with the help of two examples in Table 4.1.

4.3.2 Types of flexibility

de Neufville et al. (2006a) distinguish between two types of real options – options 'in' a system and options 'on' a system. Options 'in' a system means designing various infrastructure elements to create flexibility, so that the system can still be useful in case of new functional requirements. One can provide flexibility 'in' infrastructure systems so that they can be adapted to provide more capacity, change functional use, or alter productivity and efficiency. The real options 'on' infrastructure systems involve management's ability to influence a project – e.g., investing in new infrastructure, expansion, downsizing, deferment, abandonment, or phasing of investments (the system is unchanged).

Mauboussin (2000) uses a different classification from the perspective of a manager, and classifies real options into three main groups: Invest/grow options, defer/learn options, and disinvest/shrink options. Table 4.2 lists some examples in the port industry in each group. A *scale-up* option involves investment in order to create future value-creating opportunities, while a *scale-down* option allows a company to downsize a project in midstream as new information becomes available. A *switch-up* option values an opportunity to switch products, process, or plants given a shift in the underlying price or demand of inputs or outputs. A switch-down option makes it possible for an organization to switch to more cost-effective assets as it receives new information. A *scope-up* option values the opportunity to diversify into another, related industry. A study/start option allows the management to wait or defer before investing. A scope-down option is valuable when operations in a related industry can be limited or abandoned based on poor market conditions and some value salvaged.

4.3.3 Strategic approaches for flexibility

Before incorporating a real option in a port plan (i.e. invest in flexibility), we need to answer many questions – is the option technically feasible and financially viable, is it

Table 4.2: Some examples of real options in the port industry

Option	Type	Examples
Invest/grow	Scale-up	- Invest in other lands (PoR International invests in the Port of Sohar in Oman and Port of Dordrecht in the Netherlands) - Invest in steel sheet-piles in anticipation of an increase in steel prices, for a future port expansion project
	Switch-up	- Convert bulk terminal into container terminal and bulk cranes into container cranes (Waalhaven in PoR in 1960s) - Use general cargo quay for containers (Eemhaven in PoR in 1960s)
	Scope-up	- Perform value added logistics in addition to container handling (third generation container ports) - Add real estate business to the core functions of the port - Design multifunctional port infrastructure (for underground storage of CO_2/ LNG/ reefer containers)
Defer/ learn	Study/start	- Carry out expansion in phases in response to anticipated growth of demand (Maasvlakte 2, PoR) - A chemical industry takes an option on a piece of land and exercises it if a chemical cluster develops close by, in order to pool resources
Disinvest/ shrink	Scale-down	- Plan port expansion in phases; reassess in response to demand - Create an option for a client to terminate land lease in case their future demand for expansion space cannot be accommodated - Function as a 'spoke' port instead of a 'hub' port
	Scope-down	- Concentrate on niche markets

effective, and what impacts does it carry. In this section we categorize the strategies based on the timing of investment and the resulting efficiency of the system. These categories are typified as follows (Figure 4.1): no flexibility, just-for-now flexibility (expensive and inefficient), just-in-case flexibility (expensive), and just-in-time flexibility (ideal, if feasible). We illustrate these with examples from the port sector.

The common approach to planning and investment in port projects has been to change and modify (if at all possible), as and when required, resulting in massive cost-overruns. Olsson (2006) has characterized this as traditional flexibility.

The *no flexibility* option results in low efficiency of a system and can lead to obsolescence in the face of uncertainty. A tailor-made design based on fixed specification or optimized for a single user, which lacks adaptive attributes, is an example of infrastructure with no flexibility. Most of the older port projects exemplify this. These ports have closed down, changed their function, or new ports have been developed in their vicinity. An unusual example can be found in Vuosaari Harbour Project, Helsinki, Finland (Figure 4.3). Due to unprecedented growth in container traffic, there was no

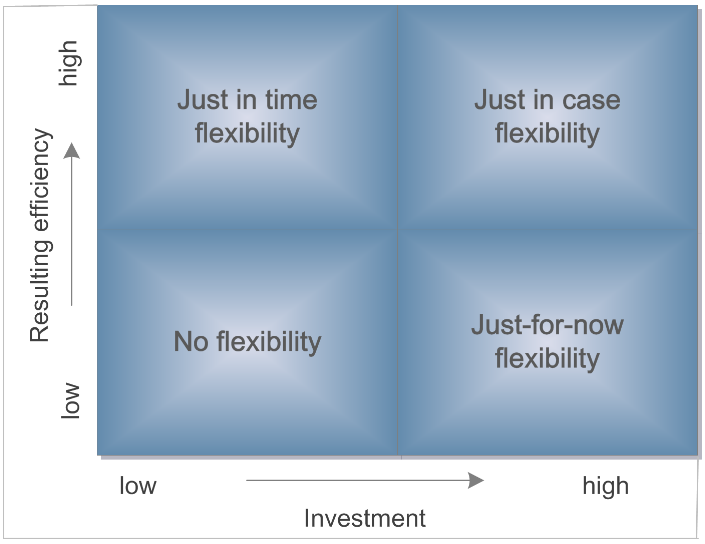


Figure 4.1: Strategic approaches for flexibility

Figure 4.2: Delta Peninsula Maasvlakte

space for expansion at the existing port at Vuossari, and the entire operation had to be transferred to an entirely new location. The Vuosaari Harbour Centre, completed in 2008, is one of the largest infrastructure projects undertaken in Finland.

Just-in-case flexibility refers to building in margins in the design of system components so that the system can be adapted in response to changed requirements. This is also known as giving an engineering structure more robustness against underestimated, unforeseen, or unknown circumstances. This strategy is expensive and a waste of resources if the flexibility is not utilized; otherwise, it can prove to be very cost-effective.

In the 1990's, when major investments in container terminals were being carried out at the Maasvlakte, fourth generation ships with a draught of 12.5 m were current. However, in PoR, the ECT/SeaLand terminal at the Europahaven, as well as the

Figure 4.3: Vuosaari Harbour Project, Helsinki, Finland

Delta 2000-8 terminals at the Amazonehaven (Figure 4.2), were provided with deeper drafts (for future ships) and deeper quays which could accommodate heavier cranes for future ships at an extra cost. This is an example of just-in-case flexibility, which has allowed the berthing of much larger than expected vessels including an 11,000 TEU container ship in 2008.

Though the planning of the Euromax container terminal in Rotterdam began around year 2000, it was ready only in September 2008. Meanwhile, the technological developments were so rapid that some assumptions became outdated during the design phase. For example, the quay cranes of the Euromax Terminal are adjustable to four heights: 37 m, 40 m, 43 m, and 46 m, depending on the size of the ship to be served (Figure 4.4). However, the first two heights (37 and 40 m) already became obsolete during the design phase. The fact that, in anticipation of market developments, designers built flexibility into their design in the form of adaptable heights, saved the day (ECT, 2008).

Figure 4.4: Euromax terminal Maasvlakte

Another example is of the ports in the UK from the 19th and early 20th century, such as Southampton, Immingham, Newport, and Tilbury. These were provided with dimensions that have allowed those ports to meet the challenge of rapidly expanding ship sizes and to prosper. Their great natural advantages, ideal locations, and densely populated hinterlands have been fully exploited in pursuing a policy of enterprise and foresight (Bellis, 1990). Many other ports and docks with limited dimensions (no flexibility) are now closed.

In 1905, following the design of a Dutch Engineer de Rijke, the Port of Osaka in Japan was converted from a river-port to seaport at an enormous expense. This laid the framework for the present prosperous port, which is currently a part of the second biggest urban and industrial zone in Japan (Takamura, 1990).

Just-for-now or ad hoc response to changes in requirements entails high costs to change the system. This is applicable when the existing system is not adaptive (has no flexibility). In 1967, the former director of the Port of Rotterdam, after a visit to New York, brought in the first container line for Rotterdam. The port reacted to this development in a very flexible manner, by converting the Eemhaven, then under development as a general cargo port, into a container port (that involved lining the mouth of the Eemhaven, expansion of ECT, and deepening the existing quay wall of Pier 7 in Waalhaven). Figure 4.5 shows the arrival of S.S Fairland in the Eemhaven. The just-for-now flexibility in response to flexibility in decisionmaking helped seize an opportunity. Today, PoR is the biggest container port in Europe.

Figure 4.5: Containership S.S. Fairland in Rotterdam in 1966

Just-in-time flexibility is exercised when there is most need for it. This type of flexibility requires careful monitoring of the environment. It is cost-effective, there is no wastage of resources, especially if the system is adaptive, and in times of high volatility this type of flexibility is most desirable. Mulberry Harbour was constructed in 1944 in Normandy. It was a flexible port that could be taken anywhere, up-anchored and removed to another site if necessary. Due to its ability to be reconfigured, it could deal with both military and civilian vessels. This represents just-in-time flexibility. The mobility, flexibility, and versatility that were the themes of Mulberry have not been perpetuated in any noticeable measure (Bellis, 1990).

The Charleston coal terminal was built during the 1979-1981 coal crisis. Even though the Master Plan did envision an ultimate 'super' facility, the coal company chose a staged approach involving a small initial investment. The subsequent stages were to be implemented only if the business volume developed. When the coal crisis subsided, Charleston emerged as one of the few ports without a huge debt (Yu, 1989). Just-in-time flexibility with an eye on basic economics and rapidly changing needs proved to be invaluable.
Clearly, flexibility that can be exercised on demand is most desirable.

4.4 A framework for flexibility

4.4.1 The port as a three-layer infra system

Figure 4.6: Three-layer inframodel of a port

We will now propose a useful framework within which to identify and incorporate flexibility in port infrastructure systems. Unlike some other systems, a port has a well-defined physical network structure, and physical goods flow through the links and nodes in the system. Some of these nodes are active where the physical good is processed, changed or converted (e.g. oil refineries or distribution centres), and the others are passive where only buffering or (re-)routing takes place (e.g. bulk or container terminals or nautical infrastructure), or it is transferred to other modalities. Figure 4.6 based on Herder et al. (2008), depicts the port as a three-layer infrastructure model (inframodel). The model distinguishes three generic layers: a physical infrastructure layer, an operational layer, and a services layer. The distinction among the layers is based on functionality, with the lower layers providing the conditions necessary for the existence and proper functioning of the higher layers. Each layer comprises physical, technical, operational, and institutional components, as well as actors and their interactions. The (overlapping) boundaries of the three layers showing various actors, is shown in Figure 4.7. A description of the three layers follows.

The bottom layer covers the physical infrastructure including the basic infrastructure, superstructure, and the equipment (Table 3.1). The processes in this layer deal with the planning, design, construction and maintenance, and are carried out by the port

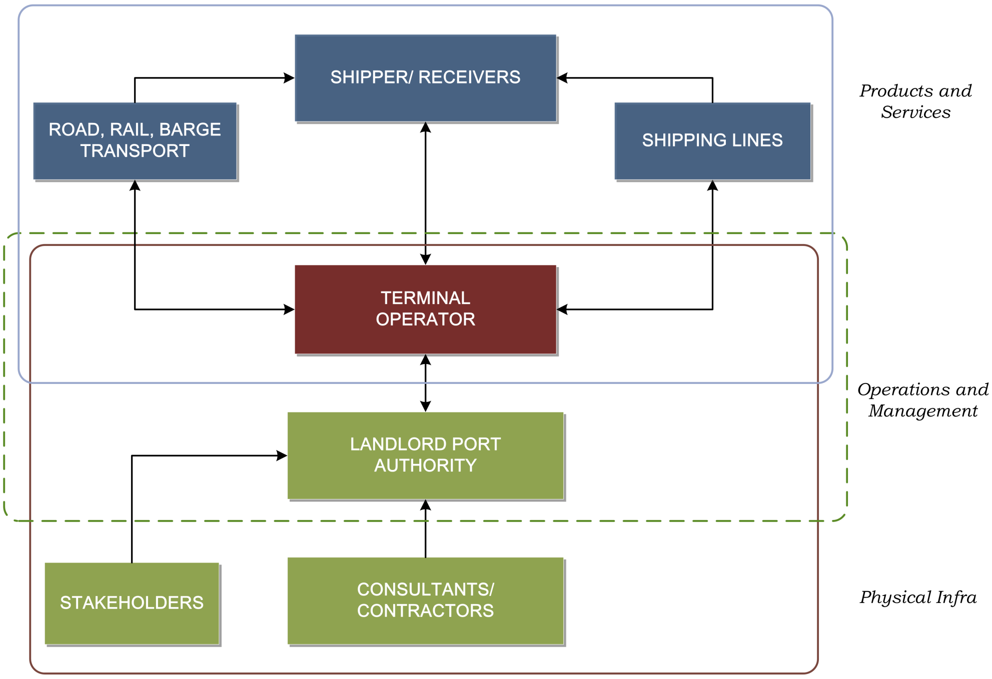


Figure 4.7: Main actors in the three layer inframodel

owner or terminal operator, planners, designer, project commissioners, contractors, etc. The scale of the physical infrastructure is enormous, with many vulnerable points that can disrupt the entire transport chain. The landlord function of the port authority requires it to build port infrastructure, find sources of finance, and take responsibility for sustainable land use.

The services provided by a port include access, protection, and vessel traffic management for ships; nautical services such as pilotage, towage, and mooring; and terminal services which include the physical transfer of goods and passengers between sea and land, storage of cargo, and transfer of cargo to other modalities. Ports also provide repair services, estate management and information management services (World Bank, 2007) in addition to providing space for industry and other value-added activities. The privatisation processes in most European ports have almost completely brought cargo handling services in the hands of private operators who manage their own terminals at one or more ports.

The *second layer*, which includes the operations and management processes, interacts closely with the maritime network and the intermodal transport network. The logistics activities such as network control, capacity management, and workforce scheduling and routing on the network assign capacity to various service providers acting in the top layer, which deal with supply and use of infrastructure-based products and services. These service providers include the transporters, shipping agents, freight forwarders, and logistic service providers. The process of delivery of the cargo to the customer involves various modalities, with actors such as railway companies, inland barge operators, and trucking companies. The market-driven trend of third-party logistics (3PL) and fourth-party logistics (4PL) involves outsourcing logistics, i.e., transportation, warehousing, and distribution functions. (The essential difference between the two is, that while a 3PL provider targets one function, a 4PL provider manages the complete process for the customer.) The extent of use of information and communication technology in the middle layer varies among ports.

In the *top layer*, the nature of service, as well as the service level can vary. The service level for container shipping lines is defined by factors such as handling costs, port dues, berthing capacity, cargo handling and storage capacity, ship services, and hinterland connections. As stated earlier, the regulation of the three layers depends upon the port organization. The Port Authority is responsible for ensuring safety and security of ship and cargo operations within the port as well as enforcing applicable laws and regulations in these and other fields such as environmental protection and labour regulations (Baird, 2000; De Monie, 2004). Verhoeven (2009) refers to these as controlling, surveillance and policing functions. The task of monitoring the implementation of concession agreements with private service providers (De Monie and Peeters, 2006), and the role of a coordinator and mediator between various stakeholders is also generally assumed by a port authority.

Each layer is subject to external influences which can include economic, technological, environmental, or regulatory changes. For instance, external organizations, at local, regional, national, and European level, can implement regulatory changes through their policies. Furthermore, in the prevailing volatile port environment, the roles of various actors are undergoing transformation (de Langen, 2004b; World Bank, 2007; Verhoeven, 2009). E.g., many global terminal operators nowadays, are connected to a liner shipping business, and the big question is if they will eventually develop complete global transport networks (World Bank, 2012).

As stated earlier, the inframodel can serve as a framework for identifying flexibility in the various layers of the model. Subsequently the outcomes of interest can be investigated due to the adaptations to the plan (Figure 2.16 in Section 2.4.3). This requires developing a model of the system of interest.

4.4.2 Desirable characteristics in each layer

The performance of each layer can be measured according to several performance attributes, using a variety of indicators. Some of the outcomes and their associated indicators are listed in Table 4.3. These performance attributes (defined in Section 4.3.1) represent public values to be safeguarded. An overall design requires an appropriate balance among various performance attributes, which entails trade-offs based on a lifecycle perspective. In addition, the requirements of sustainability, security, and safety apply to all layers. Fundamental characteristics such as flexibility and adaptability are also desirable in each layer. When incorporated in planning and design of infrastructures, in operations, planning, management and organization, or in products and services, these help to react to environmental uncertainty.

Table 4.3: Layers of the port system and desirable attributes

Layer	Performance attributes	Outcomes (performance indicators)
Physical Infrastructure	Accessibility	Degree of congestion (waiting time)
	Capacity	Degree of utilization
	Maintainability	Maintenance costs over lifetime
	Usability	Ease of use (efficiency)
Operations and management layer	Network capacity	Degree of utilization
	Reliability	Downtime
Product and services layer	Quality	Reliable service to users (service time)
	Affordability	Supply-chain costs
	Accessibility	Availability of port services (waiting time)
	Efficiency	Ratio of performance and resources

4.4.3 Flexibility available in each layer

Options, representing (a type of) flexibility in a system, are sometimes embedded in a project; at other times they have to be created and defined through strategic thinking, skilful negotiation, and wise investment decisions (Mauboussin, 2000). Infrastructure projects in general, permit integration of options that makes flexibility in function, use, and operation feasible. We go on to examine these at different levels of the inframodel. The options which have bearing upon the physical infrastructure, thus on the size, layout, or location are covered in the first layer. The managerial options relate to decisionmaking over infrastructures investments. Basically, three options are available to a manager:

– Seek alternatives to a new investment, e.g. increase efficiency in operations, generate capacity e.g. through forming alliances with neighbouring ports, or shape external influences which are coercing the need for new infrastructure,
– Invest in new infrastructure projects (thereby creating options to defer, abandon, scale-up, scale-down),
– Diversify into other activities (switch up/scope up).
Management generally possesses a degree of flexibility in decisionmaking (and can also incorporate mechanisms to permit this flexibility). For instance, it has the right, (and not the obligation) to do the following, all of which can increase the value of the project: effort to win information (over the project, project market, and procedures) through literature research, forecasts, surveys, theoretical and simulation models, model or prototype tests, and discussion with stakeholders and opponents.

In the second layer, consisting of operations and management, flexibility can be introduced in the organization, in procedures and practices (operations, customs) and regulations (labour, safety), in selection of clients/ operators, and in contracts with the terminal operator (concessions arrangements, demand guarantees, subsidies, penalties, incentives, port tariffs etc.). These mechanisms allow for responding to opportunities and change in circumstances. The terminal operator can exercise resource and schedul-

Table 4.4: Provision of flexibility in various layers

Layer	Sub-level		Flexibility
Layer 1	*Physical infra*		
	Provide flexibility in design and layout	-	provide reserves for expansion
		-	design robust infra.
		-	design flexible infra.
		-	design mobile infra.
	Decisionmaking related to physical	*infra*	
	Seek alternatives to project	-	do nothing
		-	increase efficiency
		-	influence policy
		-	shape demand (campaigns)
		-	diversify
	Start new project	-	invest
		-	abandon
		-	defer/phase/ speed up
	Plan (realize) new project	-	set up flexible specifications
		-	set up flexible selection criteria
		-	allow design alternatives during procurement
		-	set up flexible construction contracts
Layer 2	*Operations/procedures*		
	Institutional environment	-	set up a flexible organization
		-	set up flexible custom procedures
		-	set up flexible labour regulations
		-	set up flexible operating procedures
		-	set up flexible operating scale
	Project configuration	-	set up flexible specifications
		-	set up flexible selection criteria alternative
		-	apply for subsidies and exemptions
		-	include incentive- or penalty clauses
		-	handle risk through allocation & transfer or hedges & insurance
		-	involve financiers
		-	form partnerships with suppliers/contractors
		-	form alliances/coalition with operators
		-	form alliances/coalition with effected parties
	Concessions	-	set up flexible specifications
		-	set up flexible port tariff structure
		-	include demand guarantees
Layer 3	*Products and services*		
	Cargo	-	diversify as to cargo type
		-	scale expansion/new investment
	User	-	multi-user facilities
	Function	-	multi-functional facilities
	New function	-	manager/real estate developer

ing flexibility. Allocating resources in a flexible manner allows management to alter how the assets are used or deployed in the future. This is useful for hedging against risks and managing costs more effectively if the future does not turn out as expected. However, this operational flexibility is possible only at the cost of an optimal system.

Flexibility can be built into the procedures involved in the realization of new infrastructure. For example, requirements can be formulated at the level of output specifications and functional requirements, so that there is flexibility to be innovative and come up with 'satisficing'[1] solutions within the prescribed requirements. Similarly, flexibility can be built into the selection criteria for a contractor, or terms and conditions of a contract (e.g. demand guarantees, subsidies, incentives or penalties, risk insurance, hedges, collaborations, alliances), thus allowing participants to react to changes that could occur during the realization stage. Often, the managerial flexibility to change the course of a project (and increase its value), has to be sacrificed to maintain the continuity of a project.

In most infrastructure investments, deferment or staged investments are possible. Phasing of major capital investments allows taking advantage of new knowledge as uncertainty clears with time. An example is the pre-engineering phase, wherein environmental impact studies, geotechnical surveys, traffic volume analysis or market expectation studies are used to determine the viability of a project. Infrastructure projects are market or demand driven – in port projects, the demand refers to cargo or ship traffic, and in a real estate project, the demand could be for office or housing space. Such projects could be realized in phases, in response to development of demand. A project could be abandoned, expanded or contracted depending on demand shifts or switched to another cargo sector or function.

An infrastructure project involves long-term contracts with clients, financiers and construction contractors subject to uncertainty. In high-risk projects, various mechanisms are included to deal with such uncertainty to allow parties to react to unexpected events and to hedge against risks. These mechanisms can include cargo guarantees, revenue guarantees, company guarantees, partnerships, reduced payback period, etc. Governments often grant various forms of support for infrastructure projects, which may include a subsidy, a guarantee or even a direct capital contribution, which would add direct value to the project as well as indirect value by attracting investors. All of these represent options in a contractual package.

In the top layer, flexibility can be introduced in the type(s) of cargo and the scale of operations in response to customer demand, as well as the level of service offered (which includes customized service, responsiveness to unforeseen events or complaints). For instance, economics and demand can require flexible terminals which are able to accommodate a wide variety of cargo. Similarly, a low berth utilization rate at a single-user terminal can provide impetus for multi-user facilities. In other situations, congestion on a terminal can motivate setting up different service levels for various clients with regular clients getting priority. Diversification (opting for a new function in addition to the core function) or switching to cargo with the highest priced market also belongs in this layer. Similarly, non-core port services and the ancillary services can

[1]Satisficing (Simon, 1996) is a decisionmaking strategy that attempts to meet criteria for adequacy, rather than to identify an optimal solution.

be made flexible. The flexibility to implement practices that contribute to innovation in processes and products, and subsequently adoption of these innovations is essential and valuable at all three levels.

Table 4.4 illustrates the provision of flexibility in various layers of an infrastructure system. Many of these flexibilities qualify as real options as per the definition in Section 4.3.1.

Port systems are relatively well understood, since during capacity planning detailed models are often set up to further analyse the behaviour of the subsystems. A simplified approach, involving discussions with experts in the multiple disciplines that are a part of port engineering, can provide input for identifying flexibilities in the system. However, the application of generic methods for identifying flexible design opportunities 'in' complex engineering systems (Wang, 2005; Kalligeros, 2006; Suh, 2005; Bartolomei, 2007; Cardin, 2007) needs to be investigated. In addition, a focus on the macro scale, i.e. new flexible solutions, is also essential.

4.5 Identifying flexibilities in projects

Flexibilities embedded in projects are not implicitly recognized by organizations, since they do not form a part of standard methods, and real options thinking is not embedded in its culture. Therefore we present a questionnaire in Table 4.5 compiled on the basis of a literature study. This can help a project manager identify flexibilities in a project (Cardin et al., 2007; Kodukula and Papudesu, 2006). The use of this questionnaire is illustrated with an example in the next section.

An illustrative example
In the period 1996-1999, PoR formed a consortium with one of its clients Odfjell Terminals Rotterdam BV and some other firms, to investigate the innovative concept for storage of oil products in a quay wall. Besides the expected benefits due to multifunctionality, this would win (scarce) space in the existing port. After an initial economic evaluation, if the innovative alternative proved non-viable, a traditional quay wall with a single function of mooring ships would be constructed for the client. A lot of time, money, and research and engineering effort went into developing a technically feasible design concept.

Table 4.5: Questionnaire for identifying flexibilities in projects

Goal	Question
Seek alternative to the project	
Establish success criteria	- What is the success criterion with respect to this project?
Reduce uncertainty	- What are the sources of uncertainty in this project? - Can you shape this uncertainty? - Can you do research get more information on the uncertainties? - Can you insure or hedge against some of the risks? - Can you transfer risks to those that are most capable to manage them?
Identify managerial flexibilities	- Are the sources of uncertainty in this project private or market risks? - When will the uncertainty be resolved? - Is it advantageous to postpone decisions? - Can decision-making be phased? - Are there contingent decisions in the project? - Is there flexibility in changing project direction to maximize its value? - What is the investment cost in relation to the estimated payoff? - Will this project create other growth opportunities? - If so, is it possible to include their potential value in the business case? - What are the actions required to obtain or retain flexibility? - Can project be abandoned after the start and salvage value collected?
Identify design options	- Can some of the following be incorporated in the design? Modularity Adaptability to change functions Adaptability with reference to new technology
Identify operational flexibilities	- Can the processes/ operations be made flexible?
Identify functional flexibilities	- Is diversification possible? - Can the service level be adapted? - Can added value activities be undertaken? - Can non-core port activities be introduced?
Set up decision rules	- What are the actions required to change strategy? - What is the decision rule for changing strategy?

Table 4.6: ‘On’ options available in Odfjell project

Options	Type
Seek alternative	- Do nothing option - Build a traditional quay wall - Invest in a multi-functional quay wall
Reduce uncertainty	- Invest in a feasibility study of innovative infrastructure - Negotiate revenue guarantees with Odfjell
Identify flexibilities	- Introduce phasing and a go-no/go after the initial engineering phase - Form a collaboration and share risk - Create and lease extra capacity to another client, utilize economies of scale - Sell design concept to another client - Terminate collaboration - Sell assets/ share in projects (abandonment option) - Initiate arbitration process in case of breach of contract, claim compensation

However, this innovative design proved to be costly, and when the business case for various parties proved to be non-viable, the project was given a no-go. The traditional alternative was selected. Such a project has options embedded in it that can be exercised by the owner of the options, i.e., PoRA. An analysis of the project, based on Table 4.5 can be seen in Table 4.6. This project can create growth opportunities since the innovative multi-functional quay concept can be utilized at various locations and for numerous clients in the port, and save scarce space. In Chapter 7 we will suggest a quantitative as well as a qualitative approach for revealing these options to the management.

4.6 Conclusions

In this chapter, we have carried out a literature study pertaining to engineering systems design, which substantiates that flexibility is a suitable strategy for dealing with uncertainty. We have sought suitable definitions for a flexible, adaptable and robust port. A *flexible or adaptable port* 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 (which essentially means, to maintain, or even improve service levels, with little or no extra investment). A *robust port* has the ability to meet requirements under changed circumstances, without significant impact on the service level. We have also defined some terms related to provision of flexibility in an infrastructure system.

We have investigated strategic approaches to flexibility with respect to their timing and resulting efficiency. The term ‘real option’ has been introduced. An option is the right to carry out a strategic action, without the obligation to do so, now, or in the future, for a predetermined condition; and when applied to real systems and projects, options represent (a type of) flexibility in the system and are termed as real options.

These options can be physical (technical or managerial), procedural, organizational, or relate to the functions of the system, and can be translated into strategies for dealing with uncertainty. The strategies may range from developing new policies to exercising physical options in a system, or altering the project path.

We have presented the port system as a three-layer infrastructure system where the three layers are: the physical infrastructure, operation and management layer, and the product and services layer. After discussing the desirable characteristics of each layer, we explored possible flexibilities in each layer. A questionnaire for systematically identifying these flexibilities in a project has been formulated, and its use illustrated with an example.

Chapter 5

A framework for managing uncertainty

Make the plan ready for what lies around the corner – make it adaptive - D. Swanson, 2010.

5.1 Introduction

Having established that we need new planning approaches that can better account for uncertainty in the planning process, we present a framework known as Adaptive Port Planning (APP). This encompasses a new paradigm for the treatment of uncertainty. Instead of developing a static plan, this approach aims at developing plans that allow for change, learning, and adaptation over time based on new knowledge and changing circumstances.

Representatives of this paradigm are given by de Neufville (2000) and his Dynamic Strategic Planning approach, Walker et al. (2001) with his Adaptive Policy Making approach, Burghouwt (2007) with his Flexible Strategic Planning, and Kwakkel (2010) with his Adaptive Airport Strategic Planning approach. These approaches, which found their origin in airport masterplanning, all aim at making the plan more robust with respect to uncertainty about the future, although this capability is realized in different ways (Kwakkel, 2010). We also refer to Swanson et al. (2010) for a complete and concise history of adaptive policies and policymaking, beginning with the contribution of Dewey (1927) who put forth an argument in 1927, that "policies be treated as experiments, with the aim of promoting continual learning and adaptation in response to experience over time".

The value of the proposed approach lies in its wholehearted acceptance of, and its manner of dealing with, uncertainty. Thus, the methodology is not so much concerned with the description of various futures or the likelihood of their materializing (since we have only a limited control over them, anyway), but with formulating strategies and actions aimed at minimizing the chance that the plan fails. Therefore, an understanding of the plausible future changes in the world is an essential element of planning.

The proposed approach helps to produce an adaptive plan by assuming that the future is unknown. It prepares to take actions to prevent a predict-and-act plan from failing. It is a structured way of dealing with uncertainty in an existing plan through being adaptable and flexible and building capacity to adapt to change so that the objectives are achieved no matter what the future brings.

5.2 Adaptive Port Planning

5.2.1 APP Framework

The method proposed here has been derived from two methods, namely, Assumption-Based Planning (ABP) and Adaptive Policy Making (APM). Details about ABP can be found in Dewar et al. (1993) and Dewar (2002), and about APM in Kwakkel et al. (2010); Walker et al. (2012) and (Taneja et al., 2010c, 2011b). While ABP was developed in a military setting, APM, as the name suggests, aims to develop adaptive policies. ABP is essentially a post-planning tool which can be applied to make an existing plan robust, while APM is applied to create a new adaptive policy or a plan. APP has the advantage that it combines the two methods, and can be applied to a new or existing plan.

Additional steps have been introduced in the existing framework of APM to suit port planning needs. APP framework caters to short, medium, and long term planning needs. Consequently, it guides a planner to define a strategy in the first step, based on the the time horizon of the plan and the level of uncertainty. This includes selecting a forecasting method and a planning method as well as identification of alternatives.

In practice, port planning is primarily led by financial considerations. It involves decisionmaking at various stages based on a trade-offs between costs and resulting benefits. Moreover, introducing flexibility in a plan (as is the practice in APP) requires establishing its cost-effectiveness based on the probability of flexibility being utilized in the future. Therefore, additional steps, which deal with the incorporation of options and an estimation of their cost-effectiveness, and an overall evaluation of the alternatives defined in the first step, have been added to the framework.

Any port (or civil engineering) project, distinguishes two phases, namely, the design phase and the implementation phase. The design phase includes all the activities undertaken until the start of a project's implementation phase, which includes the realization phase and the exploitation phase. The exploitation phase begins after realization (construction) when the facilities are taken into use, and denotes the inflow of revenues. The realization phase can vary from a few months to a few years depending on the scale of the project, while the exploitation phase should ideally be as long as the technical lifetime of infrastructure[1]. The thinking underlying APP is that adaptation can be required at any time in response to triggers, and is an ongoing process. Thus, in

[1] Port infrastructures in use for 100 years or more are not uncommon, though it is very likely that the actual function has changed more than once during this period.

APP, no clear demarcation exists between the realization and the exploitation phases, which in fact overlap. Also, common experience is that a long gap can exist between decisionmaking and start of realization of a port project, therefore APP framework requires us to re-examine the assumptions underlying our plan.

Before elaborating on APP, we will define some relevant terms in the next section.

5.2.2 Definitions

A *plan* is a tentative solution to the inexact problems posed by an uncertain future. The *planning time horizon* is the farthest point out that a given planning effort would consider, and sets the limit of vulnerability of an assumption.
A *development* can be defined as an event or condition that: represents a change from today; is plausible within the planning horizon, and is related to the organisation and its plans. An *alternative*, which can refer to an alternative plan or a design, the prefix basic indicates that the alternative plan or design has not yet been made robust or adaptive. The process that we have called Adaptive Port Planning or APP, will result in an 'adaptive' plan, design, or policy.

The proposed adaptive approach for port planning combines ABP and APM, and though both approaches begin with looking for weaknesses in the plan, the terminology used is slightly different. ABP talks about assumptions underlying a plan.

- An *assumption* is an assertion about some characteristic of the world that underlies the current plan.
- A *critical (load-bearing) assumption* is an assumption whose failure would mean that the plan would not meet its objectives (i.e., would not be successful). An assumption is vulnerable if plausible events could cause it to fail within the expected lifetime of the plan.
- *Risk* associated with an assumption can be defined as the product of how serious the loss would be if the assumption failed and how likely it is to fail within the time horizon of the plan. Assumptions can be ranked in importance according to their risk.

APM uses the terms vulnerabilities and opportunities. These are developments that could affect the assumptions underlying the plan.

- *Vulnerabilities* are possible developments that can degrade the performance of a plan so that it is no longer successful.
- *Opportunities* are developments that can increase the success of the plan.

An assumption's likelihood of being negated, i.e., its vulnerability to change at some point in the future, depends on the length of time to that point, or the planning horizon. Without a planning time horizon, every assumption is vulnerable. With a predefined horizon, only those assumptions that could change within the horizon are vulnerable (Dewar et al., 1993).

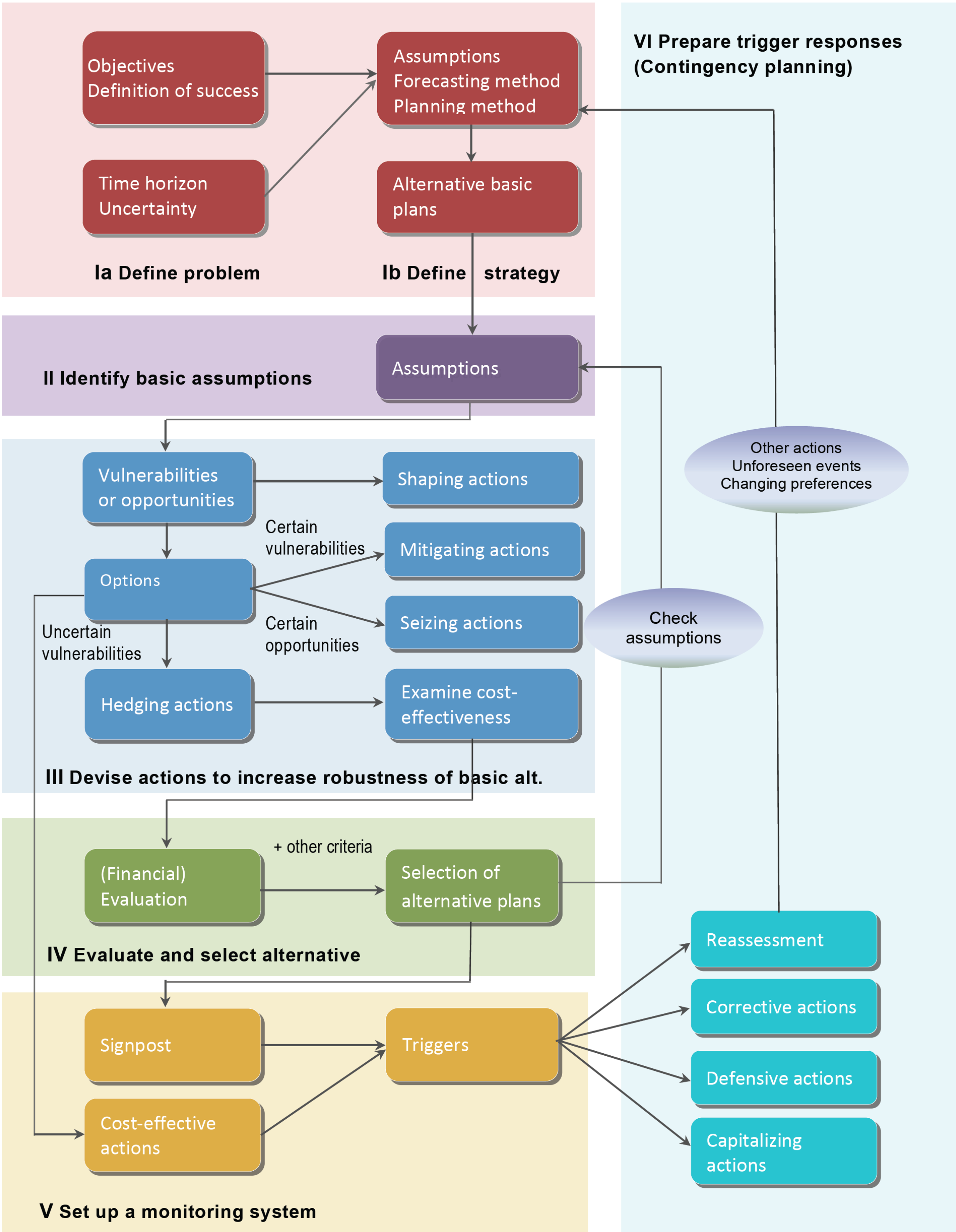


Figure 5.1: Steps in Adaptive Port Planning

5.2.3 Steps in Adaptive Port Planning

We can now proceed to discuss the six steps of the proposed approach known as Adaptive Port Planning. The various steps are illustrated in Figure 5.1 and explained below.

Step Ia Define the problem/project

This first step involves studying the objectives of the organization and the needs of the stakeholders in order to formulate the goals of the project. Based on this, a definition of success can be given, in terms of the specification of desired outcomes. This is required in order to be able to decide when the plan needs to be changed. The various constraints or boundary conditions, the available choices, and the underlying assumptions are identified next. During the realization phase of a project, success is measured in terms of three criteria: time, money, and quality. More often than not, the overall success of a project is measured on the basis of it meeting a predefined financial criterion, such as minimizing lifecycle costs or maximizing revenues. Even so, criteria related to system effectiveness, e.g., technical performance, availability, reliability etc. are specified, and need to be met.

Step Ib Define strategy and formulate alternatives

The strategy to be followed includes selecting a forecasting method, planning techniques and tools, as well as a financial evaluation method. The planning time horizon (short, middle or long) determines the choice of strategy. This distinction is arbitrary and determined not only by the project duration but also by the volatility of the environment during the planning horizon. A discussion of various planning strategies will follow in the next section. Once the project objective is defined, various alternatives can be formulated. In case of port projects these can relate to the various port layouts, infrastructure designs or the complete Master Plan. Scenarios play an important role in this step of APP. The alternatives are defined based on numerous assumptions, and as we will see, some of these are more significant than the others.

If our objective is to make an existing plan adaptive, then Step I is not required.

Step II Identify load-bearing and vulnerable assumptions underlying each alternative plan

In Step II, the load-bearing and vulnerable assumptions in the plan are identified. Identification of load-bearing assumptions requires an assessment of the consequences of failure of an assumption. Identification of vulnerable assumptions involves thinking about the future, for plausible developments that could occur in the lifetime of a plan and cause the plan to fail. If the development is in the favour of the plan, it is called an opportunity. Otherwise, the development is called a vulnerability. These vulnerabilities and opportunities are dealt with in subsequent steps. Dewar (2002) describes various techniques for carrying out Steps I and II.

Step III Increasing the flexibility and robustness of each alternative

In the third step of the process, the robustness of each alternative is increased. This step is based on specifying actions to be taken in response to the vulnerabilities and opportunities identified in Step II. There are two basic ways of preparing a plan for vulnerabilities and opportunities, either by taking actions now (in the planning and design phase), or by preparing actions in advance that can be taken in the future, if necessary. APP distinguishes between shaping, mitigating, hedging, or seizing actions to be prepared for each alternatives in Step III, or corrective, defensive, and capitalizing actions to be prepared for the selected alternative in Step V.

- *A shaping action* is an action taken now that is intended to affect the vulnerability of a critical assumption, either by reducing it or changing its nature; shaping actions work either to prevent a (threatening) development from taking place, or to steer events towards a preferred scenario. Of course, by far not all developments can be shaped and other actions are required, as discussed below.
- *A mitigating action* is an action taken in the current planning cycle to reduce the practically certain adverse effects of a plan;
- *A hedging action* is an action to spread or reduce the risk of highly uncertain adverse effects of a plan in the current planning cycle, and
- *A seizing action* is taken to seize available opportunities that are fairly certain.

Mitigating actions and hedging actions prepare the basic plan for potential adverse effects and in this way try to make the plan more robust. Seizing actions are actions taken now to change the plan in order to seize available opportunities. Defining hedging actions requires a visualization of potential impacts of an (often long term) development, which is where scenarios come into the picture. In contrast, shaping actions are pro-active and aim at affecting external forces in order to reduce the chances of negative outcomes, or to increase the chances of positive outcomes.

In this step, the options available in each alternative that can be translated into hedging actions to deal with uncertain vulnerabilities are also examined. Hedging actions are effective only if a vulnerability appears in the future, therefore it is important to establish their cost-effectiveness, especially if entailing high investments. During implementation, a flexible option can be translated into an action; this will be discussed in Step V.

Step IV Evaluate and select alternative

After actions to make the plan robust have been defined, and the options have been identified and incorporated in each alternative, we must compare the alternatives. The comparison of alternatives requires determining the effects of the alternative based on pre-defined criteria which depends upon the nature of the project. Cost being an important criteria in port projects, an economic analysis is always carried out. Often, a cost-benefit analysis which includes the future revenues an alternative can generate, and also its direct and indirect effects is carried out. The latter may be monetized or assessed qualitatively. Tools such as a Balanced Scorecard can add strategic non-financial performance measures to traditional financial metrics to give managers and executives a more 'balanced' view of organizational performance, thus supporting decisionmaking (Kaplan and Norton, 1992, 1993). The selection among alternatives is generally based on many criteria in combination with other considerations, often political or strategic. Investment appraisal for port projects will be the focus of Chapter 7.

Step V Set up monitoring system for the selected alternative

Even with actions taken in advance, there is still the need to monitor the performance of the selected alternative and take action if some of the assumptions are failing. This requires an identification of signposts. Signposts specify information that should be tracked in order to determine whether the plan is on course to achieving its success. The starting point for the identification of signposts is the definition of success specified in Step Ia. Critical values of signpost variables (triggers) are specified, beyond which actions should be taken to ensure that a plan keeps moving the system in the right direction and at a proper speed.

Step VI Contingency planning (preparing trigger responses) for the selected alternative

In this step, the plan, based on the selected alternative, is further enhanced by including adaptive elements. A contingency plan is a provision in the plan that specifies how a vulnerability will be handled, in case events or changes cause the vulnerability to appear. According to Chapman and Ward (1997), contingency plans reflect anticipated potential departures from the defined plans for a project. Contingency plans are alternative plans that can be used if the baseline plans are going wrong. They also point out that it is important to restrict the development of detailed contingency plans in order to reduce planning cost. These actions are prepared for in advance; most represent changes to the selected alternative. We can define four different types of actions that can be triggered by a signpost:

- *defensive actions (DA)* are actions taken after the fact to clarify the plan, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic plan unchanged;
- *corrective actions (CR)* are adjustments to the basic plan in response to specific triggers;
- *capitalizing actions (CP)* are actions taken after the fact to take advantage of opportunities that further improve the performance of the plan, and
- *reassessment (RE)* is a process to be initiated or restarted when the analysis and assumptions critical to the plan's success have clearly lost validity.

The measures to treat the uncertainties in Step III become a part of the scope of the project. The costs are also included in the project appraisal. The eventual costs that result from the risks that we are taking, are not included the project appraisal (except maybe in the contingency budget or the uncertainty reserve of a project). For example, extra container throughput in the event that a new shipping company decides to use a port, are not included in the demand forecasts. However, as a contingency measure, land reserves can be used to capitalize on this opportunity.

Many of the actions in this step are only possible if flexibilities have been designed into the plan in Step III. Putting reserve land to use in case demand increases, is a defensive action only possible if the land has been secured in Step III. A capitalizing action to adapt a berth for bigger ships is possible only if margins have been incorporated during design. This emphasizes the need to explore flexibility in each layer of the infra system during the planning phase.

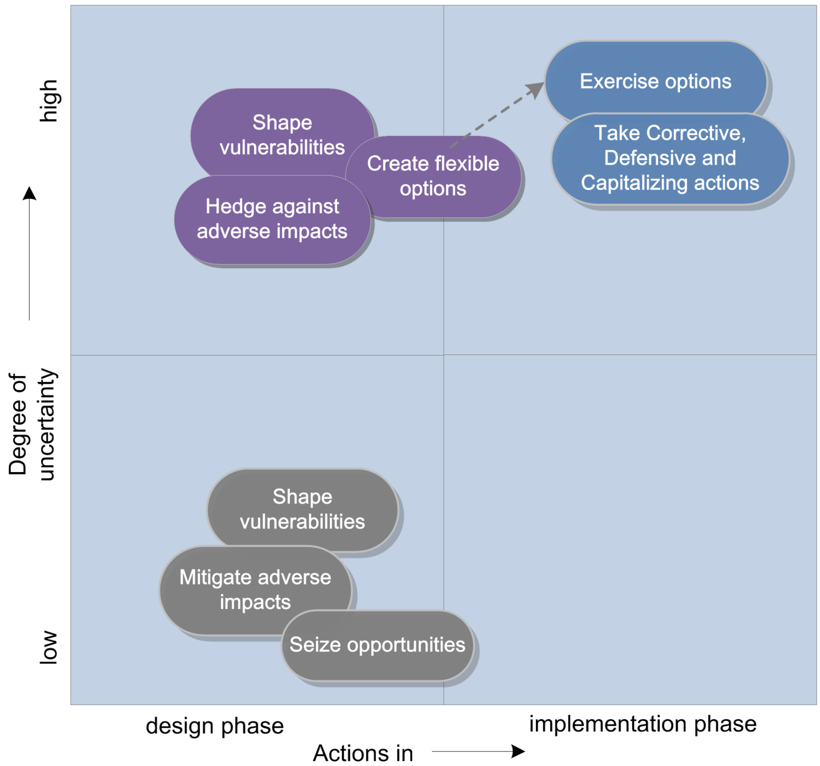


Figure 5.2: Possible actions as a function of degree of uncertainty in different phases

Next, we can go over to the implementation of the selected plan or design. Once the basic plan and additional actions are agreed upon, the final step involves implementing the entire plan. In this step, actions to be taken immediately (from Step III) are implemented and a monitoring system is established. After implementation of the initial mitigating, hedging, seizing, and shaping actions to make the plan robust, the adaptive planning process is suspended until a trigger event occurs. As long as the original plan objectives and constraints remain in place, the responses to a trigger event can have a defensive or corrective character – that is, they are adjustments to the plan that preserve its benefits or meet outside challenges. Sometimes, opportunities are identified by the monitoring system, triggering the implementation of capitalizing actions. Under some circumstances, neither defensive nor corrective actions might be sufficient to save the plan. In that case, the entire plan might have to be reassessed and substantially changed or even abandoned.

The assumptions or the vulnerabilities may have changed after the start of the process, APP is an iterative and continuous process. Depending on the planning needs (who is carrying out the planning, and what is their objective), and the chosen strategy (what is the planning horizon and what is the extent of uncertainty), certain steps can be omitted and the process simplified. For instance, in case of long-term planning, scenario planning takes over once the vulnerabilities have been identified in Step II (Figure 9.2 in Chapter 9).

Figure 5.2 is introduced to clarify the actions taken in various project phases as a function of degree of uncertainty. Cases will be introduced in Chapter 9 to illustrate different aspects and the versatility of APP.

5.2.4 Planning strategies

Table 5.1: Planning Strategies

	Short term	Medium term	Long term
Future (planning horizon)	(fairly) certain, level 1	Uncertain, level 2,3	Uncertain, level 4
Functional req.	Deterministic	Uncertain	Uncertain
Strategy	Predict and act	Adaptive Port Planning	Scenario planning
Forecasting	Single point forecasts with uncertainty margins	A few likely (relevant) scenarios that can be specified well enough	Comprehensive vulnerability analysis
Alternatives	Few alternative layouts or designs	Define alternatives within each scenario; focus on flexible and adaptable solutions	Define alternatives within each scenario; focus on flexible and adaptable solutions
Project appraisal	Deterministic business case/ decision tree analysis in addition to a MCA	Stochastic business case including real options	Qualitative evaluation of alternatives in each scenario to arrive at a robust solution
Outcome	Optimal plan for given assumptions	Adaptive plan robust in many scenarios	Plan with 'static robustness'

Various planning strategies (Step Ia), distinguished on the basis of the planning horizon are presented in Table 5.1 and discussed below.

Low uncertainty (single future)
This applies to a short term project, under the assumption that the system is stable, so that forecasting can be carried out based on the extrapolation of current trends. The management objective is clear, and in such a case, the traditional 'predict and act' planning approach is adequate. Numerous alternatives may well need to be examined. Sensitivity to the assumptions can be examined for each alternative. A deterministic business case, based on DCF method, will be sufficient to financially evaluate the alternatives. A multi-criteria analysis with weights determined on the basis of expert opinion will support decisionmaking to arrive at the 'best' solution. Even a low uncertainty project can fail to meet its objectives (measured generally in terms of time, money or quality) due to inadequate uncertainty considerations. When carried out within the framework of APP, planning is an iterative and continuous process in which regular updating and reassessment are included.

Medium uncertainty (multiple futures)
For a middle- to long-term project, scenarios of different futures need to be created (ranking the scenarios or assigning probabilities to them, however, is difficult). The first step is to identify the variables in the system. After defining the alternatives, a

range of probabilities are assigned to the selected variables through expert opinion, thereby reducing it to a case of level 2 uncertainty. This creates multiple scenarios for each alternative. The chosen alternative should perform well under all scenarios, i.e., it should be a robust solution. A stochastic business case, in combination with other criteria, can be employed to select among the alternatives. The analysis should be repeated for a range of values of the decision variable or value parameter, thereby testing the sensitivity of the outcome.

Deep uncertainty (multiple futures)
For a long-term project involving deep uncertainty, use of scenarios is to be recommended, even though we cannot attach probabilities to them. Scenario planning simplifies the avalanche of data into a limited number of possible states. Each scenario tells a story of how various elements might interact under certain conditions. A detailed and realistic narrative can direct your attention to aspects you would otherwise overlook. Scenarios explore the joint impact of various uncertainties. The objective is to see the world in terms of trends and uncertainties (Schoemaker, 1995).

Having identified a set of plausible scenarios, 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.

Unknown future:
In addition to precaution and diversification, literature suggest three ways for dealing with an unknown future (see for example, Leusink and Zanting (2009)):

- resistance, i.e., plan for the worst conceivable case or future situation
- resilience, i.e., whatever happens in the future, make sure that you have a plan that will result in the system recovering quickly
- adaptive robustness, i.e., prepare to change the plan, in case conditions change. Flexible solutions are recommended

In situations which emerge immediately after major technological, or legislative upheaval, actions to shape the market and drive it towards a more stable and favorable outcome are to be advocated, since no one necessarily knows the best strategy,

5.2.5 Comparison of traditional and adaptive planning

A comparison of Masterplanning and adaptive planning approach can be seen in Table 5.2, the table is self explanatory. It is important to point out that APP rests on the assumption that the management is adaptive, the structure and the procedures of the) organization responsible for implementing the plan is adaptive.

Table 5.2: Comparison of the Masterplanning and Adaptive Planning approaches

	Traditional approach to Masterplanning	Adaptive Planning approach
Treatment of the future	Assumes it is useful and possible to predict the future	Assumes that the future cannot be predicted, or it is dangerous to try do so
Treatment of uncertainties	Uncertainty is included in the scenarios, but planning is eventually based on single point forecasts	Imagines Black Swans and prepares for them
Planning process	Static or at most periodic	Continuous
Embedded options	Single option	Multiple embedded options make the plan dynamic
Focus	On demand forecasts	On vulnerabilities and opportunities
Approach	Target oriented	Performance oriented (thus, flexible and integrated)
Reactivity	Ad-hoc reaction to strong signals	Monitors and reacts to predefined triggers (mostly performance indicators)
Decision-making	Decisions are based on available information	Decisions are based on acquiring new information and evaluating new developments
Solution space	Limited to physical and operational space	Looks further, to shape the external environment by altering the industry structure, creating associations, and restructuring relationships

5.2.6 Some remarks

Mitigating, hedging and shaping actions

We highlight the differences between various types of actions in the APP framework through citing examples from the port sector.
It is fairly certain that the accessibility of PoR will be endangered when MV2 is in operation. In the framework of Transumo A15-project, the construction of Blankenburg tunnel to divert traffic from the A15 express way, and realization of container transferiums inland to facilitate modal shift to inland shipping (te Lindert, 2009), exemplify mitigating actions.

An uncertain vulnerability for PoR is closing down of the refineries situated here (when this will take place is uncertain). A hedging action would be to define new profitable functions for the land that will become vacant, thus avoiding the adverse impact of this development and seizing the opportunity for entering a new market.

Generally, larger organizations are capable of influencing external developments, e.g. a large port such as PoR can influence the Dutch government as well as European organizations such as ESPO, and can shape maritime policies, while a smaller port cannot. For instance, if EU decides to limit the maximum length of a container that can be hauled by road transport resulting in more truck movements to transport the same volume of cargo – PoRA can try to shape such an action. Through seeking intensive partnerships with the Municipality of Rotterdam and the DCMR environmental agency, PoRA can make the legal permit procedures more amenable, thus shaping an attractive business climate for investors.

APP and project contracting

Though outside the scope of the dissertation, for the sake of completeness, it is useful to discuss how APP can be aligned with contracting of port development projects. In case of traditionally executed civil engineering projects, following the planning phase, and before the realization phase, is an essential step when the the work specifications are created, a contract is drawn up, the tender is set on the market, and a contractor assigned to carry out the construction activities. In case another form of contracting

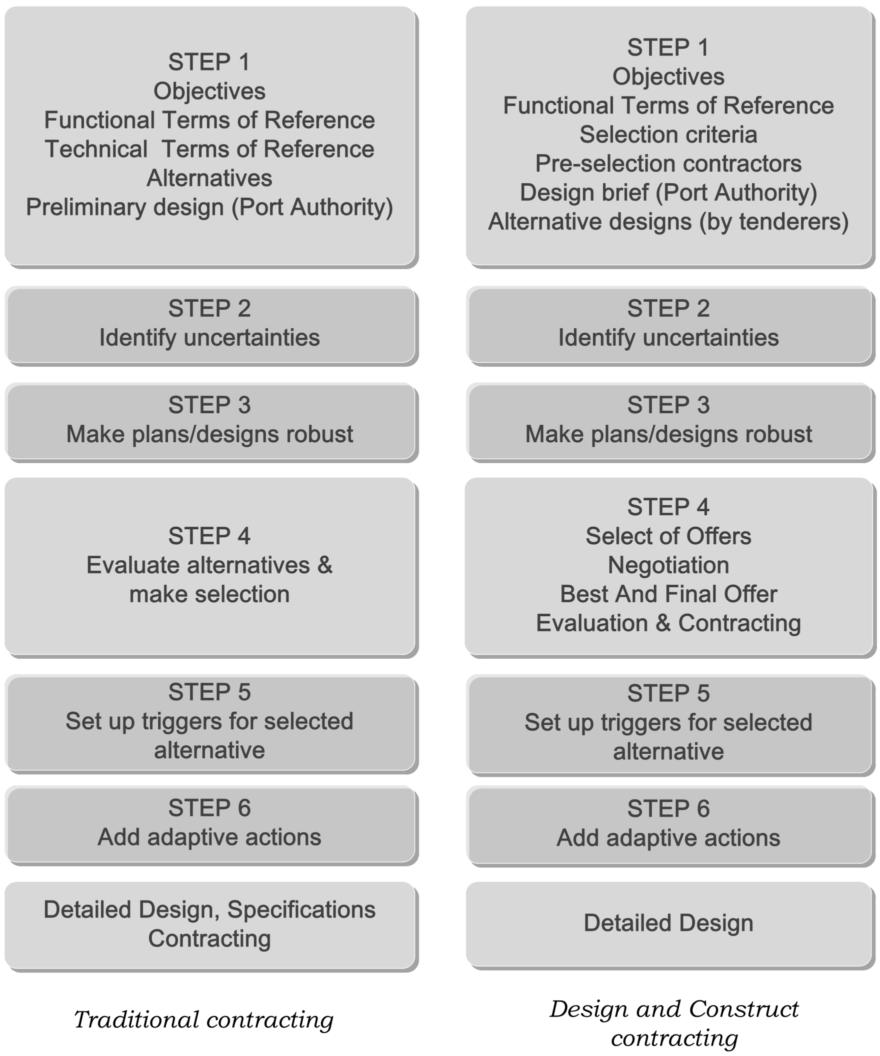


Figure 5.3: Steps in APP (traditional and Design & Construct contract)

is selected, the procedure is different. Currently, the realization of complex civil engineering projects is often arranged through Design and Construct contracts, whereby both activities are delegated to one single contractor. After a pre-selection, the contractors carry out the design activities based on a design brief drawn up by the port authority which consists of schematic drawings and general specifications of the works, the performance criteria for the works when completed; site information, and any other technical details which impinge on the works which are to be constructed. The tenderers with the best offers are invited to enter the negotiation phase, after which they prepare their best-and-final-offer (BAFO), which comprises four parts: general, technical, financial, and maintenance. An evaluation is carried out to verify that the solution offered meets the terms of requirements.

Ideally, a port authority will ask the tenderer to carry out his activities in the framework of APP, i.e., add adaptive actions to his plans, so that these can be included in the bid. He will also specify flexibility as a governing design criteria. The negotiation phase provides another opportunity to discuss these aspects before submission of the final offer. Figure 5.3 shows steps in APP for a traditional contracting procedure as well as a Design and Construct contract. Who should carry out the tasks of monitoring during the implementation phase is also complicated, a possibility would be to assign it to the party carrying out the maintenance. The port authority, as the budget holder could then determine when, and which of the already prepared actions should be implemented.

5.3 Tools and techniques for APP

APP makes use of a variety of tools and techniques in the context of a generic framework. Some of the well-known tools employed during various steps of APP are listed in Table 5.3. A few of these methods are handled here, while others have been discussed in relevant chapters. Some have been applied during the case-studies in Chapter 9. Many other methods are available, and can be selected based on their suitability for a specific situation or planning objective.

5.3.1 Brainstorm sessions

Brainstorming is a popular approach for encouraging practical innovations in an organization (Osborn, 1963). Such a session is based around a central theme. The participants are theorists, practitioners, and if possible, management. Ideas are generated, subsequently graded by the participants, and only a few survive. Most of the surviving ideas make incremental contributions to the field, and on a rare occasion, there is a break-through contribution. An important step within APP is to identify the (relevant) developments that could plausibly happen within the horizon. And, in order to figure out when an assumption can fail, how well this can be foreseen, or how much time will be required for an action associated with a vulnerability to be realized, brainstorm sessions can be organized to gather valuable inputs in an efficient

Table 5.3: Tools and techniques in various steps of APP

Step of APP	Objective	Methods/tools
Step Ia	Defining objectives (criteria and constraints)	Client sessions, Multi-stakeholder analysis, Expert analysis, Trend analysis, SWOT analysis
Step Ib	Generating alternatives	Brainstorm sessions with experts, Focus groups, Delphi, Scenarios
Step Ib	Selecting a set of alternatives	Cost-estimation tools, Trade-off studies, Multi-criteria Analysis
Step II	Identifying vulnerabilities and opportunities	Brainstorm (with multi-stakeholders), Scenarios, Focus groups, Delphi, Technological forecasting
Step III	Identifying flexibilities and defining actions to make the plan robust	Brainstorm (with multi-stakeholders), Scenarios, Focus groups, Delphi, Experts, Modelling and simulation exercises
Step III	Establishing cost-effectiveness of actions	DCF, DTA, Simulations, ROA, CBA, simulation model of physical performance
Step IV	Evaluating alternatives	Lifecycle costing, Multi-criteria analysis, Robust Decision Making, Scenarios using qualitative methods or EMA, Financial technique such as DCF, DTA, Simulations, ROA, CBA
Step V	Monitoring: Identifying trends	Media scanning, Delphi, Expert panels, Focus groups, S-curve analysis, Imaging, Actor analysis, Competitor watch, Time series analysis
Step VI	Contingency planning: Defining actions	See steps III and IV

manner. Similarly devising actions to deal with uncertainty requires brainstorming among experts.

5.3.2 Scenario based approach

Scenario planning is a means for preparing for the future (van der Heijden, 1996; Schwartz, 1991; Coates, 2000; Lempert et al., 2003; Goodwin and Wright, 2010). A typical scenario includes a representation of the initial situation and a storyline that describes the key driving forces and the changes that provide an image of the future (EEA, 2011). According to Walker et al. (2012), the benefits from using scenarios in long-term planning are threefold. First, it helps us to deal with situations in which there are many sources of uncertainty. Second, it allows us to examine the 'what ifs' related to scenario uncertainties. It suggests ways in which the system could change in the future and allows us to examine the implications of these changes. Finally, scenarios provide a way to explore the implications of uncertainty by identifying possible future problems, and identifying (static) robust strategies for dealing with the problems.

Scenarios allow for profound stakeholder participation, enabling the representation of conflicting opinions and world views. Scenarios have the potential to raise awareness of uncertainties, make risk more transparent, enhance resilience, break barriers to thinking about the future, challenge prevailing mind sets, enrich debate, and widen strategic conversation. They can include elements, such as potential discontinuities, that cannot be formally modelled (Schwartz, 1991; Coates, 2000; Lempert et al., 2003).

CPB has developed scenarios since the 1980s. They have been used to analyse strategic, long-term decisions on infrastructure projects and impacts of environmental policies. The use of scenarios, used for forecasting (within a broad meaning of the term), is on the increase specially for very long term, when there is no substantial historical data, and many correlations exist among the key variables. They are also used for developing hedging actions and other strategies.

Companies that face strategic investment decisions in new technologies or new emerging markets, develop scenarios to think through their decisions in different futures. They are of a crucial practical importance for public policy, management and strategic thinking in general: any premeditated significant action has to be preceded by such a thought experiment that anticipates the possibility of its outcomes and its implications (Aligica, 2005).

Riley (2010) recommends the use of scenario-based strategic planning for the United States Army Corps of Engineers stating that the Corps needs to shape its future pro-actively and adaptively, and anticipate the unforeseen, rather than just reacting, within a highly uncertain environment. Nevertheless, certain drawbacks have been cited in the literature over scenarios and scenario planning. We discuss these below, and show that, when combined with APP, or the thinking behind APP, and used in combination with the state of the art techniques, many of these drawbacks can be removed.

- *A factor in strategic planning has been the passion for three or at most five scenarios. This best, worst, most likely model of the use of scenarios is deficient not only in regard to the tendency to drive toward accepting the middle, but it misses the point that alternative futures are real possibilities (Coates, 2000):*

  Fortunately most practitioners recognize the dangers of arbitrarily picking a (too) limited set of scenarios. Secondly, barring black swan events, the uncertainty of the future can be appraised through a usually very limited number of scenarios within the field of probables. Experience shows that a third or less of the total possible scenarios represents 80% of the field of probables (Byl, 2002). Thirdly, if probabilistic methods are used in combination with scenarios, or techniques such as Exploratory Modelling and Analysis (EMA) are employed, a wide range of scenarios can be generated and included during planning.

– *The likelihood of a scenario is subjective and differs among scientists and policymakers:*

  APP acknowledges that in case of middle or deep uncertainty, the likelihood of a scenario is not known. We need to research all the potential outcomes, not try to guess which is the likeliest to occur (Grubler and Nakicenovic, 2001). Instead of resorting to guess work, we can make a plan that is robust across all futures that may lie ahead.

– *Many authors mention using a normative or goal-oriented scenario (Coates, 2000), defined as a scenario that one ultimately wants to get to and the strategies needed to do so:*

  In view of future uncertainties that are outside our control, devising only strategies to achieve the 'desirable scenario' may not be altogether wise. The focus should be on robust strategies.

– *Some studies suggest that the scenario approach may fail to deliver its promise because, generally, surprise is excluded from the scenario analysis. It does not help if scenarios are too risk averse, or portray the most likely future, or if they are mere variations on a current theme (Zeisler and Harris, 2000), or ignore the scenario-spoiling 'wild cards' of low-possibility futures (Marien, 2002):*

  It is possible to include discontinuities (van Notten et al., 2005) and create extreme scenarios. Subsequently cost-effective actions can be designed in the framework of APP.

– *Scenario approaches leave a gap between insight and actionable steps:*

  Although scenarios and the insights offered by them are valuable, they do not always suggest concrete actions to mitigate the impact of negative scenarios as they emerge. By the time signals point to which scenario is emerging, it is often too late to do much about it (van Putten and MacMillan, 2009). This drawback can be removed if scenario planning is practised in the framework of Adaptive Port Planning, which systematically guides planning into implementation.

5.3.3 Probabilistic approaches

Among other tools, APP uses tools that employ a probabilistic approach. This involves assigning probability distributions to many of the uncertain parameters in the system model, either from empirical data or through eliciting expert opinion. Thereafter, through simulations, an uncertainty range of outcomes with the corresponding likelihoods can be generated to support decisionmaking. The advocates of the scenario approach object to use of probability distributions, stating that the concept of probability, which is used in natural science, should not be imposed on the social sciences, because no independent observations and no repeated experiments can be made on future outcomes. The scenario approach, unlike the probabilistic approach (see Table 5.4) explicitly takes into account the 'what if-then' relationships between the scenario driving forces with the outcomes of interest (Agusdinata, 2008). Probabilistic approaches for evaluation include decision trees, scenarios and simulations (Damodaran, 2011); these will be discussed in Chapter 7.

Table 5.4: Probabilistic and Scenario approaches

Item	Scenario approach	Probabilistic approach
Types and number of uncertainties	Focus on key uncertainties	Can include all uncertain variables
Handling of uncertainties	Vivid description of futures around key uncertainties	Uses historical data or expert opinion to turn uncertainties into probabilities
	Based on what if-then relationships	Not based on reasoning. In case of conflicts averages are used
Strategies	Robust strategies	Robust strategies
	Path dependent, easy to relate to adaptive response strategies due to its qualitative approach	Less easy to relate to a specific strategy

5.3.4 Exploratory Modelling and Analysis

Exploratory Modelling and Analysis (EMA) is a technique for analyzing the behaviour of a system facing deep uncertainty. It employs the computational power of computers to create a large ensemble of plausible future scenarios, and then uses computer visualization and search techniques to extract information from this ensemble of scenarios that is useful in distinguishing among alternative decision choices (Lempert et al., 2003; Agusdinata, 2008). While performing computational experiments and calculating model outcomes across a large ensemble of plausible system representations, it takes into account uncertainty in the external scenarios, model parameters, and model structural uncertainty. EMA is useful when an overall insight is needed that can provide a summary of how the system behaves across the entire uncertainty and policy space. Even so, handling and visualizing a great amount of information is a major challenge (Agusdinata, 2008).

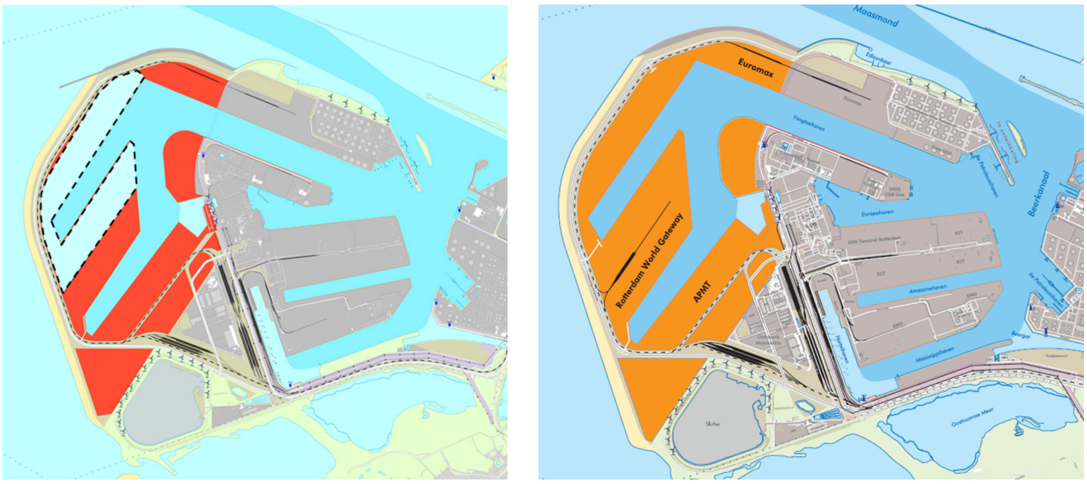
Some evaluation methods to be applied in Steps III and IV will be dealt with in Chapter 7.

5.4 APP applied to port expansion project MV2

5.4.1 Background

Project description

The port of Rotterdam, the largest port in Europe and the world's tenth-largest container port (2010), has almost reached its limits in terms of space. In the existing port and industrial area, there is hardly any room left for new companies and existing clients wishing to expand. The MV2 project, an expansion of the existing PoR into the North Sea, is a venture of the Port Authority. The planning for the project was started in 1993, the land reclamation began in September 2008, and the first ship is planned for 2013. The construction will be carried out in phases, and it is only in 2033 that MV2 will be fully operational.



(a) Master Plan MV2 (phase 1 in red)

(b) MV2 in 2033

Figure 5.4: Layout Maasvlakte 2 project

The Master Plan and Business Case

The Master Plan of MV2, presented in Figures 5.4(a) and 5.4(b), has been drawn up on the basis of several assumptions, the most important of course being the projected port traffic and throughput volumes, which are determined by dynamic factors such as market forecasts, client demands, governmental policies as well as various technical, environmental, economic, financial, and social factors. The Master Plan seeks to allocate the land within the port to the various uses required, aiming at an optimized layout of the port and the port-land interface. Progressive insights as a result of the numerous research studies, regular updating of the market forecasts, input from the contractors and the future clients, have all led to revisions in the Master Plan. It has a central role in the project and forms the basis for tendering and execution of the construction work, taking care of the necessary procedural preparations, marketing MV2 in order to attract clients, thus assuring sufficient return on investments.

The MV2 project is a business case directed project. The business case forms, at every stage, the basis for determining the profitability of the project. If the realization of the desired profit is in danger, changes can be made in advance. Directing the project by means of the business case prevents the creation of sites that would later prove unprofitable. The major elements of this business case are: investments, costs or expenditures, and income or revenue. The Master Plan forms the basis for determining the investment at any stage of the project. The harbour dues, rental fees, and quay dues are the revenue sources for the Port Authority, while the operational costs are the overhead, maintenance costs, nautical services, and working capital. The Master Plan gets more detailed in every cycle as more information becomes available and the business case gets more real. The business case and the Master Plan are closely related and provide managers with the support they need to program the implementation of the overall strategic plan (PMR, 2008).

Objectives

The overall objective of the expansion of the port of Rotterdam through construction of MV2 is to reinforce the international competitive position of the port and industrial complex (and thereby help strengthen the economic structure of the city and region, thus contributing to the Dutch economy as a whole and contributing to a better residential and living environment in the region). With a total maritime container throughput of 40.1 million TEU in 2008 handled along a shoreline of 500 nautical miles, the Hamburg-Le Havre range (including ports such as Rotterdam, Hamburg, Antwerp, Bremerhaven, Le Havre, Zeebrugge, Amsterdam and Dunkirk) ranks among the busiest and most competitive container ranges in the world (Wiegmans et al., 2008).

Besides the Port Authority, the port has other stakeholders, including the terminal operators and/or shipping lines, shippers, trucks and barge operators and of course the whole community that is affected by the construction of MV2. The stakeholders have varied, and sometimes, conflicting objectives. Whereas the port authority is concerned mainly with the financial viability of the terminal, terminal operators also demand flexible space, adequate capacity of waterways, low operating and maintenance costs, reliable handling equipment, good rail and road access, and low land lease rates. The shipping lines demand fast vessel turnaround time, good berthing facilities, around the clock service, and low total costs.

Dealing with uncertainty

Flexibility has been a major goal in the port's masterplanning. The design and construction contract with the building consortium PUMA (firms Boskalis and Van Oord) gives it an enormous amount of freedom in how it carries out the project. As long as it fulfils the functional requirements, improvement in the design can be carried out after the contract had been signed. Moreover, flexibility in time is achieved by adapting the development of MV2 to the actual market demand, and phasing the implementation of plans. The Port Landlord model makes this possible. There will be still some demand risk exposure when it decides to proceed with each further stage of development. However, once leases have been signed with new terminal operators, the terminal operators will be on the front line and will have to cope with the demand risks, whereas the Port Authority will be protected to some extent from the short term vagaries of the markets (OECD, 2010). Not only does phasing provide possibility for adaptation, but provides more certainty about impact of certain actions (such as the functioning of the created marine reserve).

At the time the present Maasvlakte was conceived, transport via containers was not in the picture. During masterplanning for MV2, an awareness of uncertainty led to use of techniques such as scenario building, uncertainty and risk analysis (Rahman et al., 1999), trend-break analysis (RAND Europe, 1997), and computer-supported simulation gaming (Bekebrede and Mayer, 2006). These were used to gain insights into future developments and to anticipate the uncertainties associated with these developments.

This strategy of anticipation involves an effort towards preventing negative outcomes and can be effective in coping with known threats and problems, but becomes ineffective when uncertainty, dynamics, and volatility increase (Wildavsky, 1991). Under circumstances of deep uncertainty and large risks, robustness can be a successful management and decision strategy. A flexible plan can adapt to the changing conditions under which a port must operate. This approach aimed at 'planned adaptation', allows implementation of the plan to begin prior to the resolution of all the major uncertainties. Over time, when new information becomes available, the plan can be adapted to meet the new conditions.

5.4.2 Adaptive Port Planning

We will now illustrate how the proposed adaptive planning approach might be applied to the case study of the port expansion in Rotterdam. Many of the challenges and the solutions have been oversimplified in order to make the planned adaptation approach clear and understandable. This case deals only with the load bearing assumptions that could cause the existing Master Plan of MV2 to fail (it is assumed that the remaining uncertainties could be dealt with through simple measures and good management). The Master Plan is made adaptive through the application of APP. Since we deal with one plan (and not numerous alternatives), Step IV of the plan can be omitted. The remaining steps of the adaptive planning approach, discussed in Section 5.2, are now applied to the case study.

In Step Ia, we define what constitutes the Master Plan of the port expansion, the major constraints and boundary conditions to be kept in mind while applying the adaptive approach, the objective of the plan, and the definition of success. In Step Ib we define our strategy. Next, we describe a brainstorm session organized at PoR, to discuss the developments or the driving forces in the external environment that can adversely affect the plan by undermining certain assumptions during the lifetime of the project. This exercise helped to identify the load-bearing and vulnerable assumptions in the plan, and constitutes Step II of the adaptive planning approach. In Step III, we define actions that can be taken in the planning phase to make the plan flexible and robust. Step V involves implementing a monitoring system and the start of collection of signpost data. Step VI identifies future actions that can be triggered by the signposts, which can serve to protect the plan.

Step Ia: Define the project

The Master Plan for MV2 (version 3.2) is illustrated in Figure 5.4(a). Figure 5.4(b) shows the end situation in 2033, whereby 625 ha of space is reserved for container terminals, 210 ha for the chemical sector, and 165 ha for the distribution sector. Before the actual construction work began, 40% of MV2 was leased for container handling to the companies APMT, Rotterdam World Gateway, and Euromax. The location of the port expansion, the form of the external contour of the reclamation-area, the port entrance, and the orientation of the port basins, have all been determined after careful study. The west side of the Yangtzehaven is connected to the basin on the east side with a channel, on either sides of which, turning areas for the ships have been created.

The Master Plan, for the purpose of our study, comprises:

- the port layout and detailed drawings;
- associated documents, such as the zoning plan, the PKB (Key Planning Decision), various permits and technical standards;
- the MV2 business case and contracts with investors, clients, and contractors.

When applying adaptive planning to the Master Plan, a major constraint is that there is no possibility for drastic adaptations in the first phase of the Master Plan whereas the following phases give reasonable room to do so. (Although the Master Plan itself may not be adapted in phase I, ABP and APM use shaping actions to deal with uncertainty through reducing the vulnerability or altering the nature of the critical assumptions.)

Definition of Success

The objective of the Port Authority (with the port expansion MV2) can be stated as follows:
"to attract cargo flows for the deep sea-related container sector, the chemical industry and the distribution parks, by creating sufficient extra space, in a sustainable manner, directly on the North Sea, while providing high-quality service by handling cargo efficiently and maintaining standards of safety, cleanliness, and security".

This objective could be met if the port development (supply) can be coordinated with the market demand for the three market sectors (the deep sea container sector, the chemical industry, and distribution). This would be indicative of a viable business case, implying a safe return on investments for the investors. (To be more specific, the Port Authority has assumed in its business case an internal rate of return of at least 8.55% on their investment and a total cost of 2.9 billion euro; this amount represents the investment including contingencies for a price index based on 2006). Success of the business case (that is integrated with the Master Plan) is based on its assumptions on both the supply and demand side remaining valid, and uncertainties, if and when they manifest themselves, being adequately dealt with.

Step Ib is not relevant in this exercise, since we are making an existing Master Plan adaptive.

Major assumptions

Many of the assumptions are related to the current sate-of-the-art technology and the existing policies. The major assumptions in the Master Plan are related to:

- the vessel sizes;
- the choice of cargo sectors to be handled at MV2;
- the timing and volumes of market demand in the chosen market sectors (the deep sea-related container sector, the chemical industry, and distribution);
- the modal shift or the distribution of the hinterland cargo over the three modalities, road, rail and inland shipping;
- cargo handling concept (equipment and operations) at the quay;
- cargo handling concept (equipment and operations) in the yard or stacking area;
- user requirements (e.g. multi- user or dedicated terminal, shared or individual rail and barge service centres, sharing of equipment or not, value added activities or not), and
- the existing policies/ regulations with regard to standards of security and sustainability (that include, among others, the issues of nautical safety, port accessibility, emissions and noise pollution).

Step II: Identify load-bearing and vulnerable assumptions underlying each plan

As an aid towards identifying load-bearing, vulnerable assumptions in the existing Master Plan and subsequently improving its robustness and adaptability in the face of uncertainty, a brainstorm session was organized at PoR. The aim was of the session was to:

- obtain strategic insights into the major driving forces or developments in ports and the shipping industry;
- discuss the implications of these developments for MV2, and
- identify which of the developments could undermine the assumptions in the Master Plan for MV2.

The external developments that could undermine the assumptions in the Master Plan can be broadly listed under four categories: technology, market and economy, politics and legislation, and environment and society. These developments can influence the demand directly or undermine the other assumptions in the Master Plan. Among others, the planners and decisionmakers from PoR were invited to participate in the brainstorm session in order to construct relevant future scenarios and discuss plausible relevant developments. In addition to the experts, the participants also included generalists with a broad view. The session involved four steps:

- The participants were asked to list on paper, plausible future developments for each of the four categories listed above. These developments were not required to be limited to the port and shipping sector. The exact time horizon was not defined; the participants were asked to think in the long term. No probability scale was predefined for the exercise; as a result trend-break scenarios with low likelihood of occurrence as well as foreseeable trend developments appeared in the lists. (Trend scenarios assume that the future will, in all important aspects, be a continuation of the present and the recent past, while trend-break scenarios allow for structural changes in the system.) The developments could be positive or negative; what often seems to be a negative development at first may later prove to be one of hidden opportunity.

– These lists were then collected, and the large number of plausible developments was reduced to a manageable amount by sorting them into clusters. The developments that could be significant for MV2 were listed for each of the categories.

– The participants were then requested to list the possible implications of these developments for the port and the port expansion. This could help in evaluating if a particular development could lead to the failure of the plan in its lifetime.

– The list of impacts was further examined. The developments and the resulting vulnerabilities or opportunities, most likely to be significant for MV2, could subsequently be identified.

Table 5.5: Some vulnerabilities, and their key driving forces

Major driving forces	Vulnerabilities and opportunities
- Port expansion will lead to increased road transport and congestion on A15 highway, which is the major road linking the port to the hinterland - Depletion of fossil fuels - Increase in energy prices - Changing pattern of supply and demand of energy (newly emerging economies) - Geopolitical tensions between energy-importing and energy-producing countries - Shift toward renewable energy sources such as bio-fuels, wind, solar and nuclear energy	*Reduction of land side accessibility*
- Migration of activities to the west, far from the city - Demographic ageing - No workers in the port - Reduced tolerance for negative environmental impact - goes to the stock market	*Deterioration of city-port relationship*
- Vertical and horizontal integration in supply chains - Economy of scope as important as economy of scale - Focus on reliability and capacity in addition to costs - Discontinuous hinterland due to creation of transport corridors	*Changing port competition due to growing risks* and *uncertainties*

continued on next page

Table 5.5: *continued*

	Major driving forces	Vulnerabilities and opportunities
-	Increasing economic development leading to increasing consumption, e.g. in eastern Europe	*Container demand grows faster than forecast*
-	Increasing globalization (diversified market, globally networked production, flexibility of production and labour processes)	
-	Shifting of location of production centres to the west due to instability of low cost economies and increasing transportation costs	*Container demand grows slower than forecast*
-	Change in consumption patterns and customer preferences	
-	Protectionist measures	
-	Environmental constraints for sea transport, e.g., stricter controls by International Maritime Organization (IMO) and mandatory 100% container scanning lead to high costs	
-	Use of other trade routes, such as the silk route and Trans-Siberian railroad could mean loss of container traffic from the east	
-	EU requires equal distribution of containers for all ports in Hamburg-LeHavre range, thus no mainports	
-	National legislation becomes stricter than European legislation, leading to unfair competition	
-	Utilization of economies of scale	*Mega ships appear*
-	Innovation and new technologies in many disciplines makes mega ships technically and financially feasible	
-	Improved turnaround time for ships	*Increase in quay/ terminal productivity*
-	Innovation in equipment and transport	
-	Innovative handling concepts, direct transshipment to different modalities	
-	Improvement in communication and information technology (far reaching management and control of production and transport flows)	
-	Increasing focus on sustainability will demand a shift toward an environmental friendly form of transport	*Modal shift in favor of inland shipping*
-	Internalization of costs makes road transport costly, and transport by inland ships competitive	
-	Congestion on road and reduced port accessibility causes hazard for road safety	*Non-compliance with standards of sustainability, security and safety*
-	Increase in shipping traffic proves hazardous for nautical safety	
-	Increasing dependence on technology results in increasing vulnerability	
-	Low emission quotas specified in the contracts are exceeded	
-	Reduced container throughput	*MV2 must accommodate*

continued on next page

Table 5.5: *continued*

	Major driving forces	Vulnerabilities and opportunities
-	No container handling permitted on MV2 due to negative environmental impact	*other cargo sectors and activities*
-	No road transport permitted from the port	
-	Activity and industry from Waal- and Eemhaven area has to shift to MV2 to improve quality of the living environment	
-	MV2 must become 'energy port' for renewable energy as refineries and petrochemical industry disappears from the port	
-	PoR goes to the stock market and shareholders insist on space usage with high turnover	
-	European legislation takes market power from the port	

Table 5.6: Some wildcards and their impacts

Wildcards	Impacts
Container is replaced by 'mega-box' to utilize economies of scale	New equipment, handling methods, and transport logistics will require enormous investments
New generation container ships, smaller and faster, are designed to achieve greater flexibility	This will stimulate multi-porting instead of main-porting, and the resulting changes in distribution patterns would require new infrastructural investments
Sea level rises faster than expected	As temperatures and water levels rise, all efforts are geared to stopping further damage. Economy and trade suffer
Global climate change leads to extreme weather conditions and large tides, making entrance of ships via Maasmond and Yangtzehaven impossible	Ships will choose to call on other ports
Credit crisis	Access to credit is key to the survival of maritime trade and trade shrinks as the credit markets freeze
Disruption of the information systems controlling port flow	Even a tiny disruption of port operations will affect the entire supply chain
Closure of choke points such as Suez canal, Panama canal, or Strait of Malacca	Longer shipping routes will make sea-transport costly
Fossils fuels are exhausted	Trade and sea transport suffer due to political turmoil and increasing transport costs; production is regionalized
Terrorist attacks, cyber warfare, world conflict, unforeseeable social upheaval	Such events could leave the world in a state of shock and disarray, and with a depressed economy

continued on next page

Table 5.6: *continued*

Wildcards	Impacts
PoR is subject to far reaching European regulations	The competitive position of the port will be threatened

Table 5.5 gives a list of the major driving forces and the resulting vulnerabilities and opportunities, identified during the brainstorming session. Table 5.6 lists some trend-break developments that could have a significant impact on the Master Plan.

Step III: Increasing the flexibility and robustness of each alternative

As we have seen, the development of MV2 is complicated by the many diverse trends and developments, which present both vulnerabilities and opportunities. Some of these developments are relatively certain and others are uncertain. The Port Authority can add shaping and mitigating or hedging actions to the current Master Plan. Shaping actions can include promotional or marketing campaigns, tariff regulating strategies, use of concessions and incentives, new collaborations, uncertainty absorbing contracts with the clients, restructuring of vertical relationships with contractors or customers, and instituting new market mechanisms such as bidding and auctioning systems. Mitigating and hedging actions aim at reducing certain and uncertain adverse effects of a plan; this can be achieved by physical alteration to the Master Plan, changes in manner of operation, or diversification.

Certain developments

Some examples of relatively certain future developments (see Table 5.7) are increase in energy prices, reduction in land-side accessibility, deterioration of port-city relationship (unless actions are taken), and the changing nature of port competition (due to changing function of ports). The actions, in response to these vulnerabilities are listed in the table and discussed further in Section 5.4.3.

Table 5.7: Some Certain Vulnerabilities, and Responses to Them

Vulnerabilities and opportunities	Mitigation (M), Shaping (SH), and Seizing Actions (SZ)
Reduction of landside accessibility	SH: Invest in R&D into the landside accessibility in Rotterdam and neighbouring area and new transport alternatives SH: Use price strategies, internalize external costs in pricing of road transport to stimulate transport by rail and inland ships M: Invest in a network of container transferia, inland container depots (extended gates concept) M: More TEU per truck, night shifts for trucks, and improvement in cross border rail connections in Europe M: Invest in infrastructure for inland ships M: Stimulate transshipment M: Invest in underground infrastructure

continued on next page

Table 5.7: *continued*

Vulnerabilities and opportunities	Mitigation (M), Shaping (SH), and Seizing Actions (SZ)
Energy price rise in the long term	SH: Invest in R&D into cost-efficient renewable sources of energy
Deterioration of cityport relationship	SH: Improve living environment in the city SH: Attract new activities and stimulate economic renewal in the city area SH: Make the port attractive by stimulating recreational and multicultural activities
Changing port competition	SH: Invest (timely) in infrastructure and hinterland connections, investment in R&D SH: Offer integrated services and increased reliability and safety SH: Diversify, also in non-port-related activities increasing the capacity to absorb losses and cross-subsidize within the port SH: Assume role as facilitator in the supply chain

Table 5.8: Some Uncertain Vulnerabilities, and Responses to Them

	Hedging (H) and Shaping (SH) actions
Container demand grows faster than forecast	SH: Negotiate uncertainty absorbing contracts (additional income from the concessionaire) H: Invest in modular, interoperable infrastructure H: Invest in improving hinterland connections H: Adapt Master Plan
Container demand grows slower than forecast	SH: Stimulate promotional or marketing activities by PoR as well as the terminal operator SH: Negotiate uncertainty absorbing contracts (compensation by the concessionaire) H: Invest in modular/flexible infrastructure H: Spread risk by diversification into other cargo or non-port-related functions, such as real estate
Mega vessels appear (a): ships bigger than 12,500 TEU and smaller than 18,000 TEU, length more than 450 m)	SH: Competitive advantage for MV2, set up positive campaign, increase tariffs H: Define new nautical rules, reduce ship speed in basins for certain wind conditions and passing ships H: Reserve budget for dredging, bollards, fenders, bigger tugboats
Mega vessels appear (b): ships bigger than 18,000 TEU (draught less than 17.4 m; length more than 450 m)	SH: Set up negative campaign against mega ships, announce increased tariffs

continued on next page

Table 5.8: *continued*

		Hedging (H) and Shaping (SH) actions
	H:	Invest in R&D to study feasibility of ship size and nautical requirements
	H:	Re-evaluate Master Plan and redefine nautical rules
	H:	Invest in R&D to study implications and adapt Master Plan
Increase in quay and terminal productivity	SH:	Negotiate uncertainty absorbing contract with operator
	SH:	Terminal operator must invest in improving hinterland connections
	SH:	Invest in R&D to study implications
	H:	Adapt Master Plan to accommodate reduced demand for space
Modal shift in favor of inland shipping	SH:	Set up positive campaign to stimulate this development
	SH:	Invest in R&D to study implications for the Master Plan
	H:	Adapt Master Plan, provide additional facilities for inland ships
Non-compliance with standards of sustain-	SH:	Install monitoring systems
	H:	Impose penalties, fines, internalize external transport costs to discourage transport costs
ability, security, & safety	H:	Invest in road and underground transport infrastructure, widen waterways

Uncertain developments
Most of the identified developments are uncertain. The real challenge for the development of MV2 is presented by the uncertain vulnerabilities and opportunities. The timing and volume of demand, ships that will call at the port in the future, technological innovation leading to increased productivity, modal shift in favour of inland shipping, and non-compliance with standards of safety and security, are all vulnerabilities for the Master Plan. The vulnerability of other cargo sectors to be accommodated at MV2 than in the present Master Plan is treated further as a wildcard. Table 5.8 presents some of the hedging and shaping actions that can be taken now to handle these vulnerabilities. Further discussion follows in Section 5.4.3.

Step IV: Evaluate and select alternative

Step IV involving selection of alternatives is omitted.

Step V: Set up a monitoring system

Step V sets up the signpost monitoring system, specifies the triggers, and identifies the actions to be taken when trigger levels of the signposts are reached. Triggers are very often the performance indicators of an organization. No generic performance indicators exist for ports. However, the performance of seaports as a whole is traditionally assessed by comparing throughput, e.g. in terms of tonnage or number of containers handled, while port authority performance indicators measure berth or crane utilization, tonnage handling, and waiting times. In the case of stevedores, performance indicators include the number of vessels and cargo handled, the cargo handling rate, containers handled per crane, units per man/shift, number of employees, average hours worked per week. Shipping line performance indicators, on the other hand, are concerned with the possible delays: the average delay to vessel awaiting berths, the average delay alongside berths or non-productive time (Notteboom, 2003).

Table 5.9 shows the signposts to be set up for each of the vulnerabilities and opportunities presented in Table 5.8, and the possible responsive actions in case of trigger events. The numbers used as triggers are illustrative and need to be researched, as do the selected triggers. The tables are by no means complete and are intended only to illustrate the adaptive approach for dealing with uncertainty.

Table 5.9: Contingency Planning

Vulnerabilities and opportunities	Monitoring and trigger system (active from 2013 onwards)	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP)) to be taken in implementation phase
Container demand grows faster than forecast	Monitor throughput and number of ships	
	If demand increases by 25% take DA-action	DA: Use strategic land reserves and form strategic alliance with ports of Amsterdam and Antwerp
	If demand doubles, take CP-actions	CP: Speed up expansions
		CP: Invest in common transshipment hub for ports in Hamburg-LeHavre range at a strategic location
	If demand explodes, take RE-action	RE: Reassess next phase of Master Plan
Container demand grows slower than forecast	Monitor throughput	
	If throughput is less than half of forecast, take DA-actions	DA: Delay investments, and reduce tariffs
		DA: Diversify into other industries
	If throughput decreases below 30% take CR-action	CR: Cancel further expansions
	If demand fully breaks down, take RE-action	RE: Reassess entire Master Plan
Mega vessels appear (a): ships bigger than 12,500 TEU; smaller than 18,000 TEU appear (draught less than 17.4 m; length more than 450 m)	Monitor developments	

continued on next page

Table 5.9: *continued*

Vulnerabilities and opportunities	Monitoring and trigger system (active from 2013 onwards)	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP)) to be taken in implementation phase
	If no. of ships per year <10 take DA-action	DA: Define nautical rules with respect to wind, passing ships, turning circles, etc
	If no. of ships per year <30 CR-action	CR: Invest in bollards, fenders, bigger tugboats
	If no. of ships per year >30 take CP or RE action	CP: Adapt infrastructure to handle bigger ships
		RE: Reassess next phase of Master Plan
Mega vessels appear (b): Berthing or access for ships bigger than 18,000 TEU (draught approx. 18 m; length more than 450 m)	Monitor developments	
	If no. of ships per year <10 take DA-action	DA: Negotiate with Euromax phase 1 and adapt one berth to receive larger ships
	If no. of ships per year <30 take CR-actions	CR: Consider dredging of Eurogeul to increase tidal window; widen Yangtzehaven; adapt one berth for bigger sips and define nautical rules with respect to towage, turning, passing ships, etc.
	If no. of ships per year <50 take CP-action	CP: Consider common transshipment hub for ports in in Hamburg-LeHavre range at a strategic location
	If no. of ships per year =>50 take RE-action	RE: Reassess next phase of Master Plan
Mega vessels appear (c): Handling ships bigger than 18,000 TEU	Monitor developments	
	If no. of ships per year <10 take DA-actions	DA: Discuss terminal concept with operator
		DA: Offer reduced rates
	If no. of ships >50 take CR-action	CR: Terminal operator must invest in improving hinterland connections, e.g., in a network of inland container depots and container transferia
	If no. of ships per year >100 take RE-action	RE: Reassess next phase of Master Plan

continued on next page

Table 5.9: *continued*

Vulnerabilities and opportunities	Monitoring and trigger system (active from 2013 onwards)	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP)) to be taken in implementation phase
Increase in quay/terminal productivity	Terminal operator must give adequate warning over new terminal or logistic concept (if different from business case)	
	If productivity increases by 20% take DA-action	DA: Extra transport to hinterland not by road, only by inland shipping
	If productivity increases by 50% take CR-action	CR: Terminal operator must invest in improving hinterland connections and in network of inland container terminals and container transferia
	If productivity increases 40% take CR- and RE-action	RE: New agreement over profit sharing with terminal operator
		RE: Reassess next phase of Master Plan due to reduced demand for space
Modal shift in favour of inland shipping	Monitor modal split	
	If share for inland shipping >45% take CR-action	CR: Invest in berths for inland shipping
	If share for inland shipping >55% take RE-action	RE: Reassess next phase of Master Plan
Non-compliance with standards of sustainability, security and safety	Monitor shipping traffic, road and rail movements, emissions, noise, water quality, etc.	
	If standards are not met, take appropriate CR-action	CR: Penalties for the users

Step VI: Contingency planning for the selected alternative

This steps involves preparing defensive, corrective and capitalizing actions (see Table 5.9). The planning phase will be followed by an implementation phase, during which actions specified in Tables 5.7 and 5.8 under Step III, and the monitoring plan and contingency plan specified in Table 5.9 will be implemented. During implementation, the signposts might indicate for example, that a vulnerability of the plan has appeared in the form of increased or lowered demand, or that the norms established for safety, security, and the quality of the living environment have been violated. The actions specified in Table 5.9 would then be implemented.

The land reclamation for MV2 was started in September 2008, and in 2013 the first phase will be fully operational. Many of the actions proposed in Tables 5.7 and 5.8 are already being taken by the Port Authority and the literature pertaining to them

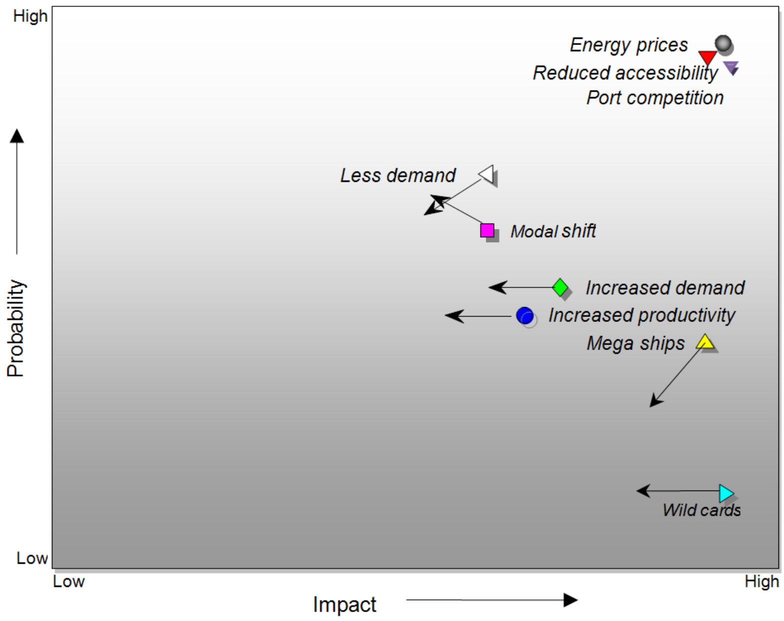


Figure 5.5: Impact-Probability (Risk) chart

can be found in the Environmental impact assessment documents (Projectorganisatie MV2, 2007).

5.4.3 Adaptive port plan

Impact-Probability chart

Risk mapping is a tool used by organizations for managing risks, through first prioritizing them, then deciding which of the risks should be addressed, and subsequently, allocating resources for dealing with them. In this section, we rank the uncertainties identified in Step II, on a impact-probability (risk) chart (Figure 5.5). Though the impacts of the vulnerabilities we have identified can be estimated in various ways, e.g. in terms of loss in the market share, reduction in service level, reduced returns etc., we assess the impacts of the uncertainties based on the adaptations required in the Master Plan. The assessment is purely qualitative. As can be seen, all the uncertainties have a (medium to) high impact on the plan. Further, the probabilities assigned to the vulnerabilities in this graph are purely for illustrative purposes. Nevertheless, the graph is useful for the subsequent discussion over how the actions proposed in Steps III and IV, for each of the vulnerabilities, can either lower their impact and/or decrease their likelihood. The direction of the arrow indicates if the probability and/or impact of the vulnerability can be reduced through the proposed actions.

(fairly) Certain developments

The fairly certain developments lie in the top half of the impact-probability chart. The vulnerabilities in this high-impact, high-probability zone need to be addressed.

Land side accessibility is a major vulnerability for the port and the situation will worsen with further development of the port. A shaping action for this vulnerability could be to invest in R&D into innovative solutions, and employ tactics that will make transport by inland ships competitive. Mitigations could be in form of new logistic concepts, such as a network of inland container depots and container transferia in the hinterland of the port, trucks that can transport more TEUs at one time, night shifts for road transporters, and improvement in cross border rail connections in Europe. Widening of the access road to the port, investment in infrastructure for inland ships and underground infrastructure (Oranje tunnel and Blankenburg tunnel) could also be possible mitigations.

Crude oil and natural gas prices will increase in the long term, due to growing demand and reduced supply, unless there is breakthrough in the area of alternative cost-efficient sources of energy. A shaping action, to invest in research and development of new technologies, will increase the chance of this happening, but offers no guarantees.

Deterioration of city-port relations can be prevented by improving the living environment in the city, and stimulating economic and recreational activities in the port and city area.

Wildcard or trend-break developments

Wildcards belong at the bottom right corner of the impact-probability chart. Sea level rise, global climate change, credit crisis, terrorist attacks, and policy changes, are all examples of wildcards. Wildcards can only be handled through contingency planning; specific strategies and actions to reduce their impact just in case they do occur is the closest we can come to handling these uncertain developments. Sometimes survival of the organization depends on handling these vulnerabilities. The great Hanshin earthquake that destroyed the Japanese port of Kobe on January 17, 1995 provides an excellent example of dealing effectively with a wildcard. At that time, Kobe was Japan's biggest international trade hub and a major production and logistics center. The global impact of closure of the port was mitigated by the fact that a large part of Kobe's business involved the handling of containers and that the container-handling infrastructure was relatively standardized in most Japanese ports. The diversion of container ships to the neighbouring ports was accomplished with relative ease and with minimal delays. The worst fears of the closure of Kobe paralyzing global trade did not materialize (Coulter, 2002).
Some wildcards, relevant for our case study, are listed in Table 5.6, but are not discussed further.

Uncertain developments

The uncertain vulnerabilities that we have identified are likely to have a medium to high impact on the plan, and the probability or the level of risk also varies between medium to high in Figure 5.5. In the planning phase, the available choices are to lower their impact through hedging actions or lower their probability through shaping actions. In the implementation phase, defensive, corrective and capitalizing actions will protect the plan.

 # Container demand grows faster or slower

The realization of MV2 is planned in stages. New port and industrial areas are created only when there are clients. The optimal condition would be if the market demand for each sector materializes exactly as envisaged in the business case and can be coordinated with the realization of new port areas. Any deviations will have an impact on the business case. However the timing (and volumes) of future market demand remains uncertain.

The capacity and design of the port's major facilities (such as the shipping channels, berths, equipment, storage areas, the internal road and rail connections and the hinterland connections) are dictated by the traffic forecasts. Increased demand (beyond the bandwidth defined to take into account the uncertainties) presents an opportunity and the contract with the terminal operator should allow the port to benefit from this development. However, unless adequate infrastructure and space is available, this development can lead to congestion in the terminal and in the hinterland, and reduced service. A shaping action would be to negotiate a contract that ensures income from this development.

A hedging action would be to plan modular terminals that are flexible and can be expanded or downsized. If demand increases, say by 25%, speeding up expansion plans and until that time using the strategic reserve space, and creating alliances with the neighbouring ports of Antwerp and Amsterdam, will reduce the adverse impacts of this development. If demand increases, say by 50%, the ports in the Hamburg Le-Havre range could invest in a common terminal at a strategic location. If the demand explodes, the plan would need reassessment.

In case of reduced demand, demand guarantee clauses in the contract with the terminal operator will safeguard the interests of the port authority. Shaping actions to attract cargo, such as lower tariffs or added service, could reduce the probability of this development. However, investment in modular and flexible infrastructure (also called building in physical options) easily up-scaled or down-sized, will make diversification into other cargo sectors and markets easier. Diversification in port and non-port related activities will make absorption of losses and cross-subsidization within the port easier. If demand is less than half of forecast, delay investments. If demand breaks down, reassess the entire Master Plan.

 # Mega vessels appear

Once the land has been reclaimed and the fixed infrastructure such as channels and basins created, the port must be able to accommodate future ships. As technology improves, ships size continues to evolve in order to utilize the economies of scale. Appearance of ships bigger than the ship size assumed in design of the port infrastructure poses a threat to the plan. PoR is via the Eurogeul and Maasgeul, accessible for ships with a draught up to 22.50 m, (though access for ships with a draught greater than 17.40 m is tide-related).

The largest design ship in design of MV2 is a 12,500 TEU ship with a length of 382 meter and draught of 17.0 m. On the basis of this design ship, a depth of NAP -20.0 meter will be provided for safe navigation and berthing. Research has established that ships with a length of 450 meter can carry out all manoeuvres, though under certain restriction over wind conditions, other shipping traffic, and speed. Thus, if ships in the range of Malacca-max with a length of 450 meter, a draught of up to 18.0 meter, and a capacity of up to approx. 18,000 TEU were to appear, the development would offer an opportunity for MV2. Redefining nautical rules and increasing tariffs, corrective action such as investing in larger capacity bollards, fenders and tugboats, and adapting part of the infrastructure could be actions of the Port Authority.

If ships with a length greater than 450 meter, or draught more than 18.0 m were to appear, depending on their call frequency, measures would be necessary (see Table 5.9). The probability of ships bigger than Malacca-max appearing in the future can be reduced through shaping actions, whereby organizations such as International Maritime Organization (IMO) or European Seaport Organization (ESPO) set up a negative campaign against such vessels, which are bound to place additional demands on port infrastructure and in turn cause extra ecological and societal pressure.

A capitalizing action could be to adapt the Master Plan now. In the event that these vessels do appear, but have a call frequency of say 50 ships a year, a hedging action could be for the shipping companies and the ports in de Hamburg-LeHavre range to invest in a common transshipment hub terminal at a suitable location. Not all ports would be required to invest in dredging and infrastructure to handle these mega vessels. A defensive action, if the ships call only about once a month, could be to adapt one berth at the existing Euromax terminal in order to handle these ships, since the first 600 meter of Yangtzehaven will be widened to create berths for inland ships. If the ships call, say 3 times a month, an additional corrective action could be increasing the capacity of Maasgeul and Eurogeul (meanwhile, the widening of Maasgeul by 240 m is already being carried out).

 # Increase in quay and terminal productivity

Increased productivity (handling speed of containers measured in TEU per quay length or TEU per terminal area) will benefit the terminal operator. The Port Authority must invest in R&D to study the implications of this development. The terminal operator must give adequate warning if the terminal concept is other than in his business case, and arrive at agreement over profit sharing with the port. Therefore, he must ensure that the extra transport is by other means than road, invest in reducing dwell times of containers, improving hinterland connections and create a network of inland container terminals and container transferia. These actions will reduce the adverse impact of this development, namely congestion at the terminal and in the hinterland, reduced service and negative environmental impacts.

 # Modal shift in favour of inland shipping

If there is a modal shift in the favour of inland shipping (environmental friendly mode of transport compared to road and rail), the positive effects of this development should motivate extra investment by the government, since it is responsible for the construction and maintenance of adequate connections to the hinterland. Investment in additional infrastructure for inland ships and measures for promoting the transition from road to water transport would help the port, which will experience only a limited impact from this development.

 # Non-compliance with security and safety standards

The port development in the Netherlands is guided through national and European policy documents (national seaport policy documents prepared by the Ministry of Infrastructure and Environment and European policy documents prepared by European Maritime Safety Agency, which set down requirements for maritime safety, pollution by ships and maritime security), and codes of practice on environmental and social issues established by European Sea Ports Organization .

In order to remain viable, modern ports must be able to accommodate larger vessels and a much greater volume of throughput more cheaply and efficiently than ever before, without increasing the potential for environmental damage. This could result in changes in the national legislation or creation of new European Union Directives geared towards stricter regulations in order to maintain standards of sustainability, safety, and security. These would be risks for the existing Master Plan.

One of the principles underpinning the MV2 construction is that even if shipping traffic increases, security levels in and around the port complex must stay the same. This is why there has been extensive research into which measures can be taken to safeguard the current security levels. Norms have been specified as to the emission of fine dust and CO_2, noise, and accessibility of the port for emergency services. If the required standards of sustainability, safety, and security are not met, due to any reason whatsoever, the plan will be threatened. Installing monitoring systems, and monitoring and imposing penalties in case of more than 10% increase in the levels specified in the norms, would be corrective actions.

5.5 Conclusions

In order to cope with various uncertainties, the traditional systems of engineering practices are increasingly trying to incorporate fundamental properties such as flexibility, versatility, and adaptability into their designs. A designer or a planner can endow the system (subsystem or one or more of its internal degrees of freedom) with characteristics of flexibility and adaptivity, but he still needs to scan and monitor the environment for changes to instigate timely actions. A framework for managing uncertainty is required, which is where adaptive planning comes in.

Adaptive Port Planning (APP) is an approach that identifies, in a structured way, the uncertainty in an existing plan, and subsequently improves its robustness through taking actions either in the planning stage, or by preparing actions in advance that can be taken if an uncertain future materializes, in response to triggers from a monitoring system (that monitors the external environment for unexpected developments and alerts planners for the need to modify or reassess plans). APP makes the original plan effective across a variety of futures. We have illustrated the approach through the use of a case study in which an existing Master Plan was made adaptive, by incorporating pro-active actions that aim at seizing opportunities and attempt to shape the external forces. APP proposes various planning strategies depending upon the planing horizon and the level of uncertainty. The many tools and techniques then also vary. These have been discussed and will be illustrated in subsequent chapters through case studies.

Although extreme and black swan events cannot be predicted, addressing them during planning is important. In some cases, survival of the organization can depend on doing so, and at other times they can reveal hidden opportunities. Adaptive planning raises awareness about the notion of surprise, allows for a structured incorporation of radical fluctuations in the future patterns and trends under analysis, and equips the organizations with new mental categories of radical change, as well as a set of new policies to mitigate their extreme effects.

Another advantage of Adaptive Port Planning is that a unified picture of risk strategies or action plans can be presented to the stakeholders in the planning stage, and even though formal financial investment and permit procedures etc. will only be started later, there are no big surprises for the stakeholders (even the wild cards will have been brought into picture). This will improve the organizations ability to manage risks effectively.

In the following chapters we will examine the various steps of of the Adaptive Port Planning framework.

Chapter 6

Flexibility in port infrastructure

Flexibility enables functionality under uncertain conditions and emerging requirements, thus make flexibility a part of the solution.

6.1 Introduction

Having introduced the framework of Adaptive Port Planning in the previous chapter, we proceed to discuss various steps in detail. This chapter deals with flexibility in port infrastructure (Step III of APP). We focus here on the bottom layer of the three layer infra model, i.e. physical infrastructure, which is related to the core business of a landlord port authority.

As a first step, in order to gather views, perceptions, and attitudes about flexibility in the port sector, we conducted a survey. We followed this up with a brainstorm session about flexible solutions for port infrastructures. The most promising ideas that emerged during the session are explored in this dissertation. In a retrospective study, we attempt to trace examples of robust, generic, and flexible structures in the Port of Rotterdam (PoR) that have survived the test of time by reacting flexibly to changing demands. We also investigate why many innovative logistic and infrastructural concepts that were proposed in recent times, despite intensive engineering effort and investment in pilot projects or feasibility studies, have never been implemented. These insights are invaluable for successful implementation of APP. Since (traditional) quay walls represent relatively inflexible structures, which are vulnerable to unexpected changes, we devise a framework with strategies for adaptation and reuse.

6.2 Brainstorm session

6.2.1 Objective

Ports being designed and constructed today will be, in most cases, in service for 50 or more years, stretching into 2060 and beyond. This is a very long time horizon, with much uncertainty, nonetheless, decisions must be made today. Brainstorming is a technique that can aid planning and decisionmaking by thinking about the future environments in which today's decisions must be made, as well as the repercussions of these decisions in different future worlds (Cann, 2010).

As discussed in Section 5.3.1, brainstorming with a diverse group of people is an efficient manner to acquire information and viewpoints in a short time. took the initiative to organize a brainstorm session with the central theme 'Flexible Port Infrastructures'. The purpose of the session was to exchange ideas about flexible solutions for port infrastructure with a group of people from the port sector with varied backgrounds (i.e., with different interests, perceptions, and foci). Therefore, participants from consulting engineering firms (Royal Haskoning, Rotterdam Public Works Department), terminal operating firms (Europe Combined Terminals, APMT), staff of the Port of Rotterdam Authority from various disciplines (planning and realization of infrastructure, Harbour Master office, logistics studies, Project team Maasvlakte 2), and Delft University of Technology were invited to participate.
We sought to answer the following questions:

- What are the views of the various stakeholders in the port (related) industry about flexibility?
- Where can we incorporate flexibility in port infrastructures?
- Where is flexibility needed most while planning and designing port infrastructures?

The brainstorm session consisted of the following steps (see Appendix A):

1. Survey: In order to examine their viewpoints concerning flexibility, the participants were asked to fill in a survey, the results of which were to be discussed in Step 3.

2. Idea generating session: Next, the participants were divided into groups and asked to propose interesting flexible solutions for port infrastructures, first individually, and then as a group. These could take the form of sketches or descriptive text. The best ideas from each group were then presented to the rest.

3. Discussion: The most promising solutions were brought up for discussion with the entire group.

6.2.2 Survey

Perceptions, together with the values and available means, drive actions. Therefore, it is important to gather the various perceptions about uncertainty and flexibility, and if needed, alter them. The survey consisted of 20 propositions divided into three categories (see Appendix B):

- Uncertainty and flexibility
- Flexibility in infrastructures

– Implementation of flexibility

For each proposition, the participants could mark one of four choices: agree completely, agree a bit, disagree a bit, and disagree. The propositions were framed to examine the various perspectives about flexibility. The questions were general in the first category and specific in the second category. The third category was aimed at barriers or bottlenecks to implementing flexibility. A summary of the results is presented below.

Uncertainty and flexibility

The majority of the participants agreed with the following propositions:

– Ports need flexibility in order to devise strategies against uncertainty.
– Flexibility in infrastructures can facilitate adaptation, and is a means to extend the economic lifecycle of infrastructures.

60% of the participants concurred that flexibility in one node of the supply chain does not offer a solution, while the rest held a more favorable view. The majority were of the opinion that, in the future, flexibility will dominate the assessment/appraisal criteria for large scale engineering projects. The common viewpoint was that flexibility creates extra complexity in projects. Some opposed the statement that flexibility can reduce efficiency. There was unanimous agreement that flexibility, while positive for one party, can be a risk for another.

Flexibility in infrastructure

Most participants opposed the provocative propositions that flexibility in physical infrastructure is a myth, and that it was better to direct flexibility at processes and procedures. The majority (more than 66%) agreed with the following propositions:

– Modular construction can be profitable only on a large scale.
– Floating quay walls for container handling are suitable only in very few situations.
– Designing structures with extra margins and providing overcapacity is the only way to deal with uncertainty.
– The phasing of a port project is an effective manner of dealing with uncertainty.

60% of the participants were of the opinion that movable structures are not cost-effective.

Implementation of flexibility

The majority agreed with the following statements:

– Implementing flexible solutions is more difficult than devising them.
– The costs and value of flexibility should be included in the business case.
– In order that flexible solutions are implemented, the engineering, commercial, and financial divisions must think along the same lines.

Surprisingly, only half of the participants agreed with the following statements:

- Institutional rules and regulations will not allow flexibility to play a useful role.
- The government (and the society) must also financially contribute towards sustainable, flexible solutions.
- Only if land becomes more expensive in Rotterdam will innovative underground solutions become interesting.

6.2.3 Idea-generating session

The discussion pertaining to flexibility brought up specific instances in PoR such as, provisions of special fenders in certain harbours to berth Queen Mary 2, one of the largest cruise vessels in the world, and strategies for dredging to receive Berge Stahl, the biggest bulk vessel in the world, as well as generic solutions.

The ideas generated by the participants were not limited to concrete physical solutions (in spite of being so asked), but extended to other domains. This is a clear and useful indication that issues surrounding flexibility, such as the methods for planning, design, and project appraisal, civil contracts and tendering, and the institutional aspects related to implementation of flexibility are equally significant. Also interesting are the different perceptions about flexibility in infrastructures. For the purpose of discussion of the results, the ideas are grouped into the following three categories:
1) Physical solutions
2) Other (than physical) solutions
3) Perceptions about flexibility
The ideas thought to be most relevant and significant in each category are discussed below.

1) Physical solutions:

There was a great deal of overlap in the physical solutions that were presented, and the following terms were mentioned numerous times:

- Modularity
- Standardization
- Recyling
- Underground infrastructure
- Reusability
- Multi-functionality
- Shorter design lifetime

2) Other (than physical) solutions:

The following suggestions were thought to be potentially useful:

- Adopt new approaches to planning and design
- Adopt phasing (allows flexibility in time)

- Adopt a new business model
- Make the environmental regulations less burdensome
- Coordinate cargo with other ports
- Split the port into two parts in order to encourage competition and innovation
- Stimulate open (source) tendering
- Allocate risk where it can be dealt with most efficiently

3) Perceptions about flexibility:

Most participants confessed to not consciously thinking about flexibility. Once they were formally instructed to do so, the viewpoints were very insightful. Some of the observations are given here:

- It is important to arrive at a working definition of flexibility in the context of port infrastructures
- Flexibility requires physical and financial space
- Flexibility in one link of a chain can reduce flexibility in another link, therefore a degree of optimization is necessary
- Flexibility is a determinant of three factors: requirements of the client, available resources (includes budget), and the available technology
- The design parameters of a project should be identified at the beginning of a project, and it should be established which parameters are fixed or variable (i.e. which degrees of freedom are available)
- The interface water-land (pier, dock, jetty, quay, locks) seems to be the most inflexible element. The water-water interface on the other hand can provide a lot of flexibility (e.g., floating quay walls, floating cranes, ship to ship transfer)

6.3 Discussion of results: Survey

The seemingly most controversial statements from the survey (in conflict with broad opinion) were brought up for discussion. If the underlying way of thinking is likely to present a barrier to implementation of flexibility, it is vital to confront and alter it. This can be done in different ways such as discussions with experts, development of new tools, and looking to other infrastructure domains for solutions. We discuss three statements and the possible ways of altering the thought processes responsible for them.

- *60% of the participants were of the opinion that movable structures are not cost-effective.*

  The feasibility evaluation of a movable (thus reusable) infrastructure requires an estimate of the likelihood of its reuse, as well as of the costs and benefits of a second or even third period of reuse (extended lifetime). We suggest in the dissertation that standard practices of project evaluation should be revised to include methods that can include the value of flexibility.

– *Many participants did not agree that institutional problems and rules and regulations will not allow flexibility to play a useful role.*

  This goes against the general opinion but is accepted at face value since this positive attitude should go a long way towards stimulating flexible and sustainable choices.

– *Many participants did not agree that the government (and the society) must also economically contribute towards sustainable flexible solutions.*

  Since quantification of indirect effects of a port project is extremely difficult, some of the participants found that little can be done in this regard. However the need for modelling tools in order to estimate indirect impacts and include these in the decision making, is being recognized, as shown by Almodovar and Chang (2010)[1]. Investment in such a modelling tool will also enable landlord port authorities such as the PoRA to apply for government subsidy and stimulate sustainability endeavours.

6.4 Discussion of results: Ideas-generating session

Many of the oft-repeated themes (an indication that they found favour by most participants) during the session were:
1) Strategies for flexibility
2) New approaches to planning and design
3) New business model
As a part of our research on flexibility, we proceed to investigate these further.

6.4.1 Strategies for flexibility

The flexibility-related concepts have been defined in Chapter 4. Before going further, we would like to distinguish between two types of flexibility in physical infrastructures, i.e. active and passive flexibility. The attributes which facilitate reuse of an structure (without adaptation) such as design robustness and versatility, fall into the category of passive flexibility. The attributes that facilitate adaptation of an structure or its elements for reuse represent active flexibility, e.g., interoperability, compatibility, scalability, standardization, and modularity. Attributes such as durability, recyclability, and maintainability promote reuse of infrastructure and its elements in both the cases.

[1]The US Army Corps of Engineers (Corps) constructs, operates, and maintains navigation infrastructure in navigable waters of the United States. The evaluation of alternatives is based on a comprehensive benefit cost analysis at the National level. Up until a short time ago, the evaluation did not explicitly include the regional and local benefits generated by ports improvements. However, a study is currently underway under the 2009 American Recovery and Reinvestment Act (ARRA) to develop a model to estimate the regional economic impacts and significance of the Corps' ports and navigation infrastructure. Economic measures such as jobs, income and sales of the Corps ARRA spending and annual budget are being estimated, as well as impacts from all secondary economic activities associated with the Corps' navigation missions. Regional economic models were developed for regions throughout the United States impacted by Corps funding. A modelling tool is set up and preliminary results have been presented.

Moses (2004) states that though the generally recognized properties of engineering systems are function, performance, and cost, a lifecycle perspective on the system emphasizes non-traditional properties or goals of systems, often called *ilities*, which include: flexibility, adaptability, scalability, safety, durability, sustainability (through reuse), reliability, recyclability, maintainability, and quality in order to manage the evolution of systems in an uncertain world. de Weck et al. (2012) suggests that these properties of engineering systems concern wider system impacts with respect to time and stakeholders rather than being primary functional requirements.

Flexibility goals differ per system. Flexibility can be directed towards improving efficiency, maintainability, accessibility, and sustainability, or reducing engineering efforts or costs. It can be employed during construction as well as during use. For instance, robust design of a concrete jetty allows relocation of foundation piles in case obstacles are encountered during piling without the need to redesign. Flexible structures can absorb energy in case of earthquakes, extreme berthing, or under other dynamic loading. During the brainstorm session, the flexibility objective was not explicitly specified. The implicit assumption was that flexibility was essential in order to extend the economic lifetime of infrastructures.

We find it useful to create a framework that lists the various flexibility objectives, the types of flexibility (attributes) required to achieve these objectives, and maps the proposed flexibility strategies onto the flexibility objectives. The framework, based on Egyedi (2002), as applied to physical infrastructure, can be seen in Figure 6.1. It appears from the figure that the most common strategies contributing to flexibility in physical infrastructure are: generic designs (with built-in margins), standardization, and modularity. We will discuss these further.

Generic design refers to a design shared by similar objects, for instance, quay walls. Generally, quay walls are designed for specific situations and to suit local site conditions. 'Generic' structures on the other hand, are not designed to meet specific site conditions or even specific functional requirements. This requires designing for an extreme scenario, and building margins in design. Undeniably, in many cases, this can be wasteful. But for inflexible and indivisible port infrastructures, keeping in mind the rapid changes in the environment, investments in a generic design can prove to be very cost-effective. For instance, PoR can be distinguished into clusters or areas having quay walls with the same retaining height and similar functions, and a generic design can be devised per area. This can save on engineering costs of designing for various locations or situations, and provides flexibility for reuse of elements. Yet another advantage is that generic designs or specifications allow for competitive bidding by contractors who carry out the construction. The limitation of generic designs is that they can cover a range of extreme requirements, but in case of black swan events they prove inadequate.

Standardization is the strategy of development and implementation of designs to achieve the required levels of interchangeability and flexibility in use. The use of standard prefabricated units in the construction industry is very common, e.g. prefabricated concrete or steel elements for diverse applications, where a particular element or form is repeated many times. Containers, which are manufactured as per ISO standards are a prime example of standard modules. Standardization helps achieve mass

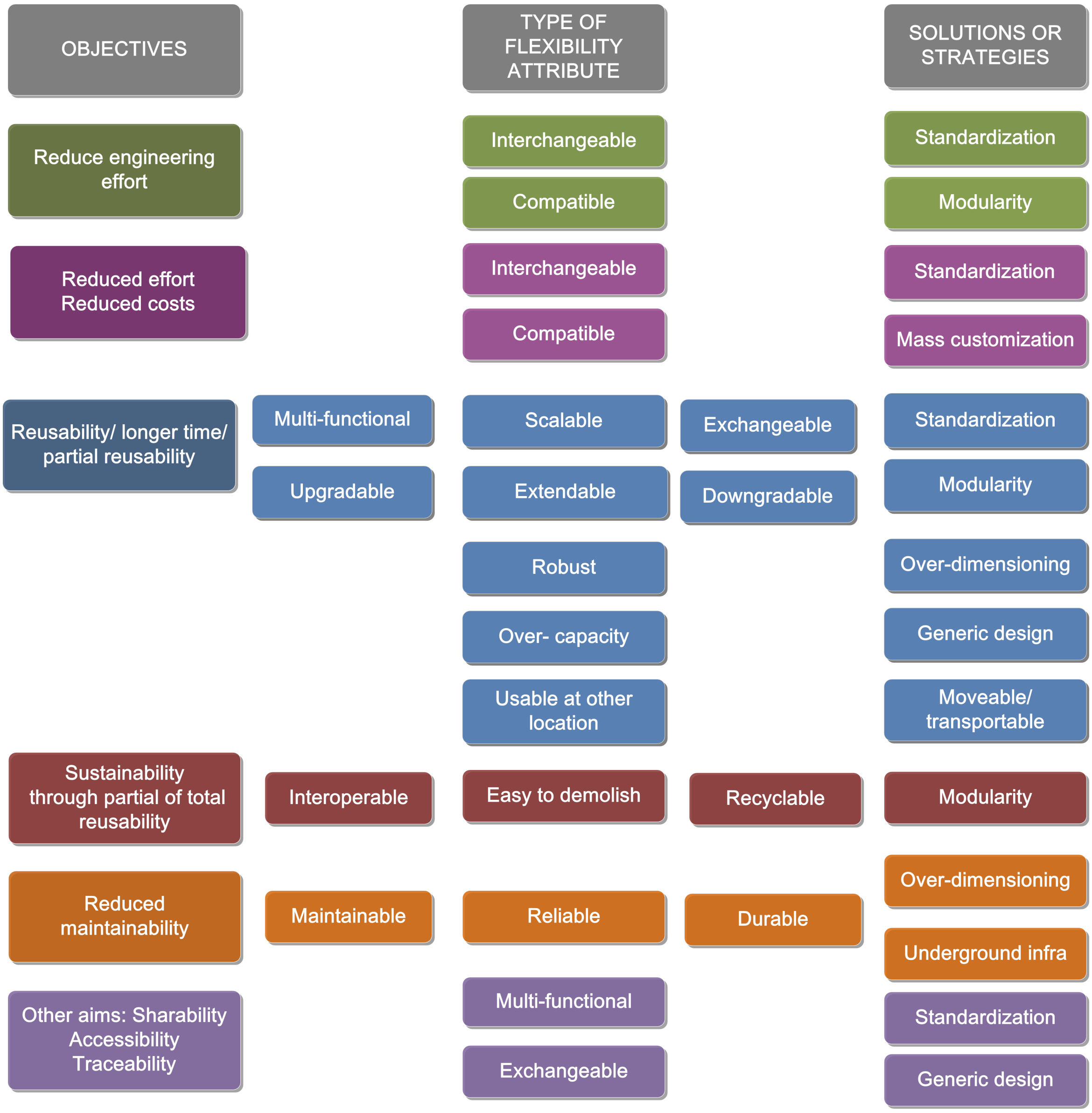


Figure 6.1: Mapping flexibility attribute on to objectives

customization, and economies of scale. Chase et al. (2006) defines mass customization as a method of 'effectively postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network'. Modularity is closely related to standardization.

Modularity in design refers to use of standardized units or dimensions for facilitating flexibility in use through attributes such as interoperability, interchangeability, and scalability in systems. Modularity organizes and enables parallel work, thus providing an efficient division of labour and efficient reuse of resources during construction. Work on modules can go on simultaneously, hence the start-to-finish time needed to complete the job decreases. This makes modular systems economic (Baldwin and Clark, 2003). Modularity in the design of a complex system allows modules to be changed and improved over time without undercutting the functionality of the system as a whole.

The modular design of a complex system encourages innovation in the modules. In short, through splitting a complex engineering design into modules, multiple valuable design options in the system are created. In oil and gas industry it goes by the name of 'Design one, build many' (Bradley et al., 2009), i.e. standardized designs suitable for a wide range of conditions.

Modularity in processes refers to the possibility of dividing an engineering project into phases; each phase or module represents an incremental commitment. In fact, Hall (1980) recommends this approach of minimal commitment at each decision stage as a part of an anti-disaster strategy. Through being able to accommodate rapid change, modularity can reduce negative effect of uncertainty, and even create new opportunities. Modularity can therefore be an enabler for flexible decision processes. (This was also the general consensus in the brainstorm session – phasing a project provides the option to delay or postpone decisions till uncertainty clears up.)
Design modularity and standardization have brought about a revolution in complex engineering systems. These aspects have also been a focus of many studies in the context of port infrastructures. Attributes such as durability, reliability, and maintainability are desirable in all systems. Constructability and deconstructability facilitate reuse. Simple detailing, i.e. simple connection between modules, separation of functions, hierarchy of disassembly, realistic tolerances, homogeneous materials, simple structural elements (avoiding indeterminate and pre-stressed or post-tensioned structures) are essential for deconstruction[2].

6.4.2 New approaches to planning and design

Much of the discussion during the brainstorm session focussed on the seeming drawbacks in the current approach to structural design. Some suggestions for a new approach were put forward by the participants; these were incorporated in Table 6.1 that compares the new/revised approach with the traditional approach. The four project phases referred to in the table are design or front-end phase, realization phase, exploitation phase, and reuse or demolition.

The results of discussions about the flexibility-related requirements in different project phases are presented in Figure 6.2. The arrows indicate that these requirements need attention during the design phase. The suggestions of the participants concerning revised design considerations are incorporated in Table 6.2. In an ideal situation, the revised approach uses performance based specifications allowing users flexibility in choosing materials, design concepts, and construction methods to meet the defined goals and objectives. It allows earlier use of new technology and encourages non-traditional, innovative ways to meet performance criteria. This widens the marketplace, no longer limiting the acceptable suppliers to those manufacturers or countries with specific resources (ASME, 2004). This approach considers a variety of design

[2] *Lifecycle* of an infrastructure is expressed by de Ridder (2012) as follows:
Lifecycle *total* $= \sum$ Lifecycle *parts* + *physical relation between parts*. This underlines the importance of designing for deconstruction. *Lifecycle costs* include all the costs associated with system lifecycle and include research and development and engineering costs, construction costs, operation costs, and phase-out costs. The phase-out costs include recycling and disposal costs.

Table 6.1: Approach to planning and design of projects

	Traditional approach	Revised approach
Planning phase	Not much attention for front-end phase of a project	More attention for front-end phase of a project
	Designs based on fixed specifications	Design based on range of specifications
		Includes identifying options that can be translated into strategies for dealing with unexpected events
Decisionmaking	Premature commitments and lock-in (lock-in with respect to decision-making on large infrastructure projects is created when sub-optimal policies are used as a consequence of e.g. path dependency, even though a better alternative is present (Flyvbjerg et al., 2003))	Postponing decisions and lock-in, leaving room for manoeuvring, also known as flexible decisionmaking

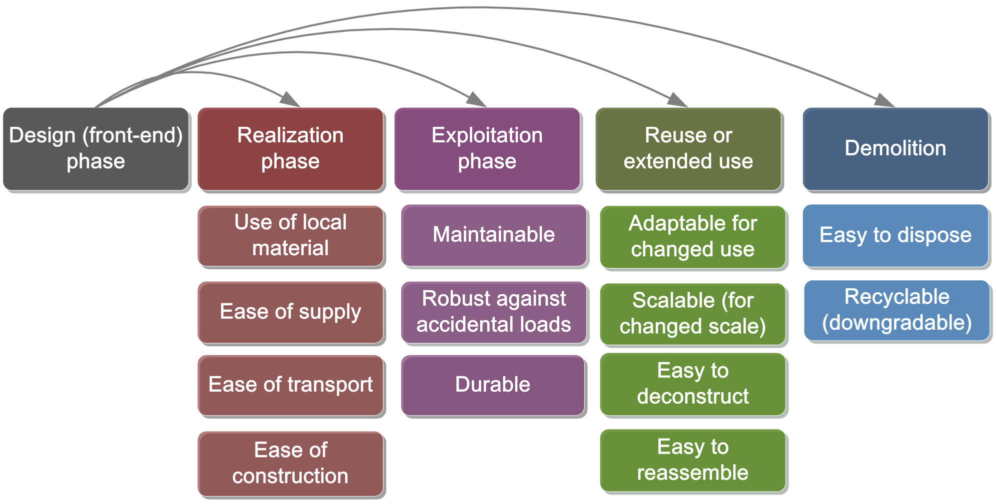


Figure 6.2: Requirements in different project phases

scenarios and a range of conditions including extreme scenarios. It rates lifecycle properties as highly as traditional properties.

While investing in an infrastructure, the major requirement is that it should fulfil its desired function at least throughout its planned lifetime. There are four ways of designing infrastructure for the future:

1. Assume that design requirements, and relationships among the design parameters will remain the same, predict by extrapolating into the future, and select traditional fixed designs. This is also known as designing under assumed certainty. Ad-hoc adaptations follow according to need;
2. Designing for a short time and demolish, i.e., design to match the planned eco-

Table 6.2: Design considerations

	Traditional approach	Revised approach
Terms of reference	Criteria based on product	Performance based criteria
	Based on similar projects in similar situations, no room to look at cutting edge technology	Monitors external environment to clear uncertainty and learn from state of the art technology
Specifications	Standard	Additional functional requirements as to safety, sustainability, availability
Design scenarios	One scenario of the most plausible condition	Many scenarios and range of conditions
Design type	Client-specific design	Generic design
	Often robust design	Minimum design Flexible/adaptable design Robust design (with margins)
Design lifetime	50 years or more	Very long lifetime in case of generic design Shorter service life equal to length of contract in case of minimum design
Indicators/ Properties	Usability, constructibility	Maintainability, flexibility, adaptability, recyclability, availability/ usability
Use of resources	Use of extra resources thought to be more cost effective compared to major changes later	Proposes flexible resources as being more cost effective
Costs	Lifecycle costing (including maintenance)	Lifecycle analysis including costs and benefits from reuse of structure, components or materials
Risks	Focus is on project risks	Focus is also on strategic risks and surprises

nomic lifetime. This planned obsolescence, resulting in a minimum design, is a policy of deliberately designing a product with a limited useful life, so it will become obsolete or non-functional after a certain period of time. Frequently applied in industrial design, it is an uncommon practice in infrastructure design, and even considered unacceptable (Bellis, 1990) except in case of temporary structures;

3. Generate plausible future scenarios and produce designs that perform reasonably well in different futures. (Here, different futures reflect the various combinations of alternative economic, environmental, social, and technological conditions that may materialize);
4. Assume that the future cannot be predicted and implement flexible designs that can be adapted for different future scenarios that materialize.

These approaches can be related to four types of design: traditional design, minimum design, robust design (called generic design if it pertains to an extreme scenario), and a flexible design. We will pursue this line of thought in the next section. Traditional design belongs in the category 'no flexibility', while the adaptations likely to be required belong to 'just-for-now' category. The robust and generic designs fall in the category 'just-in-case' flexibility, while flexible designs exemplify 'just-in-time' flexibility. The design approach is preferably selected during Step I of APP.

6.4.3 Business model

Table 6.3: Approach to project appraisal

	Traditional approach	Revised approach
Project appraisal	Evaluation of a single alternative (point-based design)	Many alternatives are kept alive (set-based design) keeping in mind the uncertainty
	Project business case	Business case that includes a portfolio of related projects
	Unit of analysis is the project	Unit of analysis includes a wider context than the project
	Evaluate design using usual discounted cash flow analysis	Evaluate design and associated flexibilities: A form of option analysis, if the *design* is modular/ adaptable or if the *project* is modular
	Examines projects impact on future users	Goes beyond and examines project impact on society as a whole (this applies to larger projects)

The general opinion in the brainstorm session was that focus on individual business cases often leads to no-go decision for many worthwhile projects. A project despite having a negative NPV, can have many indirect beneficial effects, and can influence other projects positively (this will be illustrated in a case study in Chapter 9. Therefore, the overall business case (say for a portfolio of projects) should find precedence over a project business case. Communication with the decisionmakers was also mentioned as being a general problem. A modified approach to project appraisal is presented in Table 6.3. That focus on individual business case is one of the reasons why flexible alternatives do not meet the feasibility criteria and end up in the waste paper basket, was a significant conclusion that followed from the brainstorm session. This aspect has been further addressed in Chapter 7.

6.5 Flexibility in quay walls at PoR

6.5.1 Introduction

Flexibility is difficult to implement in large infrastructure projects because of their indivisibility and irreversibility (Miller and Lessard, 2001). Recently, a great deal of research has focused on flexible solutions for engineering systems. We will investigate if research in the port sector has resulted in new concepts, and if these have found implementation. This investigation, carried out through desk research and interviews, is limited to the Netherlands and includes projects in the Dutch universities, often sponsored by industry, engineering consultants, or port authorities. A distinction is made between robust, generic, and flexible structures. But first, we examine the traditional quay walls in Rotterdam for their robustness, flexibility and adaptability.

6.5.2 Traditional structures

Many different types of quay walls have been used through the ages in PoR (CUR, 2005a). Most of these are of a fixed design. Since begin 1990s, a combined steel quay wall with a concrete relieving platform supported on piles, has been a standard in Rotterdam. The underground structure of this quay wall, comprising elements such as steel pipes, sheet piles, concrete piles, anchors or MV piles etc. is already modular. These prefabricated modules are delivered in many types and sizes. Standardization of sizes can increase the cost-effectiveness through facilitating reuse[3]. The superstructure can be assembled out of prefabricated modular constructions, the advantages being saving on engineering costs, faster delivery times, faster construction, less maintenance, and easy replaceability. However, once in place, this quay wall, like most quay wall types, is relatively inflexible. Some other quay wall types such as L-wall, block-wall, or caisson quay walls, designed as prefabricated modular constructions, can be reused at another location.

Design for demolition has not been an accepted concept in infrastructures[4].

Flexibility in traditional designs

In Table 6.4, we examine the robustness and flexibility of a standard Rotterdam quay wall to fulfill its functions in changed situations. These functions are: berthing and mooring; providing bearing capacity for the loads due to handling of goods; retaining soil behind the quay, and providing area for cargo handling activities. Robustness is essentially achieved through reserve capacity, i.e. margins in designs (Column 2), while flexibility results in ease of adaptation (Column 3). The conclusion is that there are only limited design margins in the design of a quay wall with respect to all the functions. However hidden reserves often exist as is often demonstrated while re-evaluating quay walls under changed loads (from new quay cranes, heavier mobile

[3]This is illustrated in a case study in Chapter 7.

[4]London Olympics 2012 is a trail blazer with this approach. Permanent venues have only been constructed if a long-term use was perceived. If not, then temporary venues were built.

Table 6.4: Flexibility with respect to functions of a quay wall

Function	Reserve capacity	Ease of adaptation in case of more extreme requirements
Berthing and mooring	Capping beam or deck equipped with fenders and bollards has the capacity to redistribute loads	Local adaptation in form of extra reinforcement at the location of bollards and fenders is often sufficient
Bearing	Small design margins are available to take care of overloading	Limited adaptation by providing extra piles under relieving floor and grouting pile toe
Retaining soil	Small design margins in retaining height	Limited adaptation through accepting lower dredging tolerance and providing bottom protection
	Small design margins to take up extra loads	Limited adaptation through strengthening steel retaining wall
Storage	A minimum area behind the quay wall is essential to support the cargo handling function of a quay wall	Must be taken into account during initial planning

cranes) or in changed situations, (e.g. deepening of the basin due to scouring). This might be accounted for by one or more of the following:

- higher safety factors employed in designs either due to inability to model structures accurately, or due to inadequate knowledge of soil and material behavior in the past;
- capability of (indeterminate) structures to redistribute loads, which provides capacity to withstand overloading;
- increase in concrete strength with age.

Due to these margins, some old quay walls in the city area of Rotterdam are functioning well beyond their lifetime (even though serving another function, such as recreation). The conclusion from the third column is that the adaptations of the structure at a later stage are limited. Literature research confirms that though possible, these adaptations, especially those associated with increasing the retaining height, are extremely difficult and costly.

A study for increasing the construction depth by 3 m in front of a 300 m long quay wall in the Caland canal investigated many alternatives (IGWR, 1978). The cost estimates varied between 5.5-6.5 M€, and the required construction time was 36-40 weeks. This amount if indexed (at a rate of 2% for 30 years) is comparable to the cost of a new quay wall in 2011. A similar study in 2001 involving the deepening of the quay walls at the Europahaven in PoR by 3.50 meter, (IGWR, 2001) also weighed many alternatives. The alternative proposing a new 400 m long berth proved to be the cheaper than alternatives proposing upgrading, with minimum construction risks.

In 2001, a workshop was organized to seek solutions for the problem of deepening the berths in PoR in response to increasing ship sizes (Heukelom, 2001). Many solutions, aimed at reducing loads, physically modifying the quay wall or the soil, and even adapting the ships and logistics, were proposed. These were evaluated on basis of criteria such as the effect on the basin width, costs, time required for repairs, disruption to normal activities, impact on operations, future flexibility, durability, technical feasibility, risks, and the impact upon the supply chain. The solutions, which scored the best, proposed the following: reducing the soil pressure on the quay; re-evaluating the design philosophy; and adapting the logistics. Clearly, the constructive adaptation of structure does not score well for the criteria mentioned.

If we consider the relative contribution of different load types acting on the quay wall to its total costs, the retaining height makes the largest contribution (CUR, 2005a). In recognition of the fact that (loads associated with the) retaining height contribute significantly to the costs of a quay wall, the quay walls in the Europahaven at PoR were designed for 3 meter extra retaining height. This provision of robustness has resulted in flexibility to cope with unexpected appearance of mega vessels.

6.5.3 Generic structures

We have discussed generic designs in Section 6.4. This type of structure was once popular with the major land developers due to the simplicity of construction and associated low costs, and no engineering costs.

Generic structures for ports were a subject of many studies. ‘Modular quay wall’ (Heijden et al., 2008) proposes generic designs for distinct areas in PoR with similar functions and retaining heights. Each design employs a modular superstructure. Though more expensive compared to a site-specific design, it offers the advantages of faster construction and possibility of reuse of the superstructure. These advantages were not monetized during the feasibility evaluation.

‘Quay wall of the future’ (van Breugel, 2003) proposes a modular quay wall of fibre reinforced polymer (FRP) that can be reused due to its modular structure. The cheapest variant is twice as expensive as a traditional quay wall. Again, the added benefits from reuse have not been included in the financial evaluation.
Generic structures have not found application in PoR.

6.5.4 Flexible structures

In recent times, many studies have been devoted to flexible, relocatable, and reusable structures. Incorporating attributes that facilitate the reuse of a structure lowers the risk of these constructions losing their functionality and becoming obsolete. We will discuss these studies in the following categories, and also seek out examples in PoR:

- Relocatable structure
- Multi-functional structure
- Multi-user structure
- Underground structure (which represent flexible use of space)

Relocatable structure

Aside from quay wall and piers, the other means for transfer of goods is on water, or on buoys or piles. We have seen that quay walls and piers are relatively inflexible, with few alternative uses. Both initial construction and expansion require large amounts of capital.

Buoys or dolphins require smaller investments, are multi-user facilities, and can be relocated (these are however, not suitable for container handling due to excessive motions of moored vessels). Two ships positioned alongside, moored with buoys or piles, can transfer cargo from one ship to another. Direct ship-to-ship transfer decreases delivery times, and floating storage provides flexibility making this a cost-effective solution for uncertain growth markets such as the liquid bulk sector. This concept is very old and much used, and the facilities recently constructed in Caland Canal (PoRA, 2006a) have proved very profitable.

L-wall, block-wall, and caisson quay walls represent gravity based structures prefabricated in a building pit or dock, that in principle can be relocated. Caisson constructions dating from 1800s are common in Rotterdam. In a detailed study, Boskalis and van Hattum and Blankvoort (2001) investigated the possibility of reusing the caissons in the Merwehaven for another location in PoR. They ascertained that the additional costs of reusing, even without upgrading, were comparable to that of a new (traditional type of) quay wall. Also, new caissons need to be reused three to five times in order for the costs to be comparable to a traditional quay wall. Not surprisingly, reuse of caissons is not common practice.

Floating structures for container terminals are also a focus of numerous studies (Paus, 2004; Ali, 2005; de Rooij, 2006; van der Wel, 2010; Bijloo et al., 2010; Zijian, 2007), and research is going on worldwide with Korea, Japan, and Singapore being on the forefront. A modular floating structure can easily be extended, given a different configuration, or relocated. Yet, no examples can be found in Rotterdam. In comparison to a traditional quay wall, a floating structure is far more costly. The present forecasts indicate a shortage of capacity for container operations in PoR after 2033. If land reclamation is not a viable alternative for environmental, financial, political or technical reasons, the concept of a floating terminal could become interesting.

Universal relocatable quay wall (Fecken, 2001) proposes stacked and coupled triangular concrete blocks. The structure can be built in water, easily dismantled and assembled, and adapted to new functions. It is suitable for temporary construction or extending an existing structure. It is more expensive than the traditional solution in case of larger retaining heights, despite taking the extended useful lifetime through reuse into account.

Containerland (Exalto, 2002) uses stacked containers as building blocks, with a concrete deck on top to spread the loads to the corners of containers. The advantages are quick creation of temporary space, possibility of rapid disassembly, and flexibility of reuse at another location. The costs are lower in comparison to a traditional alternative that involves land reclamation requiring a long settlement period. The lifetime, in absence of corrosion protection measures for the steel containers, is relatively short. Despite possible opportunities for application, such as creating temporary space during the expansion project MV2, Containerland has not been employed.

Maxisteck (IGWR, 2000) is an open structure similar to offshore jacket constructions. It consists of a platform (which is a steel frame and a concrete deck) supported by piles. This prefabricated structure allows fast and easy construction. It offers the same advantages as Containerland in addition to the possibility of transporting and reusing steel elements. Such a structure has been constructed in Nagoya, Japan but not found favor in Rotterdam.

Dismountable LNG jetty (Koorengevel et al., 2010), as the name suggests, can be dismantled and relocated, so that it can have a longer useful lifetime. Initial costs are slightly higher as compared to a traditional jetty designed for a lifetime of 50 years. However, if the period of use at one location is likely to be shorter, this is a cheaper solution. Due to fast (dis)assembly time, a client who is moving to a new location, can reinstall and reuse it there.

Multi-functional structure

As stated earlier, most civil structures are non-transportable and difficult to put to other use. The costs are considered to be sunk, i.e. irrecoverable. Multi-functional structures, with the capability of accommodating another function such as storage in combination with cargo transfer, or suitable for different cargo, is likely to have a longer useful lifetime. Due to this advantage, this concept was a popular subject for research (e.g. 'Multi-purpose quay wall Odjfell' (PoRA, 2006b), 'Underground storage of minerals' (Dijkema and Willemse, 2008), and 'Multi-functional quay wall' (Dommershuizen et al., 2000). These concepts have not been implemented.

Multi-user infrastructure/terminal

As the name indicates, a terminal that can be exploited by more than one user or client is a multi-user terminal. At present, most of the quays in PoR are dedicated to one client or cargo segment. The berth occupancy is relatively low, and the quay and other facilities are not employed optimally. Multi-use results in an increase in the berth-utilization and shared costs for the users. Another advantage is that clients who are not situated directly next to water can make use of these terminals. A few decades ago, the innovative concept of a 'grey terminal' was investigated at PoR – this is essentially a multi-user terminal, where the quay and the crane can be rented per hour. It was expected to cater to niche markets that do not require specialized handling. It was put on the market, but never implemented.

Underground structure

Underground construction increases spatial flexibility through making available space that can be put to other uses. Many recent studies have proposed concepts over multi-functional use of space through underground storage of products (O3, 1999; Notenboom and Reijm, 2006; van Groningen and van de Graaf, 2006; Pals and Ligteringen, 2005; Dijkema et al., 2007; Dijkema and Willemse, 2008). These have, till now, not found application in PoR. During the financial evaluation of such concepts, the benefits of double use are seldom considered so that the financial feasibility criteria cannot be met. The availability of low priced land does not stimulate investment in underground structure.

Our observations is that reuse, whether of infrastructures, structures, elements, or material, is infrequent.

6.5.5 Reuse as a flexibility objective

The strategies for flexibility in physical infrastructures presented so far, such as standardization, modularity, generic, and robust designs have focussed on reuse of the port infrastructure, thereby initiating a new lifecycle of the structure itself. These result, through the reuse of the capital intensive infrastructure, in the greatest pay-offs and represent the highest form of waste reduction. However, reuse as components or raw materials integrates the structure into a lifecycle of another structure, and also contributes to sustainability. Recovery from products to obtain raw materials or employing reusable components is an important means of reducing disposal volume and costs. Reuse is most easily justified in the case of components with high manufacturing costs, long innovation cycles or lifetimes, and high ecological impact during production (Eshagh, 2012).

We will attempt to devise a framework for the various strategies for reuse. Until recently, the ladder of Lansink was an accepted guiding principle for use of secondary material in construction (Lansink, 1980). New insights in lifecycle analysis and ecocosts have supplemented this and resulted in a flexible and dynamic approach known as the Delft ladder (Hendriks, 2000). This involves 10 steps in the following order: prevention; reuse of structure; reuse of components; reuse of material; useful application of residual material; immobilisation through useful application; immobilisation without useful application; incineration with energy generation; incineration, and disposal in a landfill.

According to van den Dobbelsteen and Alberts (2001), in buildings, the supporting structure is responsible for two third of the environmental load or impact from material use. This share is likely to be even larger for port structures, and underlines the need for reuse. To enable this, an integral design process and conscious choices are required. In case of a quay wall, these choices are related to the designs, the detailing (thus avoiding monolithic constructions or connections and joints), and the construction method. The ease of dismantling the components or modules as well the ease of dismounting the components fixed to the bearing structure (e.g. fenders, bollards, rails), plays a large role here. These activities are required to take place rapidly, economically, and with minimum environmental impacts.

The selection of materials must be carried based on characteristics such as recovery, reusability, and recyclability. Reuse of material can be high or low value use, in which case terms such as upcycling and downcycling are employed. Similarly, the selection of components must also be based on the criteria of deconstruction, maintainability, and ease of transportation. Reuse of components can be be for a similar or different application. A deconstruction friendly design requires that the structure be broken into its constituent components, and subsequently design criteria for each of these elements set-up in a manner that would facilitate easy disassembly of the structure (Giglio, 2002). The design selection must be based on its flexibility and adaptability for

Table 6.5: Strategies for reuse based on Delft Ladder

	Strategy	Design criteria
1)	Reuse of infrastructure (without adaptation)	Design for durability Design for maintainability
2)	Reuse of infrastructure (with adaptation)	Design for flexibility Design for adaptation Design for deconstruction (modularity, construction details) Design for easy transport Design for durability Design for maintainability
3)	Reuse of components (similar or new application)	Design for deconstruction Design for easy transport Design for durability Design for maintainability
4)	Reuse of materials for similar applications	Select for reuse of materials in own cycle Design for easy segregation and recovery (e.g. homogeneous use)
5)	Reuse of materials for other applications	Select for recyclability Design for separability (e.g. homogeneous use)
6)	Disposal	

another function or use with minimum alterations, at the same or at a new location. The characteristics of an infrastructure system such as scalability, modularity, and standardization promote this. Segregation of functional elements is instrumental in promoting adaptation.

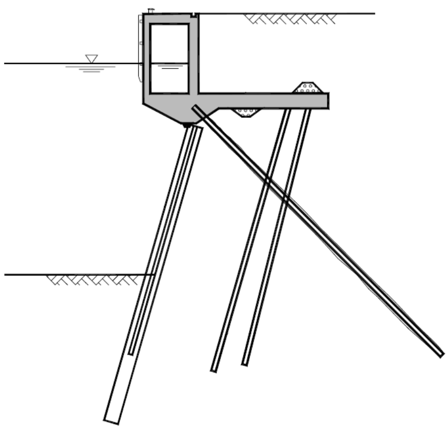


Figure 6.3: Cross-section of the wall to be demolished

Thus in a way, the Delft ladder prescribes the design criteria and the manner of

Table 6.6: Examples of reuse

	Step	Example
1.	Reuse without adaptation	Not relevant in the current situation
2.	Reuse structure with adaptation	Rotate superstructure, provide extra anchors, and use as a deep water quay wall Use as a quay for barges
3.	Reuse components	Use the hollow element as a small tunnel Place a wall and deck and use as a floating pontoon Use in a breakwater Use the L shaped wall to serve the function of a dike Use for storage of liquids Use for storage of dangerous material Use as a bunker Use as a landmark Use a part of the quay wall as climbing wall Use for (destructive) material testing
4.	Reuse materials	Reuse concrete as gravel for road construction or aggregate for new concrete; recycle steel
5.	Reuse material for other application	Use concrete as riprap for stabilising slopes or for filling gabions
7.	Disposal	Dispose off in a landfill

construction of a structure. In Table 6.5, we present six strategies of reuse, in their hierarchical order, that seem relevant for infrastructures. The strategies determine the design criteria, which are stated alongside each strategy. Design (for construction as well as deconstruction), construction methods, and construction materials, if carefully selected, guided by the principles of flexibility and sustainability will yield flexible constructions. In order to illustrate the framework, we consider an existing quay wall in PoR that was required to be demolished. As can be seen in Figure 6.3, it has a steel foundation and a concrete superstructure. Table 6.6 illustrates the use of the framework presented in Table 6.5 to investigate the reuse possibilities of the concrete superstructure (PoRA, 2000).

6.6 Reasons for non-implementation of flexibility

The previous section concluded that many flexible design concepts have not found implementation at PoR. In retrospect, we can distinguish many examples of successful innovations in the port sector and specifically at PoR, but we can also unearth a large number of promising concepts which have never been implemented (Taneja et al., 2012c). We trace the developments of some of the flexible concepts, dealing with design and logistics, and analyse the factors responsible for their success or failure.

The flexible design concepts included in the study were: the multi-functional quay, the multi-user terminal, Containerland, Maxisteck, the floating quay wall and the floating transshipment terminal. These have been described in Section 6.5.4. The flexible logistic concepts included the MultiCore pipeline, the Container Transferium, and the floating crane. This investigation, in addition to a literature study and desk research, required us to conduct interviews at PoR. Some of the interviewed individuals had played an important role in these endeavours and were able to provide very useful information.

MultiCore pipeline (Port of Rotterdam and Vopak), is a multi-user pipeline which has proved very profitable for PoR, and studies for expansion are under way (MultiCore, 2012). The following factors have contributed to the success of the concept:

- This unique initiative contributes to efficient use of space, safety, land side accessibility, and environment and sustainability, all strategic issues which need addressing by PoR;
- There is no upfront investment in expensive infrastructure, since it is a PoRA initiative. This is by itself unique since pipeline investments are done by private parties;
- Phased development in response to demand;
- Flexibility in the concept; it is possible to lease variable transport capacity (pipeline length) for a variable time (5–25 years) and a range of products;
- Reduced administrative procedures, since MultiCore takes care of the required permits for usage of its pipelines saving the clients cost and effort;
- Support from the government in the form of a 2 M€ subsidy from the Ministry of Infrastructure and the Environment.

Container Transferia (CT) (Port of Rotterdam) is a logistic concept which is in the process of being implemented after facing initial resistance on many fronts (PoRA, 2012). This innovative concept will take care of present bottlenecks such as decreasing reliability of flows, longer waiting times for inland shipping, rapidly declining accessibility of Maasvlakte for trucks, capacity limits of sea terminals, fine dust and CO_2 emissions, and inaccessibility of port for emergency services. The following factors have contributed to the success of the concept:

- PoR has taken a leading role when it comes to obtaining support and approval from the authorities, both national (Project Randstad Urgent) and local, as well as assumed the role of a manager to supervise the market parties. This has been the key factor in overcoming institutional barriers;
- The business model has been prepared after careful considerations in order to avoid vested interest or a conflict of interests. PoR will serve as landlord, investing in land and infrastructure in exchange for competitive rent. CT will be a neutral terminal which is free to act both commercially and operationally within formulated boundary conditions. A separate, independent organization will run the terminal. Such a model prevents controversy among the collaborators;
- For the CT to compete with direct truck transport to the Maasvlakte, a customs regime was necessary to make the terminal and the seaport a single area. Attention has been paid to such aspects by involving customs in the project;

– An added stimulant has been the enhanced green image for the participating companies, and in due course, CO_2 certificates for them.

Floating crane (initiative of many parties involved including Delft University of Technology, PoR, APM terminals, Kalmar and Royal Haskoning), makes double sided container handling in combination with a fixed crane possible. In spite of the many advantages (Nieuwsblad Transport, 2005a), and the existing potential markets, many practical and institutional barriers exist (Nieuwsblad Transport, 2005b). The cargo of a mega-container ship has diverse sources and destinations, which makes it difficult to plan a fast and efficient handling from container to inland vessels (and vice versa). The possibility of being able to influence the stowage planning of the container or inland vessel is almost negligible. Customs and empty containers add to the problem. Issues such as distribution of the costs and benefits among the parties are required to be resolved before such a concept can be implemented.

Despite the failure of the 'grey' terminal concept to take off, in September 2009, the management team at PoR initiated a pilot study over **multi-user terminals** (ITR, 2009), with the aim to achieve high berth utilization at quays and jetties. An exploratory brainstorm session highlighted the need for an investigation into legal/organizational problems which play a role in case of shared use of handling facilities. It also suggested an investigation into how multi-user contributes to raising berth occupancy and the handled cargo volumes. The study was expected to give insights into the financial, commercial, and legal aspects related to this concept.

Table 6.7 summarizes the advantages and the possible reasons for (non)implementation of these innovative concepts. An analysis narrows down the following enablers or deterrents to innovation:

Network and framework failures

Key deficiencies of companies, and failures in systems can be responsible for the failure of the innovation process. Various authors (Carlsson and Jacobsson, 1997; Smith, 2000; Edquist, 1997; Woolthuis et al., 2005) have proposed frameworks for analyzing or addressing failures in innovation systems. Network failures refer to problems in interaction among actors in the innovation system such as inadequate amounts and quality of links, 'transition failures' and 'lock-in' failures as well as problems in industry structure such as too intense competition or monopoly. Framework failures include gaps and shortcomings of regulatory frameworks, intellectual property rights, health and safety rules etc., as well as other background conditions, such as the consumer demand, culture and social values.

The no-go decision for the multi-functional quay concept can be attributed to a network failure, since the parties did not come together to find a viable solution, after the business case proved non-viable (Rebel, 2009). Likewise, the mandatory custom check acts as a barrier to the concept of floating transshipment hub in combination with a floating crane, that could allow the containers to by-pass sea terminals (and the customs), with many benefits for all parties. This represents a framework failure.

Table 6.7: Reasons for non-implementation of innovative concepts

Innovative concept	Issues/advantages	Possible reasons for non-implementation
Multi-functional Quay (Consortium CO3)	Efficient use of space, diversification (reduced risk)	High costs and tight schedules; advantages such as lowered market risks both for client and PoR are not included in business case; lack of triggers such as high land prices
Multi-user terminal (Leader PoR)	Intensive use of resources (quay and equipment)	Market approach (business model, collaboration among potential users) not clearly thought out
Containerland (Leader PoR)	Relocatable, reusable hence sustainable and economical, fast construction of temporary land	Limited requirement of temporary land; design for demolition is not an accepted concept in infrastructures.
Maxisteck (Leader PoR)	Relocatable reusable, hence sustainable and economical	Expensive, lack of trigger e.g. deep water or high price of sand for reclaiming land; long-term benefits of a relocatable structure not made explicit in a business case
Floating quay wall (numerous studies worldwide)	Relocatable, thus sustainable	Costly in comparison to reclaiming land in Rotterdam, needs triggers, e.g., deep water or scarce and costly sand
Common floating transshipment terminal (numerous studies in different parts of the world)	Reduces congestion in the hinterland, improves modal split	Institutional problems e.g. customs if placed outside; lack of triggers e.g. increasing congestion and decreasing accessibility
Floating crane (for double sided container handling in combination with a fixed quay crane)	Increased productivity, promotes modal shift	Costly (logistics requires an inland barge terminal); institutional problems e.g. customs, no trigger, e.g. congestion
Container Transferium (inland terminal in the hinterland allowing containers to be transferred to and fro from sea terminals using barges)	Efficient use of space and equipment on terminals, improved accessibility and modal split, CO_2 reduction, safety improvement, new business model- interaction with market & legal bodies for permits, subsidy grant	Being implemented
MultiCore pipeline (underground pipeline bundle for distributing oil, chemicals, and gas)	Space efficient, improved accessibility, CO_2 reduction, safe, flexible concept, initial investments and permits by PoR, subsidy grant	Implemented

Costs and risks

Mostly time tried design solutions and logistic concepts are preferred by organizations. Since these have been widely applied and therefore optimized (for some situations), and experience has been gained during their implementation, they carry reduced risk and costs. Innovation, in such cases, takes a back seat. For commercial organizations, the high costs coupled with a long payback period, are a critical issue for implementation of innovative concepts. Additional investments in research, pilot studies, and model tests is required in order to establish the technical feasibility of these concepts.

The classic go-no go thinking, based on economics, seems logical, but it has the unintended consequence of stopping innovation dead in its tracks (van Putten and MacMillan, 2009). Innovation requires other considerations and approach. The value creating potential of pilot projects needs to be brought into picture, but is not possible with traditional valuation methods. Monetizing added advantages of flexible solutions, such as double use of space (underground infra), increased utilization (multi-functional, and multi-user infra.), and extended lifetime (relocatable infra such as Maxisteck) will also help to tilt the scale in favour of innovative infra.

It is only very recently that tools that help to quantify environmental and social impacts related to an infrastructure project are becoming freely available to designers and planners. Extensive research is required before we learn enough to be able to validate these tools.

Compatibility with the existing system

The compatibility/ interoperability of an innovative concept, and therefore its integration into the existing system, both from a technological and organizational perspective is vital for its success. This requires an understanding of the entire value chain. The required changes, especially at the institutional level, maybe difficult to implement, requiring approval at European or international level. This is one of the reasons why many of these promising concepts such as the floating crane and floating transshipment terminal are on hold. Also, many cargoes require highly specialized facilities as the focus on seamless and efficient logistic operations (requiring facilitating infrastructure) increases. These new demands mean that innovation into flexibility takes a back seat.

Triggers

Many of the barriers to innovation vanish if a certain threshold of necessity is reached. New technologies will gain momentum when the need escalates as the following examples illustrate. Once accessibility became the biggest threat for PoR, especially due to the planned port expansion MV2, Container Transferium, a new tunnel and many other initiatives got an impulse (Transumo, 2009). The concept of double sided handling took shape in response to the productivity demands of a modern container terminal. Floating structures will become appealing once land reclamation is not an option due to environmental regulation. Underground port infra will get an impulse once space becomes expensive or scarce.

Entrepreneurial initiative and collaboration

Innovative technologies carry with them significant uncertainties and risks that may be beyond the capacity of a single organization to consider in isolation. Innovation requires capital, resources, specialized knowledge in many fields, information about the target market, willingness to take risk, the capability to handle risk, and a degree of leverage with various actors (the public sector, private sector as well as the private citizens). The many requirements clearly indicate that cooperation is essential to assemble expertise. Collaboration spreads the risk of innovation, and critically brings diverse intellectual and expertise to the problem(s) (Dale and Hamilton, 2007). Collaboration requires entrepreneurial initiative, and generally the party with the largest stake assumes leadership. The success of MultiCore pipeline and Container Transferium was partially due to the leadership of PoRA, their market approach, and the well thought out business models.

In Rotterdam, the factors that seem to be a barrier to implementation of innovative flexible designs mentioned above are: favourable local conditions (e.g., sheltered location, easy availability of fill material, small tidal range), the market situation (e.g. availability of inexpensive land and fill material), as well as institutional factors.
Such insights are essential for the successful implementation of APP.

6.7 Conclusions

The long lead times, high capital intensity, large unit sizes, and inflexibility once in place, all add to the problem of designing and constructing (physical port) infrastructures for an uncertain future. Since perceptions drive actions, insights into the viewpoints of stakeholders can be helpful in promoting flexibility. Therefore, we organized a survey at PoR to gain the perspective of the various stakeholders in the port (related) industry about flexibility. We followed this up with a brainstorm session about promising flexible solutions for infrastructures.

The view that flexibility in port infrastructure is an effective tool for dealing with future uncertainties was unanimous. Among the favoured strategies for flexibility in physical infrastructures were: design modularity, standardization, generic, and robust designs. The session also established that the issues related to implementation of flexibility, such as approaches to planning, design, and project appraisal need to be modified. In keeping with the suggestions of the participants, we propose modifications to the current design approaches. The four alternative approaches to infrastructure design are: design for fixed specifications and resort to ad-hoc adaptation, design for obsolescence and demolish, design for robustness through building in margins, or design for flexibility. All these approaches must be considered at the beginning of each project (instead of opting for a client specific design) and followed by a trade-off of the conflicting attributes.

Also, the project appraisal procedure is based on returns expected from individual business cases. Most participants were of the opinion that it was the main reasons why flexible design alternatives are not chosen over more traditional solutions requiring smaller capital investments. A solution would be to include (the costs and value of) flexibility in the business case or alternatively, to evaluate the project returns for a number of projects in a portfolio.

Flexibility facilitates reuse, concurrently optimizes use of natural resources, limits waste and pollution in the environment, and can result in significantly lower lifecycle costs (despite the costs associated with incorporation of flexibility and subsequent adaptations), and conserves energy resources. Flexibility and sustainability considerations, which include designing for deconstruction and reuse, must be incorporated into all designs. Our investigation established that examples of flexible infrastructures in PoR, or of reuse in general are few and far between. The practices related to reuse are limited to down-cycling materials into low-grade applications. A framework that guides adaptation and reuse has been presented.

Though many innovative logistic and infrastructural concepts were proposed in recent times, despite intensive engineering effort and investment in pilot projects or feasibility studies, none have been implemented. An investigation into the factors underlying failed and successful innovative endeavours through tracing some innovations at PoR corroborated that innovation is shaped by the interplay of need, economic, and institutional factors. The first lesson is that the value of flexibility needs to be made explicit. Secondly, the strategies for flexibility cannot be regarded in isolation from the efforts made at the institutional level to incorporate and implement flexibility. These insights are invaluable for a successful implementation of APP.

Many of the suggestions following from the brainstorm session have been dealt with in the remaining chapters and case studies.

Chapter 7

Valuing flexibility

Flexibility needs to be justified to the decisionmakers; therefore it must be measured in the most recognized unit, that is money - Nilchiani, 2000

7.1 Introduction

The volatile environment of today complicates decisionmaking at each turn. This also applies to the task of selecting among various capital investment opportunities and determining the right time for investment. The importance of investment appraisal in the port industry arises from the need for infrastructure investment combined with the primary objective of a commercial firm to maximize profit and shareholders wealth. The changing port environment with increasing need for innovation and flexibility, stricter cost control, and higher and quick returns on investments, add to the pressure of accurately valuing a project.

An insufficient analysis of an investment opportunity, use of inappropriate techniques of financial analysis, omission of value of flexibility, and decisionmaking based on wrong assumptions, can result in the rejection of the best alternatives (and opportunities)[1].

The rapidly changing economy is leading to yet another new paradigm. Corporate valuation may no longer depend on traditional fundamentals but rather on future expectations, since the value of a project depends on future prices, future technology, and future conditions of the market (Dixit and Pindyck, 1994; Mun, 2002). In recognition of the fact that under uncertainty, the value of a project or design alternative is driven by the flexibility it provides for adaptation, modern methods that include the cost and value of flexibility are being suggested. We will examine these in order

[1] Recently, there have been numerous examples of engineering projects that are technical successes, but financial failures (Sakamris and Flyvbjerg, 1997; Flyvbjerg et al., 2003). Some examples of recent unsuccessful investments by PoR: Rotterdam Port Experience, an education centre that gave the visitors insights over the port, has been permanently shut down one and half years after being set up. Investment in facilities for Lyondell B.V. at the Maasvlakte led to loss of revenue for the port due to lower cargo volumes than projected in the business case. Investment in the engineering of an innovative concept for a multi-functional quay wall for the company Odfjell could not be earned back, since the concept was never implemented.

to select a method suitable for port projects and port markets to be applied in the framework of Adaptive Port Planning.

Many have recognized that uncertainty about the final value (which depends on the occurrence of some specific state of the world) causes assets with flexibility to have 'option-like' properties. In recognition of these properties, the methods of modern finance theory, such as Real Options Analysis (ROA), have gained popularity in the last years for valuing flexibility. We will also examine how far the practices related to investment appraisal and asset management at PoR can benefit from this approach. We can then make recommendations over the relevance and usefulness of modern evaluation methods for the port sector. The application of selected method(s) will be illustrated through applying them for cases in PoR.

7.2 Evaluation during APP

The determination of the economic value of projects during project appraisal can be required:

1. to evaluate a project for its own merit;
2. to compare the relative merit of a project with other competing projects in a portfolio, and
3. to compare mutually-exclusive alternatives within a project. During port planning, these alternatives can pertain to designs, layouts, or complete master plans.

The last is particularly relevant in the framework of APP, when the superiority of a flexible/innovative solutions over traditional solutions has to be established before the management. After the basic alternatives have been devised in Step I, the mitigating, shaping and, capitalizing actions are set up in Step III to deal with 'certain' vulnerabilities defined in Step II. The judgement of the project and management team is required to respectively define and incorporate these actions to make the plan (or an alternative) robust. The associated cost, if it accrues to the project, is added to the the cost of the alternative.

When dealing with 'uncertain' vulnerabilities in Step III, the process is not straightforward. Because the probability and impact of a vulnerability are difficult to estimate, so is the cost-effectiveness of the associated shaping and hedging actions. The costs of a shaping action aimed at reducing the likelihood of a (threatening) development will very likely not accrue to an individual project. Nevertheless, the cost-effectiveness of an option which can be translated into a hedging action, needs to be determined before a decision can be made to incorporate it. For each alternative, the cost and value of such hedging actions must be included in the overall evaluation in Step IV. The corrective, defensive, and capitalizing actions prepared during Step V and to be executed in the implementation stage, may also require an option be incorporated during the design stage, after establishing its cost-effectiveness. Incorporation of an option in a previously unfavorable alternative might so enhance its value that it becomes the most attractive.

In general, an alternative will be adopted only if it has more (economic) value than other alternatives. Therefore, it should be properly modelled using appropriate methods. The current methods in the manager's tool-kit for valuing investment opportunities are payback rules, accounting rates of return, and net present value (NPV); these are inadequate to support decisionmaking under uncertainty (de Neufville, 1990; Dixit and Pindyck, 1994; Trigeorgis, 1996). Before examining alternative valuation methods, we will discuss some essential aspects of flexibility.

7.3 Some essential aspects of flexibility

Uncertainty and flexibility

We see flexibility in a project as a portfolio of actions to deal with uncertainty. In the absence of uncertainty, the returns of any initiative would be certain and no incentive would exist to implement flexibility. Options have value under uncertainty. As uncertainty increases, the value of this option, or the flexibility it provides, increases, since options provide protection against the downside of uncertainty but allow a firm to profit from the upside potential of uncertainty (Dixit and Pindyck, 1995; Amram and Kulatilaka, 1999; Damodaran, 2000; Ramirez, 2002; Eijgenraam et al., 2000; Kincaid et al., 2012).

Measure of flexibility

The fact that flexibility has different meanings in different contexts has made it difficult to develop a general metric, though efficiency, responsiveness and versatility are often mentioned. There is a general consensus over including the value of flexibility in a project evaluation, since otherwise the true value of a project is underestimated. For most commercial organizations this value refers to its economic value (and is subjective since it depends on the risk attitude of the person). According to Nilchiani (2005), the only way to give an impulse to flexibility is to measure and quantify it in the most recognized unit, that is money. Justifying flexibility requires valuing the long term potential of a design (or an investment opportunity) using other techniques than DCF. This is especially true for a marginal case where the traditional technique evaluates the NPV of the alternative as being low or negative, resulting in a no-go decision.

Cost of flexibility

Flexibility, irrespective of its location in the infra system, has a cost associated with it. Flexible infrastructure requires larger investment than traditional infrastructure. Phasing a project means delayed costs but also delayed returns and losing out on economies of scale. Abandoning a project results in an irreversible loss of resources. Flexible specifications for civil or mechanical works mostly result in robust choices that entail more costs. Flexibility in operations requires a flexible allocation of resources, which adds to the costs. Similarly, a selection criterion that places demands of flexibility on the layout, designs, or construction methods, results in costlier solutions. Hedges, such as insurance or demand guarantees, have an initial cost, as do project incentives. Hence, we need a way to value our gain to see if the investment in flexibility is cost-effective.

Value of flexibility

Figure 7.1 shows the expected NPV (EPNV) of a project and its probability– without flexibility (left) and with flexibility (right). The latter shows that NPV2 is greater than

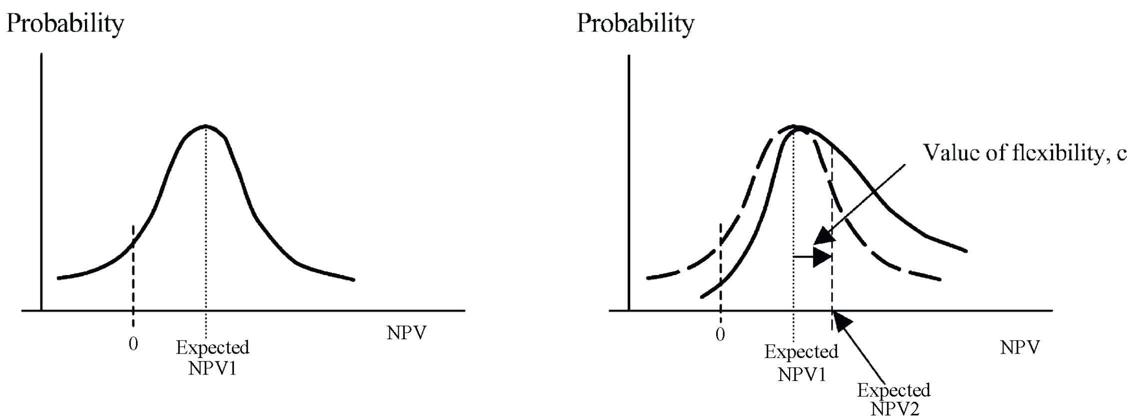


Figure 7.1: Project evaluation with and without flexibility (Yeo and Qiu, 2003)

NPV1 as well as the asymmetry or skewness in the probability distribution of the NPV or pay-off, which expands the investment opportunity's true value by improving the upside potential while limiting the downside losses.

The value of flexibility can be calculated using the following formula:

Value of flexibility (c) = ENPV2 - ENPV1
ENPV1: Net present value without flexibility (base case)
ENPV2: Net present value with flexibility

The decision rule for exercising flexibility is as follows:
If the value of flexibility is greater than the cost of acquiring it, it should be designed into the system.

Flexibility and efficiency

Efficiency requires just-in-time actions and employment of resources; this means exercising already incorporated options. de Neufville et al. (2006a) demonstrate just-in-time flexibility in a design of multi-story park garage where capacity is created in response to demand. Such an approach takes advantage of the upside potential while cutting the downside risk. Just-in-time solutions are not always practical in infra systems, specially at the level of physical infra. In such cases, just-in-case flexibility is more to be advocated. Similarly flexibility in one link of a supply chain may reduce efficiency elsewhere, however flexibility contributes to effectiveness for long- term planning projects confronted with uncertainty.

Comparison of real and financial options

A financial option entails a relatively small initial investment (in addition to the cost associated with exercising the option) compared to the pay-off, and the pay-offs are asymmetric. This may not be true for all real options. In case of investment in physical infrastructure, most costs are incurred at the initial stage. The costs of subsequent adaptations in order to employ the flexibility are small: e.g. the cost of dredging in front of a quay wall designed for larger ships in the future, or coupling or decoupling of modules in order to upgrade or downscale a structure, or of transporting a floating pontoon to a new location are much smaller than the capital investment costs. However, the overall savings are significant, if we take into account the loss of revenue due to interrupted operations in the port during adaptation activities at a later stage for an alternative without flexibility[2]. This underlines the importance of valuing flexibility, taking all trade-offs into account.

Option-like properties

Though real options always represent flexibility, not all flexibilities possess option-like properties, and satisfy the classical definition of an option. This distinction is important since further on, we will examine the use of option based valuation methods for valuing flexibility. These 'classical' methods may not be applicable, and some flexibilities may be best evaluated using other methods. In order to select an evaluation method which matches the system under study i.e. ports, a discussion over flexibility in relation to port projects follows.

7.4 Flexibility in relation to port projects

In Chapter 4, we have discussed 'in' and 'on' options in infrastructure systems; now we examine how relevant and valuable these are in case of port projects. A comparison is given in Table 7.1. 'On' options must be valued, so that the market value of a project

Table 7.1: Comparison of real options 'on' and 'in' projects (Wang, 2005)

Real options 'on' projects	Real options 'in' projects
represent opportunities to change project course	represent design flexibility
valuation important	decision important (go or no go)
relatively easy to define	difficult to define, need engineering knowledge
interdependency/path-dependency less an issue	Interdependency/Path-dependency an important issue

can be accurately assessed and investment opportunity appraised. An 'in' option must be valued to justify its incorporation in a project or alternative. Both these option types can exist at different levels of our three layered infra system.

[2]E.g. investment in extra material for a robust quay construction is very trivial compared to costs incurred if a ship has to wait during the time the repairs or adaptations are being carried out at the quay (an 8,000 TEU ship, for instance, costs approx. $140,000 per day (Khan et al., 2011)).

7.4.1 Managerial flexibility in port projects

Managerial or 'on' options allow managers to respond to external developments and seek opportunities e.g., staging investments as markets develop, shut down and restart production as prices change, expand or contract assets or businesses as demand shifts, switch fuels or raw materials as relative prices change, or to divert cargoes to the highest-priced market (Osborne, 2008). Though generally changes to a project's scope, budget, and timing are viewed as negative, in face of uncertainty these options to change the course of a project can help to limit losses and exploit the upside. Of course, the nature of the contracts must allow this (contractual clauses levying heavy penalty on adaptation do not encourage managerial flexibility). These options inherent in a project add value since they lower the project risks, yet the very nature of port projects and markets introduces many limitations as to their applicability and effectiveness. Some observations:

- The indivisible and irreversible nature of engineering projects can result in sunk costs in case of abandonment, firstly because the infrastructure can be put to little alternative uses, and secondly, the salvage value is negligibly small.

- A port project, or any other engineering project, goes through various phases: preliminary design, feasibility study, detailed design, and realization. Since phasing is inherent in engineering projects, it should be exploited by building in clear go-no go moments based on well-defined criteria. Phasing also applies to projects of innovative character where a pilot study or initial feasibility determine the go-no/go. The initial effort of such pilot projects is small, and the subsequent phase needs only be initiated if the results are promising. This creates upside opportunity while reducing downside risks.

  Phasing a project can help to resolve uncertainty, but adds to the costs of mobilisation and de-mobilisation resources during the realization phase, and the cost and effort (re)acquiring permits etc., and delays returns. A middle sized project is therefore not likely to employ this flexibility. However larger projects, (with a longer investment horizon) face more uncertainty and therefore should incorporate phasing, creating the option to abandon or postpone the following phase of the project, and avoid or delay capital expenditure if the market deteriorates. This must of course be feasible within the constraints of the client's requirements, standard procedures, and other legalities.

- A port authority has to enter into contracts not only with its clients, but also with financiers and construction contractors. Some of these are long-term contracts (therefore face a lot of uncertainty), while others may confront high risks. In such cases, various mechanisms are included to deal with uncertainty. Cargo-guarantees, revenue-guarantees, collaborations, partnerships, reduced payback period etc., all represent flexibility in contracts, allowing parties to react to unexpected events. Governments often grant various forms of support to infrastructure projects, which may include a subsidy, a guarantee or even a direct capital contribution that would add direct value to the project, as well as indirect value by attracting investors. Concessions are sometime included in the contract to protect the interests of some project shareholders. All these represent options and should be included in the project valuation (Charoenpornpattana et al., 2004; Cheah and Liu, 2006).

- Option to wait is most valuable on assets where the owners have proprietary technology or exclusive ownership rights and the barriers to entry are high so that the owners are not losing revenues to the competition by waiting. Even then, the cost of waiting must be weighed against the advantage of waiting, since waiting can mean losing the first-mover advantage. However waiting can reduce uncertainty as additional information becomes available. Putting the construction of the Euromax terminal in PoR on hold while MV2 layout was being finalized is one such example, where it became clear that the selected location could interfere with the entrance for the MV2 project (in one of the proposed alternatives). Euromax was subsequently shifted to a new location on the opposite side of the Yangtzehaven. However delaying and restarting a project has disadvantages. The new start, mostly with a different project team, results in knowledge loss and extra costs, as was also the case with the Euromax project that was re-engineered;

- Growth options apply to exploring new generation products or processes or new markets, where strategic core capabilities are needed. These options collectively allow a company to enhance bandwidth by enhancing the upside potentials, without excessively increasing the downside risks. Nonetheless they have to be economically justified.

Modern evaluation methods demonstrate that this managerial flexibility (or dynamic decisionmaking) directly influences the cash flow streams. However, as illustrated through above examples, establishing whether the managerial or 'on' options enhance the overall value of a project needs to be carefully investigated taking all the indirect implications into account. This is far from easy.

Another consideration is that while comparing alternatives in a project, all of which possess similar managerial flexibility, these options will mostly not influence decision-making. Therefore without dealing with these further, we refer the interested readers to Mun (2002); Kodukula and Papudesu (2006); Borison (2005a) for more information, and to Leslie and Michaels (1997) who argue that it is possible to increase the value of managerial options once they are acquired, and give it the name pro-active flexibility.

7.4.2 Flexibility 'in' port projects

'In' options in a project are generally difficult to define and value. Defining them requires an understanding of the underlying engineering design as well as specialized technical knowledge in the concerned disciplines. Research is needed to understand the generality of models for evaluation of 'in' flexibility (Neely and de Neufville, 2001). The ongoing efforts aims to develop generic methods for applications to engineering design.

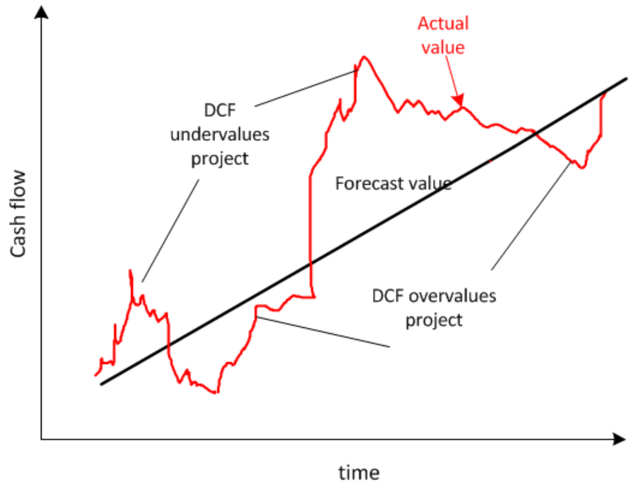


Figure 7.2: Project value versus DCF estimate

Port infra systems, however, are relatively well understood, and identifying 'in options' and studying their implications on the performance of the port is possible with some effort. In this dissertation most illustrations involve flexibility 'in' the bottom layer of the infra system, also due to the large cost implications for a (landlord) port authority.

7.5 An investigation into valuation methods

When uncertainties are small, the traditional techniques serve an important role in ensuring economic rationality and consistency in corporate and governmental evaluation of projects (de Neufville et al., 2007). The traditional methods of investment appraisal involve a financial evaluation in a business case, using standard DCF methods. In addition, literature refers to three types of probabilistic methods: scenario analysis, decision tree analysis (DTA), and simulations. A description of the well known methods mentioned in this section can be found in innumerable standard texts, research papers and thesis. Interested readers can refer to de Neufville et al. (2007) and Damodaran (2000) for a complete treatment of the subject. We examine the methods only for their advantages and drawbacks and their handling of uncertainty and flexibility, in order to select a method that can be gainfully applied in the framework of APP.

7.5.1 Discounted Cash Flow methods (DCF)

In traditional capital investment appraisal method using DCF, the present and future cash flows of a project are determined and a financial parameter such as internal rate of return (IRR) or Net Present Value (NPV) estimated. This is by far the most used technique for assessing the feasibility of port investments. IRR is a percentage, and though suitable while selecting among alternatives, it becomes difficult to compare projects that differ substantially in size and outcome. Moreover, in case of mutually exclusive alternatives, this method does not account for risks. NPV is superior to

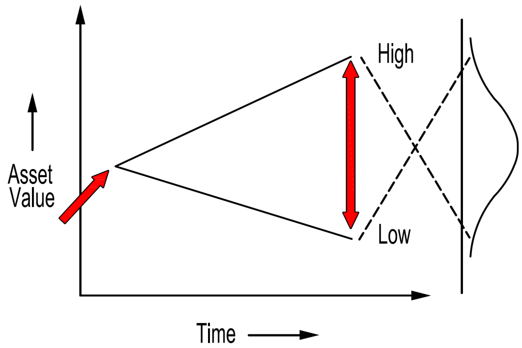


Figure 7.3: Cone of uncertainty

IRR since it considers the entire lifetime of the investment, considers the time value of money, and can include risk levels also for mutually exclusive projects, through different discount rates[3]. Yet many firms, including PoR, favour IRR since it avoids having to estimate a discount rate.

DCF uses expected value of parameters, and the decisionmaking is based on the most likely outcome of a situation, e.g., expected value of investment and potential revenues. However, the expected value can deviate from the actual value as shown in Figure 7.2 (Mun, 2002). This presents serious drawbacks (CPB/NEI, 2000; Smit and Trigeorgis, 2007). An analysis of the performance or value of a system using average estimates of uncertain parameters does not lead to a good estimate of average performance of the system. This is because engineering systems are non-linear (de Neufville et al., 2007).

The variables such as costs and revenue are uncertain, and the assumptions underlying their determination questionable, but in a business case these variables are treated as if certain. In fact, uncertainty increases over time as shown in Figure 7.3 (Mun, 2002), and a distribution can better describe the outcome (or a variable) than a point estimate. DCF, which is often used in combination with scenarios, can also lead to double counting of risks – on one hand the cost of capital is adjusted for risk, on the other hand, due to use of scenarios some risks are explicitly included in the cash flow. Flexibility in decisionmaking (as well as in design and operations), enhances the value of a project, but cannot be included in DCF method, which assumes that decisions are made now, and will not change later, so that the cash flow streams for future are fixed for the course of the project. DCF methods are adequate for a stable environment, where the projects have deterministic requirements and the management has a clear strategy. They are inadequate for port projects, which due to their long lifetime face the challenge of uncertainty, and make any point estimate of the system value virtually meaningless.

[3]A key concept in DCF analysis is, that the discount rate varies according to the risk of the asset, and a risk surcharge is added to the discount rate. This risk surcharge or premium is determined on basis of project's inherent risk and its return requirements. It is always difficult to translate risk into hurdle rate; the transition is always subjective and often arbitrary. The estimate of the discount rate is likely to change over time with changing market conditions and opportunity costs associated with other projects at the firm (Greden, 2005). Managers regularly and consciously set discount rates that are often three or four times their weighted average cost of capital.' This is not only grossly inconsistent with the theoretical model, it produces discount rates that severely undervalue innovative projects (Myers, 1984; Dixit and Pindyck, 1995).

Generally, most major engineering projects are subject to large uncertainties, and consequently marginal projects or pay-offs are avoided. If the NPV is very high, even in a worst case situation, a sophisticated analysis will not provide additional information, since the decision will be 'go' anyway (Kodukula and Papudesu, 2006; Eschenbach et al., 2007). A project with an NPV close to zero (whether positive or negative) may have a large option value that may drive the decision in a different direction. Sophisticated methods can add value to the decisionmaking process for such engineering projects.

7.5.2 Scenario analysis

Scenario analysis involves creating representative scenarios and estimating expected cash flows and asset value under each of these scenarios, with the objective of estimating the extreme values. The dispersion then gives an indication of the risk if the scenarios are worst case – best case scenarios. Scenario analysis is best suited for dealing with risk that takes the form of discrete outcomes, and for new or unpredictable risks when no historical data is available. If nothing else, the process of thinking through scenarios is a useful exercise in examining how the competition will react under different macro-economic environments and what can be done to minimize the effect of downside risk and maximize the effect of potential upside on the value of a risky asset. Due to the qualitative nature of approach, it is easy to relate scenarios to adaptive response strategies. If used in combination with DCF, one must be careful not to double count risks.

7.5.3 Cost-Benefit Analysis (CBA)

The practical development of Cost-Benefit Analysis (CBA) came about due to efforts of US Army Corps of Engineers (USCAE) for projects for the improvement of the waterway system. In a CBA, all the societal impacts of a project are assessed systematically and valued monetarily. CBA now forms the state-of-the-art in the economic appraisal of public projects in most high income countries (Grant-Muller, 2001; Hayashi and Morisugi, 2000).

A port project, either during development, or as a result of the core activities of a port, may have indirect effects (second order and multiplier effects), of consequence for the port and the surroundings. These can include lowered overall transport costs, increased development prospects for other port related industries, clustering of companies with related functions, increase in employment, increase in income and spending, and costs and benefits related to safety and security etc. Such a project could necessitate investments in public infrastructure, resulting in significant societal benefit. It could also require implementation of environmental mitigation measures that generate benefits for the surroundings such as improved working and living environment. Thus, though from the point of view of a landlord port authority a financial analysis is sufficient; in order to value a public project or a project with potentially high societal costs or/and benefits, a socio-economic analysis is more suitable. The added benefits may be relevant to show to the decisionmakers. For a port authority or a project owner to receive rightful credit, a standard procedure should be established to value the port development related external effects, so that these benefits or costs can be assigned to the rightful parties or the government.

Assessment of benefits based on an accurate impact analyses without double counting of impacts, the problem of estimating shadow prices (if the prices do not reflect the actual value), and the subjective nature of assumptions, all add to the difficulty of carrying out a CBA, and the contestable nature of the results. A socio-economic CBA is not always satisfying because bringing several effects under one denominator can imply a trade-off that should not be made by the CBA-analyst, but by the policy makers (Verhaege, 2007).

Multi-criteria analysis (MCA) is often favoured in place of monetary evaluation, since not all criteria can be valued into money in an acceptable way, or measured in an interval or ratio scale. The scores assigned to the various criteria for an alternative cannot just be added up since they have different measuring units (Verhaege, 2007). A common approach is to mention such effects as pro-memory item next to the profitability calculation, yet these mostly remain outside the evaluation. (For borderline projects, where a go-no go decision is difficult, these may tilt the balance in favour of a project carrying social benefits). A mixed form of evaluation can be considered that involves a monetized part that is integrated in an overall multi-criteria method such as the Balanced Scorecard method. This approach combines the advantages of CBA and MCA.

7.5.4 Decision tree analysis

In case of long-term projects, it is important to map out the strategic choices and the moments in time at which information becomes available (CPB/NEI, 2000). Decision Tree Analysis (DTA) is an NPV calculation that incorporates different future scenarios based on their likelihood. The cash flow for any given year is the weighted sum of the cash flows for each scenario that could occur in that year and the weights are equal to the probability that a specific scenario will occur. One benefit of structuring the problem as a set of possibilities is that it helps people realize that choices are not polar but actually include a wide range of combinations. It is a method of project evaluation that brings uncertainty, managerial flexibility and decision rules into picture. Such an analysis leads to three results: structuring of a complex problem, definition of the optimal choice for any period of time and the identification of an optimal strategy over many periods (de Neufville, 1990). DTA is ideal when the investment alternatives are defined, the decisions are sequential and contingent determined by managerial flexibility, and the ambiguity is resolved at distinct, discrete points in time.

While DCF uses risk-adjusted discount rates in order to account for market risks, DTA uses probabilities of outcomes. DTA is difficult to apply when multiple sources of uncertainty are present and the choice of discount rate remains subjective. Damodaran (2011) warns that the expected values are not risk adjusted (despite that the possibility of good and bad outcomes are factored in) and warns against double counting risk in decisions by using risk-adjusted discount rates that are set high to reflect the possibility of failure at the earlier phases. de Neufville (2003a) suggests in order to get the right value, the discount rate can be adjusted for risk for each branch of the tree as well as the actual probabilities of occurrence of particular events. de Neufville et al. (2007) suggests that DTA works well when likelihood and timing of critical uncertainties are understood, information sources are more focussed on individual projects, variables without an established price history are important, and strategy development is the main focus. DTA is best suited for sequential and discrete risks, that can be assessed either using past data or population characteristics (Savvides, 1994).

7.5.5 Simulations

The use of simulations in investment analysis was first suggested in an article by Hertz (1964). These methods describe uncertain variables in a cash flow model in terms of probability distributions. The model, which builds upon the static or deterministic business case (base case) can be set up in a simple spread sheet. A distribution can be defined in many ways (under the assumption that we can extrapolate the future) – using historical data, cross sectional data (from similar investments), or from empirical data. It can be discrete for some inputs and continous for others. There are no constraints on the number of variables that can be allowed to vary in a simulation. Correlation between variables can be treated by varying the input with the greatest impact or building the correlation explicitly into simulation. A risk-free discount rate can be used in the model. Thereafter, it is essentially a Monte-Carlo simulation of NPV that calculates in a consistent manner the expected return of the project.

We have discussed earlier that companies, including PoR, reduce risks by incorporating mechanisms clauses that formalize the expectations and responsibilities in their contracts. These include guarantees and discounts, determination of CPI, negotiated tariffs etc. These can also be built into the spreadsheet as decision rules. Flexibility, design and managerial, can be incorporated using simple logical rules (e.g. if, else, etc.). By comparing the NPV with the NPV from the base case, the value of flexibility can be estimated. The results of the simulation provide both central and dispersion measures; thus they are complicated but more insightful and realistic compared to results from DCF methods. Statistical information (such as the max., min., or 90% cumulative probability value) gives more information about project feasibility than a single NPV value computed using the expected mean of input parameters. The goal is to subsequently act on desirable properties of the entire distribution to take advantage of upside opportunities and reduce possible downsides (Cardin and de Neufville, 2008).

de Neufville et al. (2006a,b) have made a case to simplify real option valuation by promoting a 'spreadsheet approach' avoiding complex financial procedures and using available data. This method encourages a careful re-examination of the single-value estimates in the deterministic appraisal. It enhances decisionmaking on marginal projects by providing additional information on risk (i.e., the risk/return profile). It also reduces bias since the analyst does not need to use conservative point estimates, but can specify a range. Moreover, the results from a simulation are a visual reminder that we are estimating value in an uncertain environment (Savvides, 1994).

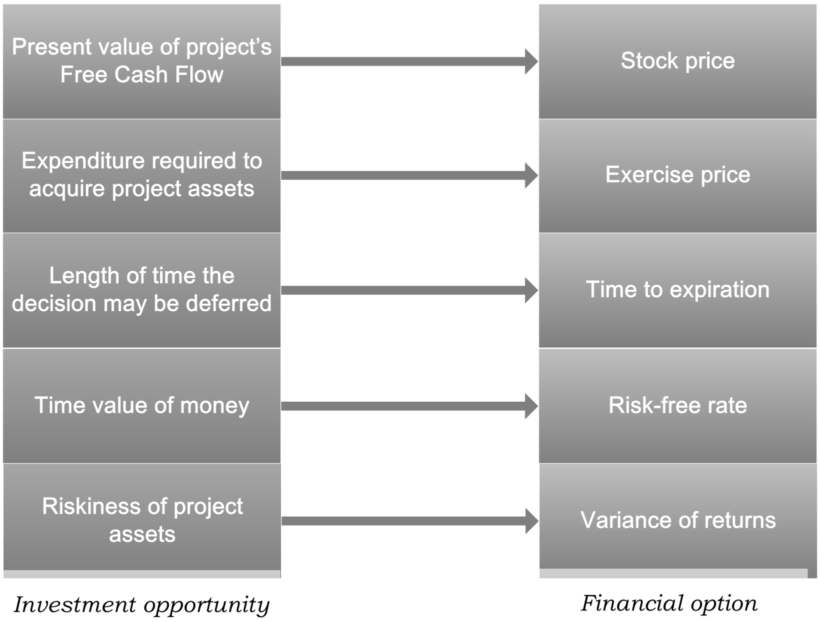


Figure 7.4: Link between investment opportunity and a call option

Simulation suffer from the same drawback as the DCF method. It does not take into account the contingency or flexibility during decisionmaking and its impact on the project valuation. A decision tree analysis or a real options analysis, in that case, is more suitable. Two other drawbacks in practice are: the problem faced in attempting to define probability distributions, and the subjectivity of the method. Questioning the assumptions on which expert input is based, can get meaningful results.

7.6 Real Options Analysis (ROA)

7.6.1 Description

Over the past decade, ROA has attracted attention as a potentially important tool for investment planning and project evaluation (Borison, 2005b), and has gathered support across the business world in academia, consulting, and the corporation (Leslie and Michaels, 1997). Recent government documents in the Netherlands have also made a mention of real options for investment decisions (CPB/NEI, 2000; Koopman and van Beek, 2007).

The method has evolved from models developed for stock option valuation by Black and Scholes (1973), based on the observation by Myers (1984) that similar models could be used to value investment opportunities in real markets; hence, the label 'real options' for this evaluation technique (Guthrie, 2009).

Real option methods include partial differential equations which can be solved using closed form solutions, analytical approximations, and numerical methods. In addition, we have the binomial and multinomial approaches and simulations. Without describing

Table 7.2: Real Options Methods and Techniques

Option valuation technique	Specific method	Limitations and advantages
Partial differential equation	Closed form solutions (e.g. Black Scholes)	Limited applicability, inherent complexity, no transparency, assumes lognormal distribution of underlying asset value, no jumps in the underlying asset value
	Analytical approximations	Computationally difficult, difficult to explain
	Numerical methods	Computationally difficult, inability to deal with multiple sources of uncertainty related to underlying asset value
Lattices	Binomial method	Offers transparency by showing project values in the future for given expected pay-offs allowing rational decisions, Ease of use, input parameters can be changed easily over the option life, transparent to communicate to upper management
Simulations	Monte Carlo	Use for European options with fixed option exercise date, can include many uncertainties, time consuming, tedious for American option without fixed exercise date

the methods, Table 7.2 summarizes the limitation and advantages of these methods. The binomial approach is favoured due to its mathematical simplicity and ease of exposition, and binomial lattices models are the most widely accepted valuation tool of ROA for flexible projects in engineering and management (Mittal, 2004; Cardin and de Neufville, 2008). Therefore, we will examine these in more detail.

The binomial lattice models (Cox et al., 1979; Copeland and Antikarov, 2001) use the same approach as decision analysis, but combine this with a consistent valuation model. The essence of the lattice analysis is to project forward the broadening range of possible outcomes that could develop from a starting point. This is done using a binomial process that projects how a process might evolve. The lattice process is carefully calibrated to maintain the characteristics of the steady process being modelled, i.e. replicate the desired trend and standard deviation of this process. The mathematics involved in calculating a binomial lattice is easier to explain without the use of often intractable and stochastic mathematical techniques applied in partial-differential equations (Mun, 2002).

Binomial lattices can be solved to calculation option value using two different approaches: risk neutral probabilities and market-replicating portfolios. The latter assumes that there are no arbitrage opportunities, and that there exist a number of traded assets that can replicate the payout profile of the asset under consideration. We present the risk neutral probabilities approach in Appendix D. A limitation of the method is that path independence may not apply in case of an engineering project. Cardin and de Neufville (2008) mention that Enumerative technique method (Wang, 2005) can be applied for path-dependent cases, but due to its added complexity, we do not consider it further.

ROA is most beneficial when competing projects have similar values when evaluated with traditional DCF method or where NPV is low and marginal. It is often applied to significant investments that warrant the additional costs of analysis. Investments in flexibility, innovation, and research and development involve extra costs, which can only be justified if they are included in the project evaluation using such techniques which recognize the value of dynamic decisionmaking on the cash flow stream.

ROA has its proponents and opponents. According to some, it is no longer a question of whether options pricing models can be applied to real options problems. It is matter of practitioner understanding clearly the assumptions and limitations behind the application, using the right tool to solve the problem, and exercising caution in interpreting the result (Copeland and Antikarov, 2001; Amram, 2002; Damodaran, 2002; Kodukula and Papudesu, 2006; Anderson et al., 2009). ROA is still not in widespread use, for some of the same reasons that delayed the use of the DCF method – a lack of understanding of the underlying tools and the benefits of the method.

7.6.2 Limitations of ROA for port projects

As we saw in the previous section, ROA is often cited as a valuation technique, yet the assumptions made for calculating the options value do not map very well with complicated investment decisions related to engineering/infrastructural projects. The problems associated with the use of option pricing models relate to three factors: the difficulty of obtaining input data for the models, the validity of underlying assumptions for engineering systems, and the problems of implementation, and the black-box nature of the results. We will discuss these problems in the context of port projects and markets.

a) Difficulty of obtaining input data for RO models
The parameters in a RO model are difficult to identify. There is no predetermined exercise price, or a predefined time to expiration (Zhao and Tseng, 2003). In an engineering system, the underlying asset, i.e. the infrastructure is not traded, thus its value and volatility are difficult to estimate. The future value can't be projected simply from the past data (de Neufville, 2010). One way of valuing the asset is an DCF calculation. Volatility could be estimated by selecting a number of reference projects, and the variance calculated based on the cash flows and discount rate. This presents a practical problem. Even if similar projects can be found, the data over the costs, and specially the revenues is difficult to obtain[4]. And if estimated from the historical data, the variance is a static value, and not a variance in project value over time. Estimating the volatility for innovative systems, for which there are no reference projects, is also implausible.

b) Key assumptions not met by engineering systems

[4] A start has been made recently at POR by making available a business intelligence tool to track harbour dues etc. The fact that the clients in case of harbour dues are shipping lines and not terminal operators, and that in case of contract income (leases), there are sometimes multiple contracts with a regular client, makes it difficult to trace the right figures.

The major assumption underlying financial option pricing models are: geometric Brownian motion which describes how the price of a stock moves, path independency, existence of a complete market where arbitrage is non-existent, and complete liquidity of the underlying asset. This restricts the practical application of financial options analysis to those projects whose outcome is a commodity traded in the world market and even assumes that the volatility of the project is the same as the observed volatility of the relevant commodity (Ramirez, 2002).

All engineering systems including ports are subject to both market and non-market uncertainties. Considerations of non-market uncertainties represents a departure from classical options theory which provides the rationale for risk-free discounting (Greden, 2005), and on which ROA methods are based. Also, not all 'in' flexibilities in the port systems possess option-like properties and satisfy the classical definition of an option. These may not be suitable for evaluation with models based on options theory.

The path independency condition means that value of a project depends only on its value at any time, not on anything we do to the system (Wang and de Neufville, 2005; de Neufville et al., 2007). The value of any engineering project however, depends on the path, which may be altered by a manager or any other changes introduced in a system. The assumption of complete markets imply that investment decisions can be made solely on the basis of market information and all owners, regardless of their beliefs and preferences will agree on appropriate project values and management strategies (Smith and Nau, 1995). In short, the value of the project would be solely determined by its market price.

Port markets and projects do not justify these assumptions. For instance, PoR derives its revenue from harbour dues and land lease rent (approx. in the ratio 55% - 45%). Generally, concessions or subsidy arrangements in the contractual agreements with the terminal operator are incorporated to shape demand or limit volatility. The current practice is to hedge against the market risks by means of guarantees that lead to a minimum return on investment of 6% - 7% for client related projects. The land lease tariffs are determined per project by the PoRA (land owner), based on a variety of considerations. The more or less monopolistic position of PoR may also contribute to the market imperfection. Complete markets also assume that all external effects have been internalized. In reality, costs such as the costs of congestion or indirect benefits of port projects are not discounted in the price.

Arbitrage is the possibility of a risk-free profit at zero cost. The options pricing model assumes that the financial assets are liquid, and trading closes any price gaps so that 'arbitrage' opportunities seldom exist. There is no opportunity for a risk-free hedge with most real options, therefore the risk-free arbitrage assumptions implicit in financial options need to be relaxed (Cobb and Charnes, 2007; Kodukula and Papudesu, 2006).

c) Problems of implementation and black-box nature of the results
RO models are complex, and often solvable only via numerical procedures. Until user-friendly software is commonly available, it is not likely that the methodology will be widely accepted. Borison (2005b) states that the field of options is growing rapidly, and our understanding of both financial and project-based options is bound to increase

over time. It is likely that basic options valuation, together with a basic understanding of frequency and volatility, will become commonplace in the near future. But for now, the state of affairs from a potential practitioner's point of view is problematic. The difficulties in comprehending the complex underlying theories gives the results a 'black box' flavour. Many suggest that at its current stage of development, strategic options analysis will benefit more from the development of a qualitative framework for analysis than from complex or black-box approaches (Cheung, 1993).

No examples are to found in literature, in which a pure financial options model is applied to value flexibility 'in' engineering systems. This is probably due to the limitations stated above, and the multiple sources of uncertainty applicable to design. Based on our criteria and suggestions from literature, we can proceed to select a method.

7.7 Selection of an evaluation method

7.7.1 Requirements from the method

APP requires that the value of flexibility be made explicit during evaluation, so that decisionmaking is in favour of flexible solutions. The selected evaluation method must meet a few basic requirements:

- The method should be simple, so that a model can be set up quickly with little effort; it should be well understood, specially as to its limitations, and it should be able to evaluate flexibility 'in' projects;
- It should meet our objective, i.e., a rank ordering of alternatives without necessarily determining an exact market value;
- The results should be intuitive, and possess the communicative power to convince the management of superiority of flexible, innovative solutions;
- The method should match the characteristics of a port system, i.e., we should be able to utilize the intricate knowledge of the port system and its processes gathered during the planning and design process, often through intensive (nautical- and operational) simulation studies;
- It should be able to model uncertainties and flexibilities as they manifest themselves in engineering systems, thus it should be suitable both for market and private risks. It should be able to deal with multiple sources of uncertainty applicable to design. The uncertainties facing designers can be continuous (e.g. demand) or discrete (e.g. a new law policy or appearance of a new competitor) and a valuation model should be able to handle the jumps;
- It should be able to simulate reality by varying all uncertain parameters simultaneously. Easy manipulation of uncertain parameters in the system model will help to get insights into system response, and the impact on the value of the system under various scenarios.

Table 7.3: Comparison of selected evaluation methods for engineering systems

Criteria	DCF	DTA	Simulations	ROA (binomial lattice)
Approach /processes	deterministic	deterministic, with a few mutually exclusive outcomes	probabilistic	uses stochastic processes built up by sequential steps occurring with given probabilities
Type of uncertainty	private and market risks - discrete	private and market risks single source of uncertainty steady/discrete	private and market risks many sources steady (no jumps)	market risks single source
Estimates of input parameters	based on historical data	based on historical data	based on historical data or specified as a function of known variables	difficult to estimate, often no comparable antecedents
Handling of uncertainty	through risk adjusted discount rate; use of scenarios; sensitivity analysis of the key variables	through probability of project outcomes	through defining probability distributions, and risk adjusted discount rate	acknowledges that uncertainty can increase the value of a project
Applicability	reasonably clear	reasonably clear	reasonably clear	the theoretical foundation of ROA may limits its applicability in any engineering context
Implementation	requires little effort	requires considerable effort if the number of branches increase	requires little effort	requires a lot of effort in data collection; each uncertainty has to be dealt with separately
Flexibility 'on' projects	cannot capture 'on' flexibility, undervalues projects that produce little or no cash flow in short term	can capture 'on' flexibility, recognizes that path of a project can be altered	cannot capture 'on' flexibility, recognizes that path of a project can be altered, long-term value of an option is recognized	
Flexibility 'in' projects	can capture flexibility through a scenario analysis	can capture flexibility through projecting it in the cash flow	can capture the range of flexibility through projecting it in the cash flow using decision rules	application is questionable due to the underlying assumptions
Results	a single number independent of probability; is not always conclusive for decisionmaking	a single number	the outcome is a probability density function; gives added insights	market value; independent of probability (arbitrage enforced pricing)
Market valuation	no link is made to the market value	no link is made to the market value		assumptions related to market mechanisms need to be satisfied

7.7.2 Comparison of the methods

In Table 7.3, we compare the evaluation methods discussed earlier. The methods are compared on criteria such as the validity of assumptions, the ease of implementation, the transparency of results, applicability, types of uncertainties and flexibilities handled, and ease of acquiring data. Scenario analysis and CBA are not included in the comparison. The former is an extension of the DCF method with essentially the same drawbacks. Since we assume that the (indirect) benefits of defined alternatives will not differ significantly, a CBA will generally deliver no added value. Even when alternatives do differ as to the intangible effects, monetizing them is problematic, and we will resort to a qualitative evaluation.

Greden (2005) suggests that if exercise of the design's flexibility depends on how the system performs physically in the future, a simulation model that includes an engineering model of the system's physical performance under uncertainty is needed.

Our objective, as stated, is to compare alternatives (plans and designs with or without flexibilities). The process of elimination brings our choice to a cost-revenue model using the tools of traditional economic analysis, such as stochastic DCF and DTA. The utility function could be the NPV, the payback period, or even total costs over the lifecycle of the infrastructure in cases where the benefits are difficult to measure. From a financial standpoint, these methods have many shortcomings (see Table 7.3), but they achieve the consistent comparison of alternatives (Kalligeros, 1998; Eschenbach et al., 2007).

Port planning requires an intricate understanding of elements, processes and the links in the system of interest. This requires getting acquainted with relevant new technologies, working closely with specialists who have detailed knowledge of the technical possibilities, and nearly always simulation studies to investigate nautical safety, optimize operations, and estimate operational parameters related to the system performance. This synthesized knowledge (of system parameters and the functional relationship between them) can be applied to set up cost-revenue models that can be employed for project appraisal.

In some cases, it may be useful to model the physical performance of the system explicitly in Step III of APP. For instance, establishing the cost-effectiveness of an individual hedging action may first require an estimation of its impact on the physical performance. Such an evaluation has both technical and financial elements. However, if multiple uncertainties and flexibilities are present, and an overall evaluation is required in Step IV, the model can become complicated. Moreover, there are no guarantees that the extra effort will lead to added insights.

Our choice of a valuation method might seem at odds with the common view that ROA must replace the traditional tools of evaluation. However, in the next section we suggest that the qualitative approach to real options i.e. real options thinking, is unmissable. It compels decision makers to take into account a lifecycle perspective and think in terms of flexibility.

Table 7.4 shows the application of the selected method for two well known uncertainties in the port sector, i.e., demand and new technology (e.g., evolution in ship sizes and in equipment, transport, handling, and logistic concepts). Flexible options incorporated

Table 7.4: Evaluation models for port projects

Uncertainty	Demand throughput	Future technology
Type of uncertainty	market (diversifiable)	non-market (non-diversifiable)
Source of information	historical data, expert opinion, monitoring external environment	expert opinion, monitoring external environment
Flexibility	Flexible capacity	Flexible capacity and flexible operational and administrative procedures
Evaluation model	Monte Carlo model based on cost-revenue	Monte Carlo simulation model based on cost-revenue for flexible designs
Assumptions/ Requirements	Exercise based on economic criteria (financial model requires path independence and a complete market)	Exercise based on economic criteria (improved physical performance is translated into economic benefits)
Limitations	Choice of probability distributions and discount rate is subjective	Choice of probability distributions and discount rate is subjective

in designs to handle these uncertainties can be value using Monte Carlo model based on cost-revenue.

Table 7.5 shows the possible application of the discussed methods for various situations at PoR. Here, simulations refers to stochastic analysis. LCC refers to lifecycle costing and the selection criteria is lowest cost. ROA method will depend on the available data, resources, and assumptions made by the analyst.

Table 7.5: Application of economic evaluation methods for various situations at PoR

Nature of project	Situation	Suitable evaluation methods (DCF/ Simulation/ DTA/ ROA models)
Client projects		
Project with deterministic requirements and clear strategy (stable future)	e.g. temporary works for use during construction phase	DCF models
Project with deterministic requirements, clear strategies and contingent decisions	e.g. decision to expand may depend on adjoining space becoming available	Single uncertainty: DTA
Selecting between mutually exclusive design alternatives	e.g. design variants for a container quay construction	In case of similar alternatives LCC is adequate; in case of multiple uncertainties, if alternatives generate different cash flows in a scenario, a DCF with simulations is required
Project with managerial options	upscale, down scale, defer, abandon etc.	If NPV is high, it means a go decision and, DCF is adequate; If NPV is negative or low, use ROA or simulations to value real options
Investment in robust design	extra margins in dimensioning of the infrastructure	A DCF with simulations for generating extreme scenarios and a distribution of NPV of the project
Project phasing due to uncertain future	Maasvlakte 2 project will be constructed in response to demand	If the NPV is high, use DCF If NPV is low, and waiting involves learning, use ROA
Innovative+ client projects		
Investment in R&D	R& D outcomes almost always involve uncertainty	Staging involves a learning option, use ROA
Investment in pilot projects, prototypes	a decision to invest in initial market test or technical surveys can have various outcomes that van influence the following decision	DTA, ROA
Public projects	not evaluated separately	

7.7.3 Value of real-options thinking

Many advocate, in the face of high uncertainty, to take a more qualitative approach to option valuation. Wang and de Neufville (2005) point out that what is required is a manner of thinking to understand, organize, summarize, and quantify flexibility. This is the reason why real options grow more and more popular, while the ingenious part of financial theory is sometimes not valid for real options. According to Alessandri et al. (2004), analytical, quantitative tools, even ones that can model dynamic decisionmaking, are not able to model the more qualitative nature of uncertainty. Qualitatively defining, structuring, and understanding a project's uncertainties; recognizing the value of flexibility in decision making; formalizing the problem of choosing among technically feasible alternative forms of flexibility; helping decisionmakers to consider alternatives that might be ignored at time nil, thereby decreasing the economic exposure to risk, is more important than considerable effort in a rigorous analysis. The power of real options stems more from an appropriate mind-set than from the result of a model (Mauboussin, 2000). Eschenbach et al. (2007) suggests that the process of building the model that requires development of data, and understanding the relationships, can be so illuminating that the model's results are secondary.

A qualitative approach assumes that a qualitative framework in combination with DCF method can provide valuable insights for the analyst and the decisionmaker. Figure 7.5 shows a NPV/options matrix. Answering the questions listed in Table 4.5 can help to identify the options in a project, while the NPV can be estimated in the usual way. A project can subsequently be assigned to one of the cells in the matrix. Cells 1, 3 and 6 have positive NPV's while Cell 2 has high option potential; therefore the decision is to invest. Cells 7 and 8 stand to be rejected, while it may be worthwhile exploring the projects in the remaining cells using quantitative methods that value flexibility.

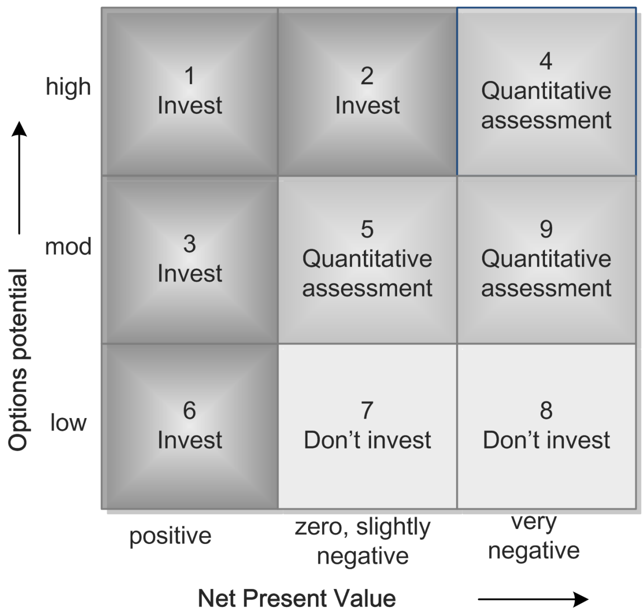


Figure 7.5: DCF/options analysis matrix

We will illustrate the qualitative approach to option valuation in the Section 7.9.5.

7.8 Flexibility requirements in contracts

The various steps in APP need to be aligned with the standard contracting and procurement procedures. Generally, the project owner has two choices: he can specify a flexible design and place a tender on the market, or he can specify the functionality desired from the design so that the market (contractors) come up with a flexible solution. The former is more or less the traditional contracting procedure and the various steps in the framework of APP have been shown in Figure 5.3 (left). If we require the contractor to incorporate flexibility, we need to introduce flexibility criteria in our design specifications as well as during evaluation of the tenders. Though a detailed examination of this subject is outside the scope of the thesis, we propose a few alternative ways of doing so.

Method 1: Traditional DCF + qualitative criteria

For some projects flexibility may be specified as general criteria. The evaluation method can be a variation on the traditional project appraisal combining a qualitative and quantitative approach. This method can be applied at the feasibility stage of a project (traditional contract), or during contracting (D & C contract). In some cases lifecycle costs instead of NPVs can be employed. The NPV is evaluated based on the tangible costs and benefits for each alternative. The intangible items are listed as pro memory items, and the flexibility criteria related to reuse can be added to these. The criteria can be established by asking questions based on the Delft Ladder (van den Dobbelsteen and Alberts, 2001). Some examples are given here.

1. Is the infrastructure reusable for another use without adaptation (is it robust against increased loads, bigger ships, another function)?
2. Is the infrastructure reusable for another function with adaptation?
3. What will be the adaptation cost as a percentage of capital costs: 0-10%, 10-20%, 20-30%?
4. Are there reusable elements/components?
5. Is the structure modular?
6. Are the elements easy to dismantle, transport, and assemble?
7. Are there reusable/ recyclable materials?

The last two are the most commonly applied sustainability criteria. This list needs to be worked out in detail. The various criteria can be assigned weights based on expert opinion and included in the evaluation using a suitable MCA method (Verhaege, 2007).

The many uncertain parameters and the qualitative nature of the method means that the evaluation is subjective. Therefore a fair comparison of alternatives may be difficult if the alternatives are similar. Willcocks (1994) suggests that managers should enter alternative estimates of intangible benefits (e.g. minimum and maximum values) into the NPV model to explore the project's sensitivity to the delivery of these intangibles. Another shortcoming of the method is that it is impossible to link the synthesized rating to business plans or to cash flow projections (Milis et al., 2009), although this factor is not important if the goal is to compare mutually exclusive alternatives.

Method 2: Use of discrete scenarios

In this method, the port owner or authority defines the technical lifetime of the infrastructure (say 50 or 100 years) and sketches a discrete number of representative scenarios. Each scenario encompasses functional requirements for the infrastructure, a period of use, and the expected throughput to be handled. A design is made corresponding to each scenario and its NPV calculated. In this way, a range of NPV's is obtained that provides more information for decision support than a point estimate. These scenarios are merely plausible descriptions of the future, and the results are indicative, but adequate for the purpose of comparing alternatives. A range of NPV's also provides an indication of risk and the selection will depend on the risk attitude of the manager. If most of the design parameters are a given, the NPVs will reflect the flexibility in design (robust, upgradable, multifunctional, multi-user). This method requires a larger engineering effort in design, but can lead to an economical and sustainable solution.

Method 3: Stochastic approach

This method is based on randomly varying the design parameters that determine the value of a project, within a bandwidth thereby taking uncertainty into account. It assumes a sufficient understanding of the functional relationships in a system (and therefore the contribution of the parameters to the project value). A few alternative designs are made using the expected values of the design parameters. A stochastic business case for each design alternative is set up at the feasibility stage. All the uncertain inputs (future costs, revenues, and timing of investments) can be varied simultaneously in such a business case. It results in a range and distribution of the possible NPV outcomes and the likelihood of their occurrence, and the value of flexibility can be estimated through comparing fixed and flexible designs. This method can capture the complicated nature of contractual arrangements and payment mechanisms, incorporates the probability of an increase in throughput, and can include available real options in a project. Therefore, it is of great value in infrastructure planning and appraisal.

Discussion of the methods:

Methods 2 and 3 can both be applied to take into account the economic benefits of flexibility in an infrastructure; these are incorporated in Case studies 3 and 2 respectively in Chapter 9. None of the above methods include indirect, i.e. social and environmental benefits of reuse. More research is required in order to monetize these and develop a comprehensive evaluation model.

7.9 Application of valuation methods to projects in PoR

Table 7.5 listed the application of various valuation methods for specific situations in PoR. In this section, we discuss their applicability to specific projects in PoR. Sections 7.10 and 7.11 include cases in which flexibility and robustness are valued using simulations.

7.9.1 Terminal expansion at the Maasvlakte

The decisionmaking related to new investments or expansions involves answering questions such as: what is the best alternative application of resources (e.g. the use of land in PoR)? Is a better alternative 'do nothing', 'delay' or 'change strategy' (e.g. intensify land use instead of developing new land)? Which design alternative is best for short term and still robust for long term? Associated with each decision are uncertainties such as market size, market share, development costs, and tariff structure, and each of these may affect decisionmaking.

An example is a valuable location at the port where facilities have recently been constructed for client G. It has 3 tanks for liquid bulk. The company S has an option for a 4th tank till end 2011, while client G wishes to expand its capacity through constructing a 5th tank. A possible location for the tank is the option terrain of client E next to his container terminal, the option expires in 2016. E wishes to realize a barge terminal at this location to improve the productivity; this is beneficial both for him and PoR. A location for the 5th tank has to be selected, such that it maximizes the overall returns for PoR while satisfying all clients. The selection is contingent on decisions taken by third parties. In addition, the usual market uncertainties related to containers and liquid bulk exist. Such a problem is amenable to a decision analysis. This involves identifying potential events and uncertainties.

Potential events:

- Signing a client for 4th tank
- S exercising its option on a tank
- E selling its option on the land adjacent to the existing G terminal
- Finding a suitable/ feasible location for the 5th tank (the possible locations are the E terminal, between E and M terminal, or a new location)

Uncertainties:

- When will a client be signed for the 4th tank? When will the construction start for the 4th tank (G assumes 2011)?
- Will S exercise its option for the 4th tank? If yes, when (between 2012-December 2015)?
- Will E sell its option on the option-terrain (and create a waiting place for inland shipping further west)?

A decision tree can be set up and the estimated pay-offs and assumed probabilities assigned to various branches and nodes. This will provide an overview of how uncertainties in the available data and uncertainties about relationships between variables will affect the probabilities of the various outcomes and any associated decisions.

The results, i.e., the path with the maximum pay-off will depend upon the assumed probabilities (given the payoffs and discount rates). For instance, a possible path could be the following chain of events: the client for tank 4 appears in 2010, S exercises its option for tank 5, which can be located next to tank 4 at the E terrain, after the option has been bought from E. Notwithstanding the subjectivity in the method, it will provide gainful insights for the decisionmaker. In a certain situation, a path will offer so much additional value, that PoR may find it worthwhile to influence the chain of events through undertaking shaping actions.

7.9.2 MultiCore pipeline

The Multicore pipeline bundle is a joint venture between PoR and Vopak. It is an underground multi-user distribution system, developed in 1997 and put into operation in 2002-2003. It offers a cost-effective alternative for transport via trucks and barges, thus avoiding investments in separate pipelines by the oil, chemical, and gas companies. Initially there was only one launching customer, today seven clients make use of the bundle (MultiCore, 2012). The customers can obtain transport capacity by simply leasing a pipeline over the required distance and connecting it with their own facilities. The permit for usage of the pipelines is arranged by the company MultiCore B.V., and the client is required to transport its products under the conditions of the permit. When the lease contract expires, the customer simply disconnects from the system. In total, today there are 80 kilometres of pipeline in a 20-kilometre stretch.

A study over the second phase expansion is under way. With such a project PoR faces multiple uncertainties at the start:

- How many clients will use the pipeline?
- What is the length of pipeline required by each client and for how long?
- Which product does he wish to transport?

Added to this are the usual uncertainties related to costs and revenues. PoR is required to estimate the number of pipes, the materials, and the diameters, and the lengths to be provided, and establish the financial viability of the concept with a business case. Though some of the uncertainties may reduce as a result of market surveys and discussions with potential clients, many are likely to remain. Each client develops his own business case and is not likely to reveal all his assumptions.

A stochastic model using historical data if available, and otherwise, market surveys and expert opinion to define the distribution of uncertain variables, and the relationship between the variables, seems to be the most realistic choice for evaluation of this project. The various sources of uncertainty are expressed as value functions in the model. The resulting probability distribution of NPV and additional statistical parameters provide relevant and more complete information for financial analysts and decision makers. This requires little effort, and the results are easy to understand.

The fact that the analyst must express his opinions in expected value terms, compels discussion about pay-offs and probabilities. Entertaining various outcomes also mitigates the risk of excessive focus on a particular scenario – a behavioural pitfall called 'anchoring'. The inclusion of a down side scenario with an associated probability will help the decisionmaker to realize that the outcome will be unfavourable some percentage of the time (Mauboussin, 2008).

7.9.3 Common-carrier steam pipe in Rotterdam

This method is also applicable for the steam pipeline network that has been planned for the exchange of high quality steam between companies in PoR area. The network is set up using 'common carrier' concept, which means that it is accessible for everyone. It can result in CO_2-reduction amounting to 400 kton annually, air quality improvement and economic advantage. The first phase has been planned in the Botlek area, where most industry is concentrated (PoRA, 2009). The potential of this concept to save energy and cost was long obvious, but the high initial investments posed a barrier.

A major uncertainty is the capacity of the pipeline (i.e. diameter), which in turn depends on the investment costs, number of clients and their requirements, and the adopted tariff structure. It is difficult for PoR to get information over individual client business cases. Initially, the companies were unwilling to provide sensitive information such as required steam capacity. The clients have the possibility of generating steam themselves, which adds to the uncertainty. A stochastic business case can be set up to examine the feasibility of the proposed concept in various scenarios. Experts with different competencies can be approached to gather data over the unknown parameters.

7.9.4 Expansion of coal handling capacity in existing port

Rotterdam is the heart of European coal transshipment, handling steam coal for power plants and coking coal for the steel industry. EMO, EECV and EBS are the largest terminals, and extra capacity is being created by expanding EMO and creating a new dry bulk terminal facility at the Hartelstrook in the Mississippihaven. The European demand for coal from overseas is expected to increase sharply in the coming decades mainly due to the phased closure of German mines (ending in 2018), and the construction of new coal-fired power plants, in both the Netherlands and Germany (PoRA, 2011a). But the long term demand depends on developments related to other energy sources including oil, gas, and biomass. Many uncertainties exist, e.g.:

- Availability, i.e., when will oil and gas reserves be exhausted;
- Progress in the development of carbon capture and sequestration (CCS) techniques that will favour extended use of coal;
- Developments in rest of Europe;
- Developments pertaining to biomass. Currently used in the form of wood pallets for burning with coal in electricity plants, it is not known, in which form, and for what applications will it be used in the future, where will it be imported from and what will be the logistic requirements at the port.

The decision over the allocation of extra space for coal handling has to be made within the coming 5 years. Only some of the uncertainties are expected to clear up within this time. Scenario planning is suitable for new or unpredictable risks when no historical data is available. The developments will need to be monitored and planning updated regularly. If at a certain stage, the functional relationships between parameters can be established, DTA can be applied.

7.9.5 Multi-functional quay wall

We introduced this project in Chapter 4, where we suggested that including the potential value of many of the options in the project through an ROA would have resulted in a feasible business case. Or alternatively, revealing these options to the management would have altered the decision in favour of the innovative solution. We illustrate both these approaches below:

Quantitative approach

An example with assumed data, based on (de Neufville, 1990), is presented for illustration.
Initial cost of engineering both traditional and non-traditional concepts is 0.1 M€ ; this requires one year.
Extra investment required for developing the concept of non-traditional quay wall = M€.
It is assumed that 10% discount rate applies.

The management would like to redeem this expense by marketing the concept to earn revenue.
Assumed payoff (after a period of 2 years) =
- 50% probability of selling to three buyers for min. 0.7 M€ each
- 50% probability of selling to one buyer for 0.2 M€

A standard evaluation results in a NPV of -1.01 M€ for the non-traditional solution, which receives a no-go decision. Such an evaluation misses the option (flexibility) that the management has to change course, therefore the traditional alternative is favoured. The management, however, decides to go ahead with the development only when buyers can be found, and otherwise abandon the project, thereby limiting the downside. In this case, the valuation results in a NPV of -0.19 M€, which though higher, is still negative.

However, the initial business case was based on a ceiling price that included quantified risk in categories such as 'unexpected events' and 'incomplete design' due to innovative nature of the project. In reality, these risks would be much lower even for the pilot project (and even lower for subsequent projects). If the extra investment is assumed to be 1.5 M€ instead of 2.0 M€, the calculation results in a positive NPV of 0.0875 M€ for the non-traditional alternative. This alters the decision, as the non-traditional alternative receives a go signal.

The three decision trees created with @Risk software can be seen in Appendix C. From top to bottom, these depict the standard valuation, valuation with flexibility, and valuation with flexibility whereby the risk is lowered.

Qualitative approach

Table 4.6 lists the options available in the Odfjell project. It is a project with a negative NPV and like all R&D and innovative projects has a high option potential. It can be placed in Cell 2 of the NPV/options matrix (Figure 7.5). This results (rightly) in the decision to invest.

7.10 Illustrative case: Valuing ‘flexibility through standardization’

7.10.1 Background

Each year some 35,000 seagoing ships and 133,000 inland vessels call at PoR. In addition to the piers and quays, dolphins are used for docking vessels in the 10,000 hectare port area. These dolphins are free-standing structures embedded in the subsoil, equipped with fenders for absorbing environmental loads during berthing, and equipped with bollards for mooring vessels. A dolphin comprises mostly a flexible steel-pipe equipped with steel or timber fenders and a removable top section with two or three arms on which bollards are mounted. The diameter of the steel pipe varies from 507 mm to 1820 mm. Usually the design of dolphins is location-specific: the dimensions of the steel pile, i.e., the length, diameter and wall thickness, are determined (among others factors) by the environmental loads, the size and speed of the berthing ship, the berthing manoeuvre of the ship, the type of soil, the water depth, and the steel quality.

7.10.2 Economic lifetime of mooring dolphins

The mooring dolphin, if protected from corrosion (the dominant ageing mechanism for steel pipes), can have a design (or technical) lifetime of at least 50 years. The uncertainty (Step II of APP) is its economic lifetime, which can be defined as the time during which the dolphin can fulfil its functional requirements at one location without adaptation. This economic lifetime is generally shorter than the design lifetime due to three factors:

- Damage due to ship collisions caused by e.g., extreme environmental conditions, wrong berthing manoeuvres, or mooring line breakage. Recently, 22 dolphins in the waiting area in the Mississippihaven had to be replaced because of the damage caused by push boats (subsequently the waiting area was relocated);
- Relocation of the company and hence the mooring facility. An example is the recent widening of the basin in Central Geul in Botlek, leading to relocation of three existing jetties;

– Increase in future ship sizes. A dolphin may need to be replaced by a larger one if bigger ships are to be berthed at the same location. The size of the inland vessels continues to increase, e.g., many of the mooring locations in PoR are being or need to be adapted to receive the 135 m container ship MS Zembla, in use since 2002.

The first two factors represent discrete and unpredictable events. The ship size however, shows an increasing trend, as ship owners tend to utilize the economies of scale in response to increased demand, but the changes are fairly abrupt. All three factors contribute to uncertainty about the economic lifetime of the dolphins. Since PoR receives huge bulk tankers as well as small inland vessels, the range of dolphin types in the port is very large. PoRA is considering standardizing the dolphins to three types: steel pipes with a diameter of 914 mm, 1220 mm, and 1420 mm. This means a larger initial investment, but greater flexibility offered by modularity and standardization. The proposed hedging action (Step III of APP) to reduce the adverse effects of the uncertain factors is to standardize (or in other words over-design) the mooring dolphins. Step IV requires that the value of this flexibility be evaluated. This is discussed in the next section.

7.10.3 Evaluating flexibility

The chance that a dolphin will have to be shifted or replaced during its (technical) lifetime is unknown. The reality can be simulated by setting up a model of the system and conducting experiments with a set of inputs. These inputs are synthetically generated so as to preserve the statistical properties of the random variables. When many such experiments are conducted with different sets of inputs, and the results statistically analyzed, planners can get a better insight into the working of the system. This model can be used to simulate the number of times a dolphin needs to be shifted or replaced during its (technical) lifetime, and the corresponding lifecycle costs.

The costs are estimated for two strategies: Strategy 1 with variable size dolphins is called the 'traditional strategy' and Strategy 2 with standard dolphins is called the 'flexible strategy' (since it offers greater flexibility of use, due to modularity and standardization). The better strategy will be the one that provides the lowest present value of the total costs over the planning horizon, which is 40 years. A total of 100 dolphins is assumed for the purpose of the analysis.

General assumptions:

– Cost of steel is €1 per kg.
– The cost of installation is estimated at €1000, €1700, and €2500 respectively for the three sizes of steel pipes.
– The age of the dolphin is estimated by sampling between 0 and 40 years.
– The rest value of the steel pipe is calculated assuming a lifetime of 40 years and a rest value of 10% (of the new value), and interpolating in between for the estimated age of the dolphin.

- The cost of dismantling the top section, removing the pile from the ground, carrying out repairs and maintenance, transportation to a new location, and mounting the top section is estimated at €4600, €6450, and €8300 respectively for the three sizes of steel pipes. This is in fact the cost of reuse.
- For intermediate sizes (in Strategy 1), the costs are linearly interpolated between the two ranges (914-1220 mm and 1220-1420 mm).
- All probability distributions are uniform. In an uniform distribution, all values between the minimum and maximum occur with equal likelihood, representing extreme uncertainty.
- The option whether to standardize or not is held by the landlord port authority; this option is exercised at the beginning.

Assumptions for Strategy 1 (traditional strategy):

- The size of steel pipes varies between 914 mm and 1420 mm.
- 0-10% of the dolphins have to be relocated due to the user relocating; 50% of these are adequate for the new location while the rest have to be replaced with a bigger steel pile.
- 0-10% of the dolphins have to be replaced due to the appearance of a bigger ship.
- 0-10% of the dolphins are damaged due to collision in 0-40 years.

Assumptions for Strategy 2 (flexible strategy):

- Three standard sizes are used in the port: 914, 1220, and 1420 mm.
- 0-10% of the dolphins have to be relocated due to the user relocating; it is safe to assume that 80% of these are adequate for the new location, while the rest must be replaced with a bigger steel pile.
- The number of dolphins needing replacement due to the appearance of a bigger ship is reduced to half compared to Strategy 1, as is the probability of damage due to ship collision.

7.10.4 Results

The decision whether to standardize or not is based on the cost criterion; the strategy with a larger NPV, or in this case, with a lower cost, is favourable. The results of the simulations are presented in Figures 7.6 and 7.7. As can be seen in Figure 7.7, there is a 95% probability that the investment costs exceed €243,500 for Strategy 1 and €165,700 for Strategy 2. Thus, investment costs over the technical lifetime of a dolphin (or the lifecycle costs), are likely to be lower for the flexible Strategy 2. There is a 50% probability that more than 15 extra dolphins are required in Strategy 1 while in Strategy 2 this probability is reduced to 8.5%. The mean value of total costs is reduced from €121,275 in Strategy 1 to €89,035 in Strategy 2.

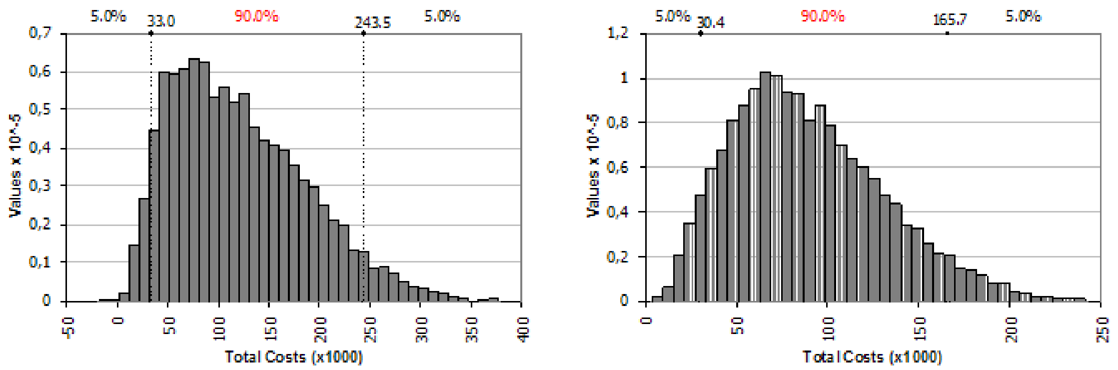


Figure 7.6: Distribution of total costs for Strategy 1 (left) and Strategy 2 (right)

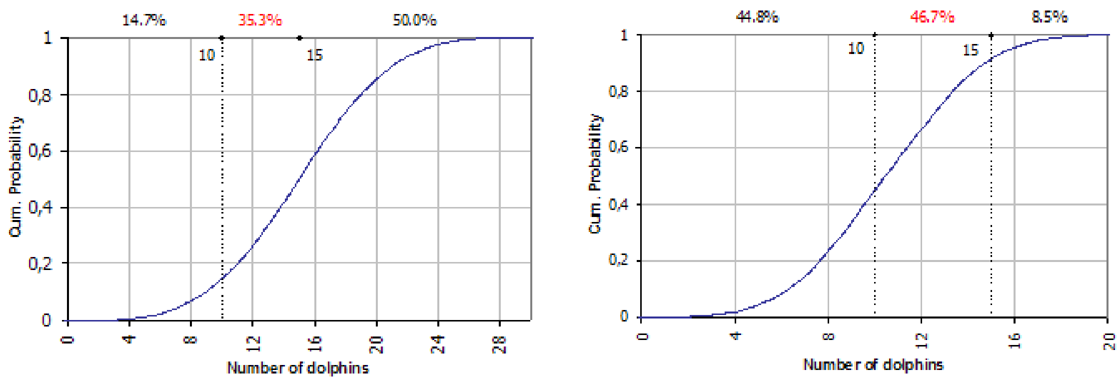


Figure 7.7: Distribution of number of new dolphins for Strategy 1 (left) and Strategy 2 (right)

7.10.5 Observations

The analysis has demonstrated that, in view of the uncertainty, the flexible strategy is by far better. (If there were no uncertainty, the flexibility would be wasted.) Standardization involves extra costs, but provides increased flexibility, which means time and price advantage for PoRA. Some additional advantages offered by flexibility in the present case (not quantified in the cost model) are:

- Delivery of large sized piles usually takes time; standardization allows stocking of a few standard sizes.
- Standardization also means that a standard piling rig can be used.
- The dolphin construction is modular and consists of two self-contained functional elements: the pipe and the top section; through standardization, the modularity is increasingly utilized, since the top section of a damaged steel pile can be reused on another pile of same size. The possibility of reuse can result in two, or even three economic lifetimes for a dolphin, allowing the investment cost to be amortized over a longer time.

– Though on one hand standardization implies over-design and larger investments, it can also mean savings due to less customization, since detailed site-specific engineering will not always be required.

Step V of APP involves setting up signposts and Step VI suggests actions to be taken in response to trigger values being reached. Since the single uncertainty is dealt with through building in flexibility upfront, these steps are not necessary.

7.11 Illustrative case: Valuing 'flexibility through margins in design'

7.11.1 Background and problem definition

In the 1990's, when major investments in container terminals were being carried out at the Maasvlakte in PoR, the major uncertainty was related to the emergent new technology and future demand throughput, which together determine the evolution in vessel sizes. Though fourth generation ships with a draught of 12.5 m were current, the ECT/SeaLand terminal at the north side of Europahaven as well as the Delta 2000-8 terminals at the north side of Amazonehaven in PoR were provided with a (larger) contractual depth of NAP -16.65 m and a construction depth of NAP -18.30 m. This incurred additional costs to build a deeper quay with a stronger structure, and to accommodate heavier cranes for future ships. The present case study applies simulation to examine the justification of these additional costs.

The uncertainty dealt with in this case is the size of future ships and other uncertainties, e.g. the quay productivity, the future tariff structure, and changes in material prices, have been ignored. The proposed hedging action is to incorporate a greater depth in the quay walls (Step III of APP). Step IV of APP requires that the cost-effectiveness of this flexibility through creating margins in design be evaluated. This is discussed in the next section.

7.11.2 Evaluating flexibility

We can evaluate two designs: a 'fixed design' suitable for 5000 TEU ships current at that time, or a 'flexible design' that could be adapted for larger vessel sizes by dredging deeper when required. The difference in the value of the two designs is the value of flexibility, and is estimated as described here. The methodology is adequate for illustration, but does not represent the complexity of a business case for the construction of a new quay wall.

A cash flow model of the system with likely projections of costs and future revenues of the project from year 1995 onwards is set up. It includes the extra investment for 3 m additional depth for 2 km length of quay wall as well as the expected extra future benefits of accommodating vessels bigger than the 5000 TEU. These benefits should include revenue in the form of harbour dues, quay dues, value added services,

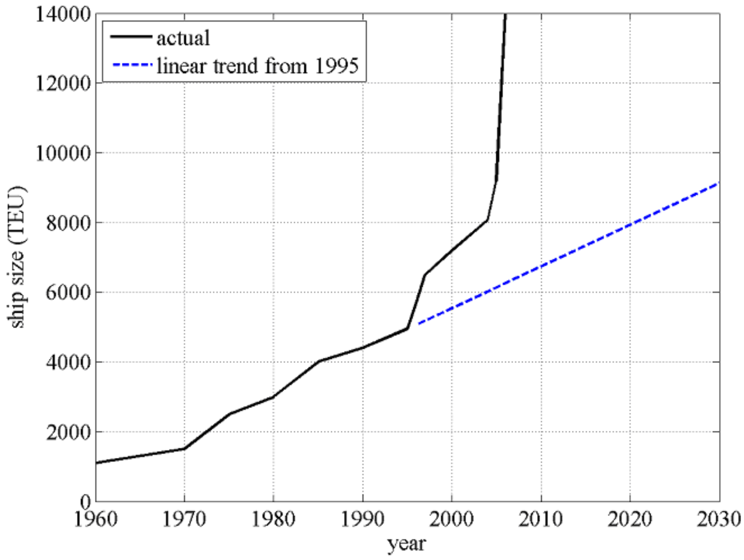


Figure 7.8: Evolution in ship size 1960-2006

and a better image for the port; however, only the harbour dues have been included in the model. Recognizing that we live in an uncertain world and the outcomes are probabilistic, we apply Monte Carlo simulation to generate numerous scenarios. Each scenario results in a different NPV. The collection of scenarios provides an expected distribution of the possible outcomes for the project, or ENPV (Expected Net Present Value). The year in which the (average) cost is equal to the (average) revenue, known as the break-even point, is determined. The assumptions related to the estimation of costs and revenue, and the results of the simulations follow.

Assumptions related to cost estimation:
Since the purpose is to illustrate the valuation of flexibility, and the data for 1995 are not readily available, the revenues and costs are based on the present rates (2010). The indirect costs and benefits (such as the tax and mitigation measures laid down to cover the economic and socio-economic costs) are not included. The investment costs in an extra retaining height of 3.0 m are estimated at 10.8 M€ (assuming direct construction cost of €1500 /m2 of quay wall area and 20% indirect costs). The inflation rate, and the repair and maintenance costs (which amount to only about 1% of the investment cost per year (Vrijling, 2005)), have been neglected in this calculation.

Assumptions related to revenue estimation:
In Figure 7.8, the general trend in ship size development up to year 2006 can be seen. The number and size of ships bigger than 5000 TEU is estimated as follows: A linear extrapolation of the curve in 1995 forecasts a ship size of about 8000 TEU in 2020. The maximum vessel size between years 1995-2020 can be read from the trend-line. As input for the simulations, the average vessel size is sampled between 5000 TEU and the maximum vessel size in that year. It is further assumed that 50 vessels larger than 5000 TEU will call at Amazonehaven north side in the first year, and that this number will grow every year at a rate varying between 10% and 20%.

The revenue due to ships bigger than 5000 TEU is estimated as follows: once the ship

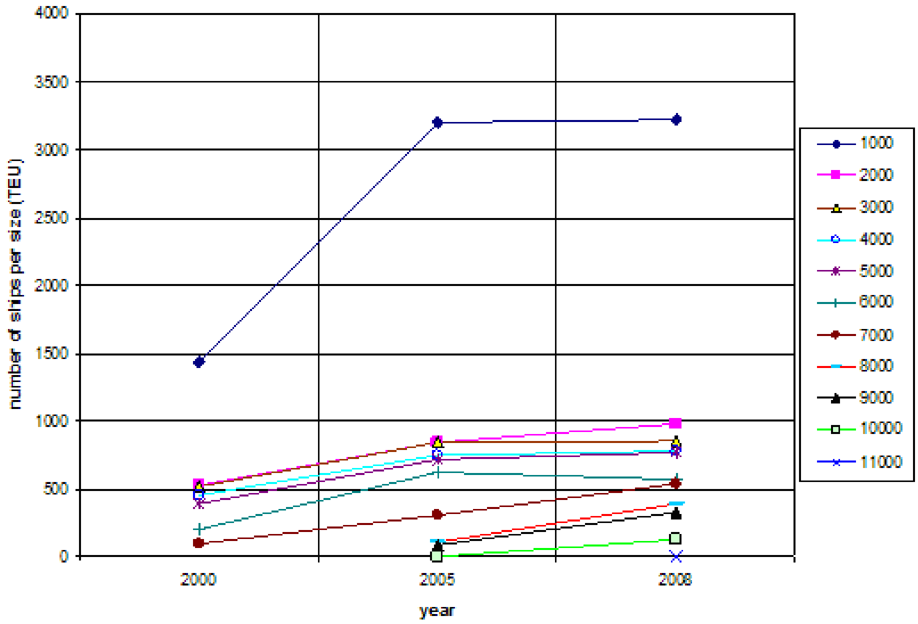


Figure 7.9: Ship size distribution 2000-2005-2008

size is known, the call size is determined assuming that total loaded and unloaded cargo varies between 25% and 60% of the tonnage capacity of the ship. The revenue generated per year is calculated using the appropriate formulas in Port Tariffs (PoRA, 2010c). The break-even point is calculated using discount rates of 4% and 8%.

7.11.3 Results

The results of the simulations using the cost model and the listed assumptions can be seen in Table 7.6. The table shows that the break-even point is reached in the 8th year of exploitation (2003) for a discount rate of 8%. With a discount rate of 4%, and growth rate of 20% in the ship size, the break-even point is reached in 6th year of exploitation (2001).

Table 7.6: Simulation results

average NPV >0 in year	number of years	% increase in number of ships	number of ships	average ship size (TEU)	discount rate (%)	ENPV
2002	7	10	97	5538	4	€1,028,578
2003	8	10	107	5615	8	€930,942
2001	6	20	149	5462	4	€2,822,802
2001	6	20	149	5462	8	€958,269

7.11.4 Observations

It has been possible to include the cost as well as value of flexibility in our model and evaluate the ENPV for a number of strategies. Some observations:

- With the insights gained as a result of the simulations, it is easier for investors to take a go- or no-go decision as to the extra investment in a deeper quay wall. The outcomes for other locations or situations would of course depend on the demand and cost and tariff structure of that port, but would, nonetheless, provide a basis for decisionmaking.
- In this particular case, PoRA, aware that adapting the quay wall for larger vessels at a later stage is almost as expensive as constructing a new quay wall, had incorporated an extra retaining height of 3.0 m in the quay wall design, and provided a contractual depth of NAP -16.65 m.
- The actual traffic data (number of vessels and call sizes in recent years) are displayed in Figure 7.9. It is interesting to note that the number of ships that called at Amazonehaven north side in 2008 was 3225, and 565 ships were larger than 5000 TEU. This is comparable to the mean value of 535 in our extreme scenario. In the year 2000, 196 ships larger than 5000 TEU appeared, while the extreme scenario of the case study (with 20% growth in number of ships) estimated a mean value of 124.
- There is of course a cost attached to exercising this option, i.e., the cost of dredging for an extra depth of 3 m, as well as the cost of not being able to berth vessels at the quay during the period the dredging is carried out.

Step V of APP involves setting up signposts and Step VI suggests actions to be taken in response to trigger values being reached. Just as in the previous case, the single uncertainty is dealt with through building in flexibility up front, therefore Steps V and VI are not relevant.

7.12 Conclusions

APP recognizes that, under uncertainty, the value of a project (or a design alternative) is driven by the flexibility it creates to adapt its function and use. The analysis of this flexibility is mostly beyond the reach of traditional tools of financial analysis. We investigated the modern valuation methods that claim to calculate the investment potential of a project more accurately. The selected method must match (the multiple) uncertainties and flexibilities as they appear in port systems. It must be amenable to the characteristics of port projects, and applicable for the (port) market being considered. The results must have transparency and the communicative power required to convince the management of superiority of flexible solutions. If we can employ the intricate knowledge of the port system and its processes acquired during planning and design, it will give give benefits (without extra efforts).

A real options analysis is found unsuitable, since many of the assumptions implicit in financial options are not valid for port projects and markets and its inherent complexity, which makes it difficult to first select an appropriate method and then implement it correctly. Not all flexibilities in the port systems (for instance, robustness) have option-like properties. These may not be suitable for evaluation with models based on options theory. Further research in this rapidly growing field may find methods to relax these assumptions through new methods.

Since our objective is to facilitate decisionmaking in favour of flexible solutions, we find the tools of traditional economic analysis adequate to achieve a consistent comparison of alternatives. Simulation using stochastic methods is convenient, because it is available as an add-in for spreadsheet programs and can include uncertainties and value flexibility from basic data on benefits and costs. This method encourages a careful re-examination of the single-value estimates in the deterministic appraisal. It enhances decisionmaking on marginal projects by providing additional information on risk (i.e., the risk/return profile). It also reduces bias since the analyst does not need to use conservative point estimates, but can specify a range. Decision tree analysis is recommended if there are clear investment choices, contingent decisions, and the likelihood and timing of critical uncertainties are understood. We suggest how these methods can be usefully applied to real situations at PoR, dealing with investments in innovative projects such as MultiCore or steam pipeline network, multifunctional infrastructure, and terminal expansions.

In this approach, a market valuation is missing, and no distinction is made between the type of uncertainty. In acknowledgement of the great value of real option thinking, we propose a qualitative framework to be used in combination with traditional quantitative methods. This should be able to reveal to the management the (hidden) potential of a project, especially if its use becomes standard practice.

We presented two case studies that value flexibility and robustness in port infrastructure using simulations. The first case illustrated how standardization and modularity can lengthen the economic lifetime of mooring dolphins and result in lower lifecycle costs. The second case dealt with uncertainty over the size of vessels to be handled at a quay wall. We estimated, using stochastic methods, the break-even point, i.e. the time after which the cost of acquiring flexibility (extra investment in a deeper quay wall for future larger ships) is exceeded by its value (extra revenues generated if bigger ships do appear on the scene). This analysis provides a decisionmaker with new insights on which to base his investment decision.

Whether the options, managerial or in design, enhance the value of a project needs to be carefully investigated taking also the indirect implications into account. The evaluation of a project or an alternative also requires that all direct and indirect impacts, positive or negative be taken into account. This is complex especially in case of intangible factors and outside the scope of this research.

In conclusion, it is useful to remind ourselves that in the end decisionmaking in real life is about risk attitude and political influences.

Chapter 8

Monitoring the port environment

Weak signals, often hidden in the surrounding noise, are the true harbingers of what might be - Zeisler and Harris, 2000.

8.1 Introduction

As we have seen, ports have to be face unanticipated risks. The classical planning approaches frequently contribute to a firm's inability to detect signals from the environment (Zeisler and Harris, 2000). Generally, there are two extremes of dealing with risks: 'wait and react' which leads to a too late response, and 'predict and act' which leads to an erroneous action – predictions are usually wrong (especially, far into the future).

We have proposed a middle route, i.e. Adaptive Port Planning which incorporates a monitoring and trigger system, that tracks the developments that form the biggest risks for the plan, and sends out a signal at the moment that a predefined threshold value is reached, which indicates that the plan is threatened. Subsequently, already thought-out strategies (as a part of a contingency plan) can be put into action in order to protect the plan. The 'timely' detection of risks is of essence, in order to instigate corrective, defensive, or capitalizing actions. The success or failure of our plan depends critically on the monitoring system and the pre-specified triggers and actions (Kwakkel, 2010; Taneja et al., 2011a).

While the concept seems relatively straightforward, it involves many difficulties. Exogenous developments form the greatest threat for port projects, and monitoring these involves a certain degree of forecasting. Forecasting, in turn, leans heavily on mathematical tools and requires not only extensive historical data, but an intensive effort to incorporate these data into a mathematical model. Even so, trend-break developments can negate the entire exercise (Chatfield, 2001).

Not only the impact of external developments on the plan, but also the impacts of port development projects are significant. Driven by the emerging requirements of investors, heightened public concern, and the scrutiny of social organizations, the market is increasingly demanding that companies adopt responsible and accountable environmental and social practices. Therefore, monitoring the environmental and social impacts of a project is implicit in planning of all large, complex infrastructural projects. Also, impacts on regional and national economic development are a part of a detailed cost-benefit analysis to assess if the large investments are justified.

Setting up a monitoring and trigger system for the critical uncertainties in a project, is also a part of APP. In this chapter, we will examine if it is at all possible to monitor developments that represent major vulnerabilities for port projects using quick, simple tools and techniques, so that timely actions can be initiated.

8.2 Setting up a monitoring and trigger system

8.2.1 Description

Monitoring aims at assessing the significance of events or developments as they occur or just after, and involves activities like measuring, scanning, detecting, analysing, assessing, and forecasting. This is only useful if we can limit the excessive detrimental impact of a development or reduce its probability, through taking timely measures. Therefore, indicators or signposts that indicate an important event or its impact need to be set up and monitored. The various steps during monitoring (as a part of APP) can be seen in Figure 8.1.

A signpost is an event or threshold that indicates an important change in the validity or vulnerability of an assumption (Dewar, 2002). For example, an important assumption during masterplanning of MV2 is the approval of the PKB (Key Planning Decision). If the PKB is not approved, the assumption fails, and if it is approved, the assumption loses its vulnerability. A signpost can be the date of PKB approval. A signpost can be a direct indicator of change, e.g. an event, threshold number or quantity. Or the signpost can be more complex and reflect interrelations between economy, society and the environment (e.g. economic indicators such as GDP). In such cases, the relationship between the development and the indicator is also not direct or predictable, and may require disaggregated data.

A signpost must fulfil the following requirements: it can be tracked; is not too costly to track; provides a preferably direct or otherwise indirect measure of the vulnerability/ opportunity/ driving force or factors affecting them; is unambiguous and not easily manipulated. A trigger sends off a signal beyond a pre-specified threshold value of the indicator. The trigger value is the threshold value beyond which action needs to be taken. Since the relationship between the signpost and the vulnerability is almost never straightforward, specifying a trigger value is not easy. If the value is less than the trigger value, a low-risk situation exists. The management response would be to continue monitoring. If the value is greater than the trigger value, a possible high-risk situation exists. The management response here would be to go over to Step VI of APP and decide whether to activate the contingency plan, which includes corrective, defensive, and capitalizing actions. This needs to be specified in a monitoring protocol.

A contingency plan is a provision in the plan that specifies how a vulnerability will

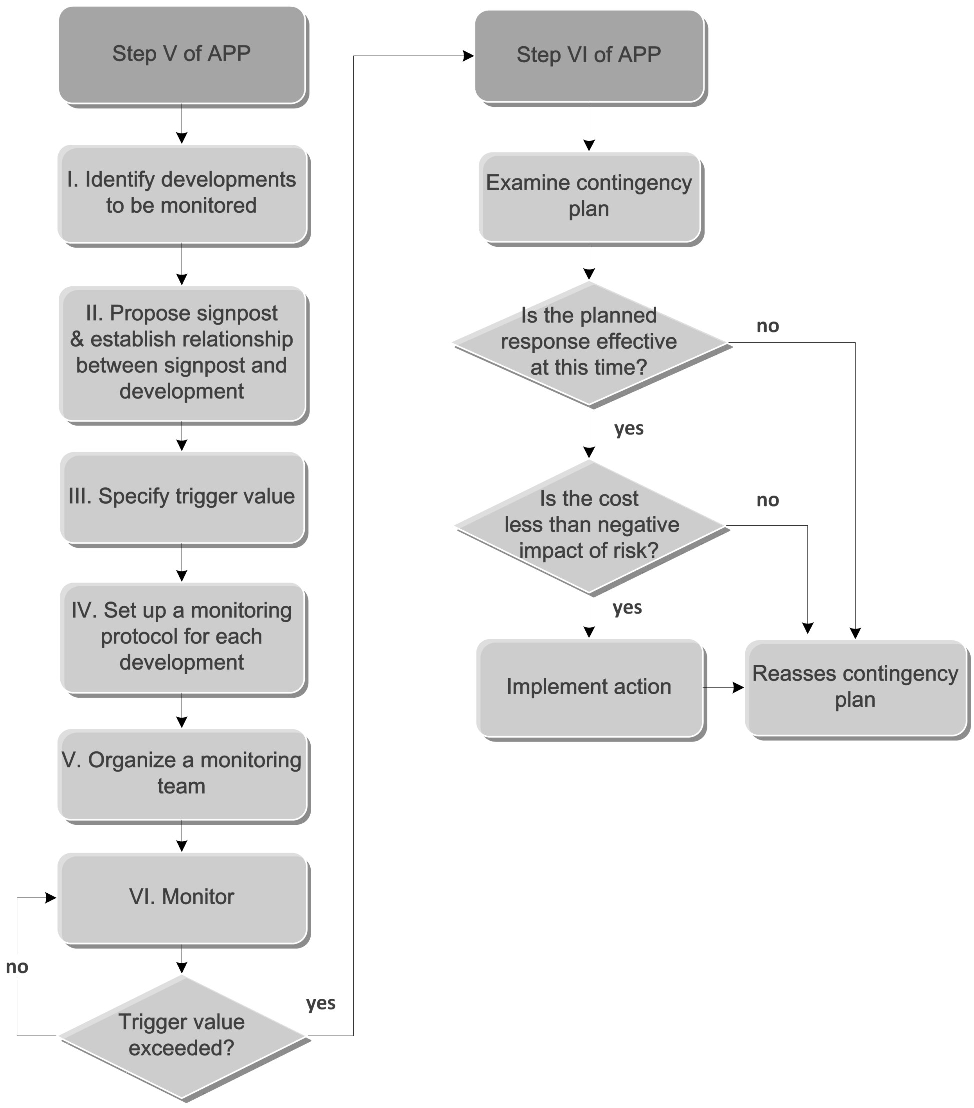


Figure 8.1: Steps in monitoring

be handled, in case circumstances change and the vulnerability appears. At the time of implementing an action in response to risk, a risk audit is required to evaluate the effectiveness of the planned risk response and its impact on the schedule and budget. It is also possible that the management is prepared to accept greater risks, either due to escalated costs of the actions, or a trade-off made elsewhere in the organization. This suggests that, in case of changed circumstances, the trigger values also need monitoring and updating, as do the contingency plans of the organization.

8.2.2 Monitoring and forecasting

The critical question when setting up a monitoring and trigger system is: what threshold value of a signpost represents a large deviation, warning us that the impact is likely to get out of hand and triggering us to take action? This involves a certain degree of forecasting. In fact, all decisions are based on some sort of forecasts. These can be obtained by intuitive means, whereby experience and judgement are used to establish future behaviours (qualitative approach); or through use of (quantitative) statistical methods, which use historical data to establish trends that can be projected into the future, or by building simulation models that mimic real (generally complex) physical systems. All of these methods have been applied successfully for forecasting in the port sector and are discussed briefly below.

Statistical analysis of time series is a method of generating forecasts based on historical data. It is applied for predicting variables such as road and rail traffic, modal split, crane, quay or terminal productivity, etc. Generally, two types of models are distinguished. The first represents extrapolative models, which simply relate movements of the dependent variable to time, and so produce forecast values directly by reference to past time periods. A regression using only one predictor is called a simple regression.

The second type refers to causal models, which postulate a relationship between the given variable and one or more independent variables in order to generate a forecast. It is necessary, however, to first predict the future values of these independent variables. There are two types of causal models: single equations, which lend themselves to regression analysis, and multiple or simultaneous equations, which are estimated as a complete system (Briscoe and Hirst, 1973). A large amount of data is usually required to successfully operate a causal-forecasting model. These can be used where sufficient historical data are available, and the relationship (correlation) between the dependent variable to be forecast and associated independent variable(s) is well known. For instance, terminal productivity is a function of variables such as the type and number of equipment, the selected handling and transport concept, area of the terminal, dwell time etc. Forecasting productivity for monitoring purposes would require future estimates of these variables, making it a complicated exercise, also in view of the uncertainty attached to each of these variables.

Discrete event simulation models have also been successfully applied to make a case for the port expansion MV2. The demand for space fluctuates strongly, and the timing of construction is important – too early means high costs, and too late means loss of clients for the port and loss to the national economy. Around 1997, there was a national debate over the urgency (and size) for construction of a MV2 (Kennisinstituut voor Mobiliteitsbeleid (KIM), 1997; van der Steen, 1997), and some studies were undertaken (RAND Europe, 1997). PoR invested in a discrete event simulation model in order to make long term projections of future space requirements. The major assumptions in the model concerned the growth rate per cargo sector, arrival patterns of future clients, and a statistical distribution of space demand based on the size of the site. The simulation results established that a shortage of space would manifest itself in 2006. Taking into account the time required for reclamation and construction of 4 to 6 years, it was decided that MV2 project should be initiated in 2002 (van Schuylenburg, 2002). Subsequently, (phased) construction of MV2 was started in 2008, and so far, the forecasts (in the most optimistic scenario) are close to the actual demand.

Simulation models that mimic real physical systems can be used to gain insights into new technology, and to estimate the performance of systems that are too complex for analytical solutions. SimPort-MV2 is an example of such a model. It was created to support the planning, equipping, and exploitation of MV2 (Bekebrede and Mayer, 2006).

Risk and uncertainty are central to forecasting and prediction. Forecasters in all domains realize the importance of indicating the degree of uncertainty attached to forecasts by providing interval forecasts as well as (or instead of) point forecasts. This will be discussed in the next section.

8.2.3 Uncertainty in forecasts: Confidence and prediction intervals

Armstrong and Green (2010) state that statisticians have relied heavily on tests of statistical significance for assessing uncertainty, which is inappropriate for assessing uncertainty in forecasting. The focus instead, should be on interval forecasts. These usually consists of an upper and a lower limit between which the future value is expected to lie with a prescribed probability. While confidence intervals tell you about how well you have determined the mean, prediction intervals can help the user to predict in which interval a future compliance should lie before it is even measured. Another advantage of the method is that as few as one future sample can be used in determining prediction intervals. Prediction intervals must account for both the uncertainty in knowing the value of the population mean, plus data scatter. So a prediction interval is always wider than a confidence interval.

Regression models are statistical models that describe the variation in one (or more) variable(s) when other variable(s) vary. The standard error measures the amount of scatter, or variation, in the actual data around the fitted regression function. It is useful in estimating the level of uncertainty in a prediction made with a regression model.

Standard error (S_e):

$$S_e = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - Y_{ih})^2}{n-k-1}} \tag{8.1}$$

where
n= number of observations in the data set

k= number of independent variables in the regression model

The prediction interval for a new value of Y is calculated as follows:

The estimated value of Y can be evaluated with a regression function.

$$\hat{Y}_h = b_0 + b_1 X_{1h} \tag{8.2}$$

At prediction interval (1-α), the new value of Y is represented by

$$\hat{Y}_h \pm t_{(1-alpha/2;n-2)} S_p \tag{8.3}$$

t(1-α/2,n-2) represents the 1-α/2 percentile of a t-distribution with n-2 degrees of freedom

S_p represents the standard prediction interval defined by:

$$S_p = S_e \sqrt{1 + \frac{1}{n} + \frac{\left(X_{1h} - \bar{X}\right)^2}{\sum_{i=1}^{n} \left(X_{1i} - \bar{X}\right)^2}} \tag{8.4}$$

The confidence interval for the average or mean value of Y is defined by:

$$S_c = S_e \sqrt{\frac{1}{n} + \frac{\left(X_{1h} - \bar{X}\right)^2}{\sum_{i=1}^{n} \left(X_{1i} - \bar{X}\right)^2}} \tag{8.5}$$

8.2.4 Selection of a method

In order to monitor exogenous developments, we will either use extrapolative models or apply simple regression models, and use prediction intervals to define the associated uncertainty. Regression models are constructed based on certain assumptions related to normality, stationarity, and auto-correlations. (Data transformation, so that the data appear to more closely meet the assumptions, is often carried out). A requirement is that extrapolation should not go too far beyond the available data range. The models are often useful for prediction even when the assumptions are moderately violated, although they may not perform accurately. Since the model is to be used largely for monitoring, which involves relatively short-term forecasting, their use is found acceptable. Prediction intervals will help the user to predict in which interval a future compliance should lie before it is even measured, and are a useful aid to monitoring while applying statistical methods.

Advanced methods, on the other hand, require large quantities of data, and extra effort for modelling and interpretation of the results. Use of these methods is not expected to influence decisionmaking (as to initiation of actions to limit the harmful impact of unexpected developments or reduce their probability). Therefore, we have not considered more sophisticated methods.

Forecasting assumes that a trend exists (whereas the trend-breaks cause the main problems, and these are not suitable for a statistical analysis). In cases where a trend can be identified, the (indirect) impacts of an action are difficult to foresee, and even more difficult to quantify. In some cases, actions (measures) devised during APP will not change the trend, only causing local changes (jump or dip in level, a sudden change in the gradient of the fitted curve etc.), and continue as before, while in other cases, they will bring about a structural change and set up a new trend, and in some cases even reverse the trend. For instance, lower prices and adequate infrastructural capacity in inland shipping might lead to a structural modal shift (trend change). On the contrary, a new container transferium in the hinterland will lead to shifting a fixed cargo volume to inland ships without affecting the general trend. Since the impacts are difficult to predict, we must continually update our observations and analysis which justifies our choice of a simple tool.

Indicator systems are also frequently employed. For instance, in order to monitor economic developments, the following indicators are effectively used: GDP growth rate, inflation rate, exchange rate, and interest rate. Environmental monitoring, carried out with the objective of characterizing the quality of the environment, involves measurements and subsequently a statistical analysis. The monitoring techniques may involve direct sampling from the source or employ remote sensing methods.

8.3 Monitoring major uncertainties in a port project

8.3.1 Monitoring in ports

Most ports monitor Key Performance Indicators (KPIs) in order to improve their performance. These can relate to cost, transport, or operational efficiency, to safety and sustainability criteria, to the throughput, or even strengthening the hub function or maritime networks. The sources of data differ. PoRA records data such as annual turnover and NPV, the modal split data is received from shipping and terminal operators, the throughput figures from other ports are derived from the relevant port authorities, while the data related to sustainability requirements is supplied by the concerned companies or monitored by PoRA (e.g. for MV2 project). The Business Intelligence and Analysis department tracks relevant market developments.

In Chapter 5, during our case study over the port expansion project MV2, we identified the following vulnerabilities for the Master Plan: changed container demand; appearance of mega vessels; increased quay and terminal productivity; modal shift, and non-compliance with standards of sustainability, security, and safety. Since port planning makes assumptions related to all these aspects, we need to monitor these in order to check if the assumptions are negated at any time. This will be dealt in detail here.

8.3.2 Lower or higher demand throughput

For a port, the total volume of cargo in any year is related to the real GDP growth rate and the cargo multiplier for a particular cargo. In Figure 8.2, the container trade volumes and the real GDP have been plotted for a period from 1995 up to 2008 for the Netherlands. It can be seen that container trade closely follows the real GDP, and certain time-lags or over-reactions can be clarified. Thus ports often use GDP as an indicator for estimating future cargo throughput.

The demand forecasts, which serve as a basis for a port Master Plan, are based on econometric forecasts. The time horizon for the long term prognoses for demand-throughput is so long, that it is difficult to estimate the global developments in the

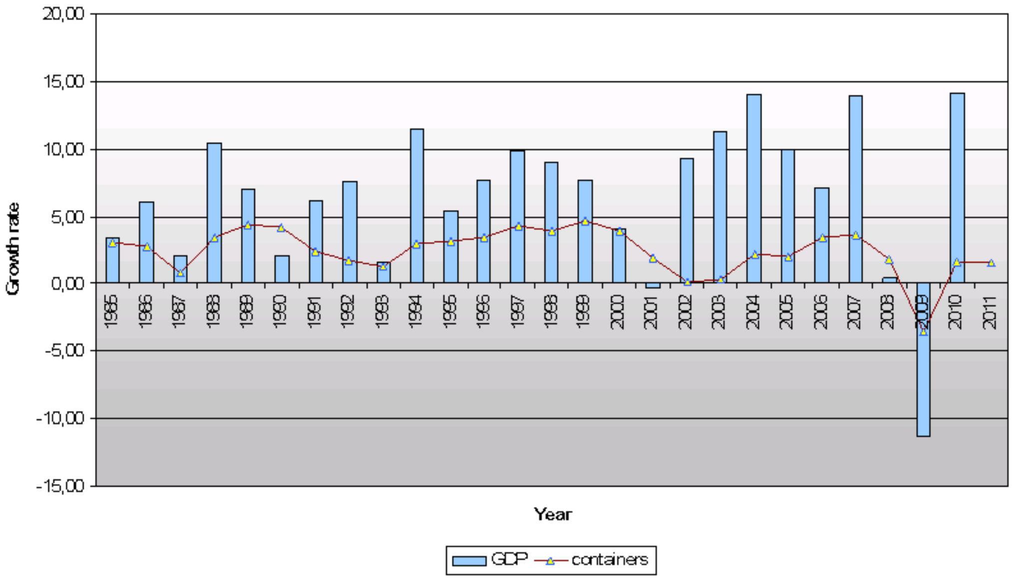


Figure 8.2: Growth rate GDP and Container throughput Netherlands

world economy with reasonable accuracy. Identifying and predicting the causal variables (drivers of container throughput, exchange rate movements etc.) and defining inter-relationship is even more difficult than predicting container volumes. In such a case, the economic relationship between GDP and trade volume is useful in forecasting the development of the container volumes.

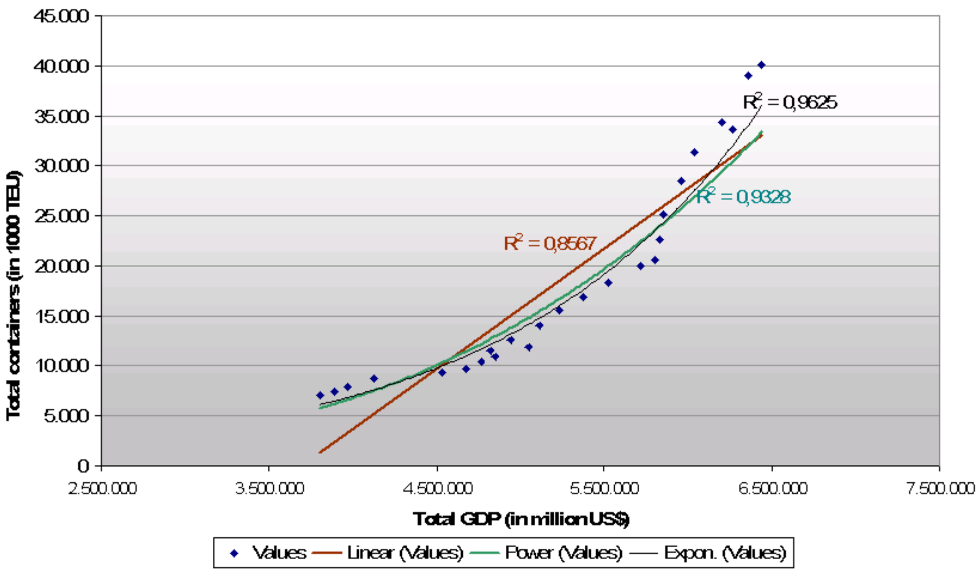


Figure 8.3: Container volumes versus real GDP

The countries in the Hamburg-Le Havre (H-LH) range have overlapping hinterlands, thus for the purpose of a regression analysis, the following countries representing more than 90% of the total market share have been selected: Belgium (ports Antwerp, Dunkirk, Zeebrugge), France (LeHavre), Germany (ports Bremen, Hamburg) and the Netherlands (Rotterdam and Amsterdam). In Figure 8.3 container volumes (y axis) are plotted against the real GDP on the x axis for the H-LH range, and curve-fitting is carried out.

As can be seen, an exponential curve gives a better fit than a power curve or a linear curve. However, logical and economic coherence criteria require forecasts to make sense and unlimited exponential growth in container volumes is unlikely. For purposes of monitoring, we opt for a simple linear regression. Subsequently, based on global forecasts (which give an annual growth rate of GDP) by organizations such as OECD, World Bank, IMF, CPB, Containerization International, container volumes can be predicted over a short term. E.g. by an annual growth rate of 2.1% in 2010 and 2.7% in the subsequent years, the container throughput for H-LH range in 2010 amounts to 42 mln TEUs in 2015 en 56 mln TEUs in 2030. A more sophisticated method forecasts a throughput of 41.5 and 47.7 mln TEUs for these years (PoRA, 2010d). For the purpose of monitoring this level of accuracy is adequate. The market share for Rotterdam or even Maasvlakte can be estimated on the basis of historical data (with a certain bandwidth).

8.3.3 Change in policies

Future regulation is an uncertainty applicable to planning, design, and investment decisions made today. And even more difficult than trying to forecast technology and innovation is forecasting policies and laws. A port development project is large-scale, complex, and has a long lead time. A great deal of research is required before development can get underway into the feasibility and impacts of the planned changes pertaining to all related disciplines as well as stakeholders. For instance, in the Netherlands, a complex and lengthy Key Planning Decision procedure, which involves an extensive Environment Impact Assessment is mandatory for large infrastructural projects. The consequence of increasing regulations and stricter policies is that the time between conceiving an infrastructure project and its implementation are becoming longer. Many changes can occur within this time, so that planning needs to start over again. Regulatory changes can include new innovative technology, new standards, or economic changes that impact costs such as tax credits or other incentives. These can result in new physical, performance, or sustainability requirements.

An increasing influence of European decision-making on the individual ports in Europe is the restriction in the growth of the port due to limited 'environmental space', and restriction of cargo sectors/ activities in the port. These could be a threat to port development plans in Europe. Environmental scanning to track forces driving policy changes as well as shifts in public opinion, and expert views acquired on a regular basis along the entire value chain, can result in advance warning of changes to come (and provide sufficient lead time for corrective actions).

It is being realized that business intelligence is key to building and strengthening a company's strategy. It enables an organization to determine market saturation, presence, and perceptions regarding the competitors, as well as how an organization compares across several significant metrics. It helps them to determine optimum policy approaches that will empower them with the key information they need to realize their company goals and recognize crucial opportunities. Environmental scanning aims at broad exploration of all major trends, issues, advancements, events and ideas across a wide range of activities, with a view to defining the potential threats, opportunities or changes for the institution, and alerting management and staff to trends that are converging, diverging, speeding up, slowing down, or interacting (Coates et al., 1985). Information is collected from many different sources, such as newspapers, magazines, Internet, television, conferences, reports, and also science-fiction books.

Various tools are employed by large corporations to systematically scope their external environment. An emerging technology, often referred to as media meta-analysis, is being increasingly used by corporations for market research, investor relations, intellectual property management, industry research, and competitive intelligence. Specialized firms help clients develop insight into constantly shifting public opinion and devise strategies to contend with the driving forces. They help to monitor competitors by first locating information, then by aggregating, filtering, organizing, and analyzing this information for meaningful results. The market studies can encompass entire industries, specific segments, or individual companies. Real-time data is fed into a sophisticated analysis system to provide up to the minute position and strength reports.

8.3.4 Mega vessels and crane productivity

The pace of technological change in the world is accelerating. Ports must be able to track impending technological changes and ask themselves how these changes will impact their planning, as well as marketing activities. The planning of a port is concerned with demand and supply of throughput in the context of future technology. Some of the factors influencing terminal design and infrastructure capacity are – ship sizes, available quay and terminal equipment, and the handling-, transport-, and logistic concepts on the terminal. The market forces have been challenging technology in the development of increasingly economical methods of moving cargo. Often, a new, (generally superior) future technology introduced in the system, different from the one it was originally designed for, can be a vulnerability. Bigger ships and cranes and equipment and handling concepts with a larger productivity than assumed during design, can require adaptations of the layout and port infrastructure. This suggests that in the planning phase, in addition to forecasting demand, it is necessary to carry out technological forecasting aimed at predicting the future characteristic of the relevant technology (related to equipment, procedures, or techniques).

Technological innovation is generally the result of an interaction of diverse technologies and since many factors influence its progress and direction, and can be very complex. This means that the uncertainty in forecasting technology is multiplied, since some of the contributing technologies may have reached their limit, while unexpected synergies may occur between some others (Meredith and Mantel, 1995). The main elements involved in the determination of future technology are economics, socio-politics, and existing technologies. The major techniques for technological forecasting may be categorized under two general headings: methods based on numerical data and judgemen-

tal methods.
a) Numerical data-based technological forecasting techniques which include trend analysis using statistical curve fitting, limit analysis, trend correlation, multivariate trend correlation; trend extrapolation; growth curves; envelope curves; substitution models etc.
b) Judgement-based technological forecasting techniques using monitoring, network analysis, scenarios, relevance trees, and cross-impact analysis

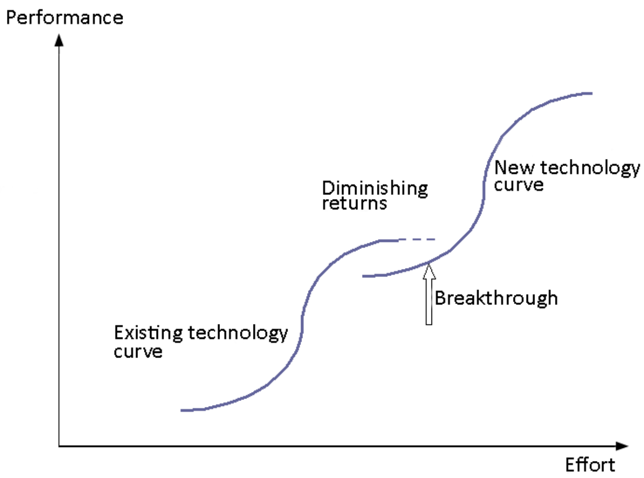


Figure 8.4: Evolution of technology; adapted from Foster (1986)

A common technique for technological forecasting is based on using historical data to establish relationships and trends which can be projected into the future and then applying expert opinion to establish future behaviours. This trend extrapolation is based on the assumption that if there has been a steady stream of technological change and improvement, it is reasonable to assume that the stream will continue now. Technologies eventually (and sometimes very quickly), reach the limit of their performance and become obsolete (Strong, 2007).

If, however, a current technology is approaching its limit, and this is not recognized, projections of past improvements may seriously overestimate future capabilities. In such a case, growth curves can give an indication of advancement of these technologies. Technologies go through an invention phase, an introduction and an innovation phase, a diffusion and growth phase, and a maturity phase. In doing so, their growth is similar to the S-shaped growth of biological life. The S-Curve in Figure 8.4 illustrates both the evolution of a given technology, and the breakthrough event when a new, superior technology becomes viable. (As we saw in Chapter 2, it is the breakthrough events which impact port planning and operations drastically.)

An S-shaped growth shows an early period of growth when relatively little advancement is being made, followed by a sharp increase, and then a flattening out as some limiting natural law or other inhibiting factor is approached. These are termed as adoption, acceleration, and maturity phases respectively. Maturity signals the beginning of obsolescence, as users look around to differentiate their products operations or services. However, it may be possible to anticipate technological change, and incorporate it in our plans. Several mathematical models can be used to generate growth curves, depending largely on the analyst's judgement about which functional forms closely approximates the underlying reality of technological growth under consideration. We will however, propose a general framework for monitoring (breakthrough) technology, and illustrate it with two cases dealing with ship sizes and crane productivity respectively.

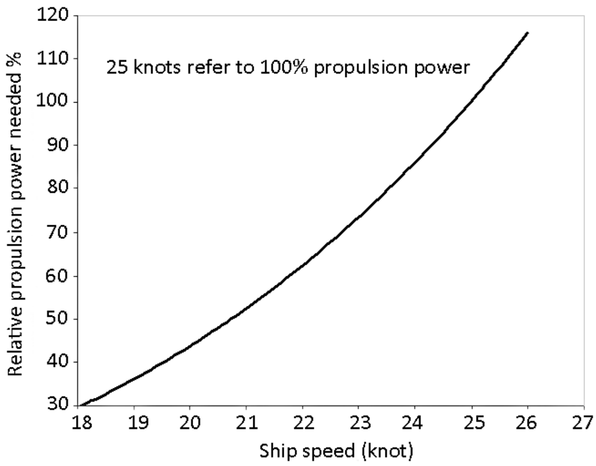


Figure 8.5: Relative propulsion power versus ship speed

a) Ship sizes

Ship sizes play an important role in port design. Shipping companies do not reveal the capacity of future container ships in the design phase in order to have competitive advantage. Therefore there has been endless guesswork over the future container ship (IAPH, 2003): Suezmax? Malaccamax? 22,000 TEU ships? Are they realistic? An attempt to answer such questions requires an examination of multiple aspects. While firms such as Hyundai Heavy Industries and Germanischer Lloyd investigate the structural integrity, manoeuvrability, propulsion and especially operation management of new designs (Probst, 2006), other firms base their forecasts on economic considerations which include vessel cost, transit time and service frequency requirements on certain routes, port productivity and overall cargo volumes (Cullinane and Panayides, 2000; Ircha, 2001; MTG, 2005).

In the past years, an analysis of vessel costs by Mercator Transport Group (MTG) showed that ships up to 18,000 TEUs in size achieve incremental cost savings, albeit at a diminishing rate. The savings achieved by increasing vessel capacity from 10,000 TEU to 12,000-14,000 TEU were thought to be marginal since a more costly twin-screw propulsion system is required to power the 12,000+ TEU vessels. However, the first ultra large container carrier of Maerskline with a capacity of 14,770 TEU, powered by a single diesel engine and largest in the world, appeared in 2006. Meanwhile, 42 such vessels are in use, and 145 ships have been ordered (HbR, 2010a).

In the last few years, fuel oil prices have risen to unprecedented levels. The rising fuel prices and overcapacity are spurring container ship lines to operate more of their ships at slow speeds in order to reduce fuel consumption (and reducing exhaust gas and CO_2 emission). A lower ship speed means lower power requirement. As can be seen in Figure 8.5, reducing speed by 4 knots reduces the power requirement to some 50%

for a typical modern large post-panamax vessel. The travel times, however become longer, and the engine must be able to operate at low loads for long period (MAN Diesel A/S, 2007). This means operating at 17 to 19 knots instead of cruising speed of 23 to 25 knots, using nine ships instead of eight, and adding a week to the voyage or reducing the number of port calls. These adaptations could mean annual savings of total $15 million to $20 million for a typical Asia-Europe route using 8,500 TEU ships (Alphaliner Weekly Newsletter reported by (Bonney, 2010)).

The Triple E vessel, introduced in Chapter 2, is designed for a top speed of 23 knots, compared to Emma Maersk's top speed of 25 knots. That tiny difference in maximum speed lowers the power output needed from the engine by 19%, which allows for slower revolutions in its engines and far greater fuel economy. The Triple E vessel's two slow running engines and two large 'twin skeg' propellers reduce energy by 4% compared to a one engine/one propeller design.

This trend of slow steaming is likely to continue and signifies that one of the physical limitations of technology (and all container ships in service) is removed, making larger vessels feasible.

b) Crane and terminal productivity

Shipping lines continue to demand fast turnaround times for their vessels, and ship sizes continue to drive the size of the container cranes necessary to serve them (from 1st generation in 1986 to 5th generation at present). Quay crane productivity is one of the critical components of terminal productivity. In fact with mega vessels coming over the horizon within the next decade, crane productivity may become the limiting component of the terminal's production and turnaround time of the ship (Jordan, 2001).

A reduction in turnaround time can be achieved in two ways: employ more cranes or reduce the average cycle time of the cranes. With the current maximum gross waterside productivities – varying from approximately 20 to 35 gross container moves per hour per quay crane in the H-LH range – it would require 10 to 15 quay cranes continuously operating on such a vessel, say, in a 24 hour period. This is not feasible at a single vessel due to a lack of space (since quay cranes need about 30 meters distance from centre to centre). Thus, the equipment needs to be more productive instead of more numerous (Sanne, 2004). Higher capital investment costs also make the second alternative less attractive.

Consequently, in anticipation of future demands, improvements in crane design and research into innovative handling concepts has continued. Container terminals have witnessed a series of innovations aimed at improving quay and yard productivity. Container gantry cranes now have longer outreaches (up to 23 containers wide), more lifting capacity (ZPMC has developed cranes with up to 120 tons of lifting capacity) and the spreaders have become more sophisticated (double lift, twin lift and tests by ZPMC for triple lifts). But again, the basic design of a gantry crane and spreader has remained unchanged since the first developments by Sea-Land and Matsons in the early 1960s (Notteboom and Rodrigue, 2008a). Various new concepts such as the elevating girder crane, Delft University carrier crane, Liftech Supercrane, CreaTech

Technotainer, Floatterm, and the Paceco Supertainer, expected to bring about 25-40% increase in productivity, were introduced (Jordan, 2002).

The productivity of a container terminal, expressed as TEU/hectare/per year is an important parameter in the planning of a terminal (Ligteringen and Velsink, 2012). In a business case (such as for MV2), this parameter is used to determine the number of containers that can be handled and the expected revenue from the container sector. During masterplanning, it is used, in combination with parameters such as dwell times and expected traffic flows for different modalities, to determine the terminal area required.

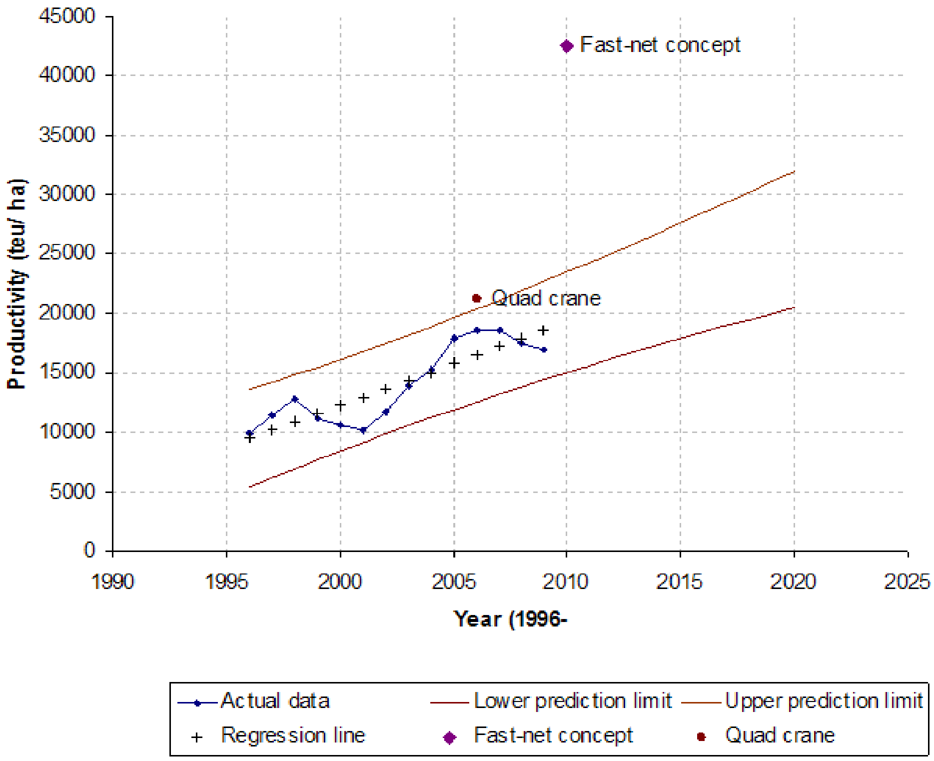


Figure 8.6: Terminal productivity

In Figure 8.6 we have plotted the data from 1996 to 2009, for a container terminal in West Europe and extrapolated it using linear regression. 95% prediction intervals and a trend line have been drawn[1]. In 2006, Dubai ports employed tandem dual hoist cranes with gross productivity of 32 boxes per hour (or 130 moves per ship based on 4 cranes). If we plot the terminal productivity based on this Quad crane concept on Figure 8.6, we see that it lies within our prediction interval and gives no reason for alarm.

Meanwhile, in October 2010, APMT terminals presented a revolutionary handling system (Fast-net) based on the first approach Figure (8.7. Replacing individual cranes is a construction with a giant guide rail over which the crane booms can move in the

[1]The trend in Figure 8.6 is plotted as a straight line, but is actually fluctuating (spike tooth) line, since the productivity (teu/ha) declines temporarily while the capacity (ha) is increased, and time is needed to re-establish the increasing trend.

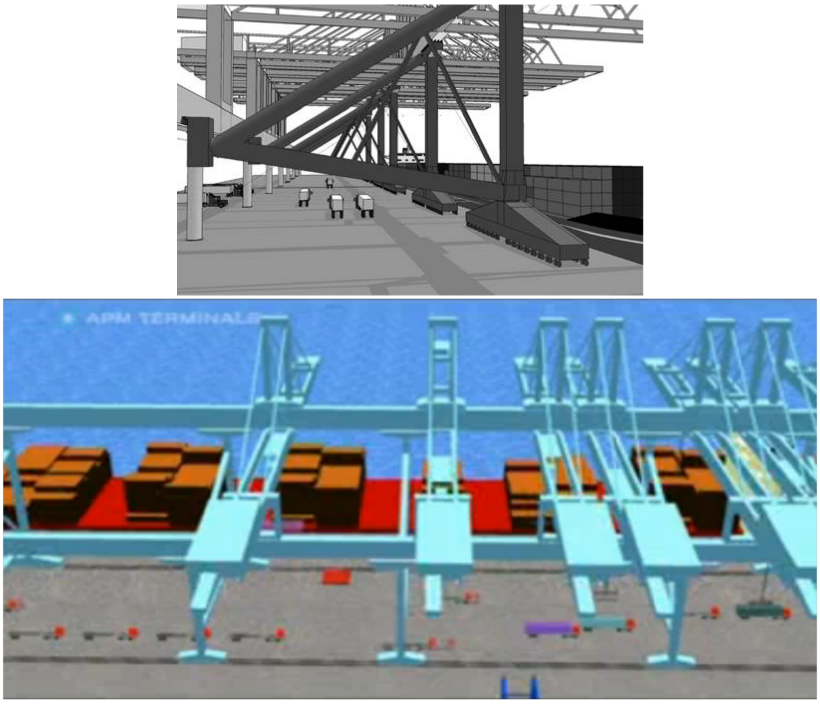


Figure 8.7: Revolutionary handling system (Fast-net)

horizontal direction, parallel to the quay and the ship (WorldCargoNews, 2010). Since this requires less space, it is possible to use more cranes per ship, thus at least doubling productivity. A concept such as Fast-net represents a break-through (as shown in Figure 8.4) and the resulting productivity lies, as expected, far outside the prediction interval (Figure 8.6). If this concept is applied, the result will be congestion on the terminal and in the hinterland during the peak periods. This is a clear indication that action is required and the terminal design requirements need to be reassessed.

Could we have anticipated such a development? Breakthroughs in technology do not come as 'bolts from the blue'. Breakthroughs are the end result of a chain, or even a network of precursor events, and these events give warning that a breakthrough is coming (Co, 2010). If we can identify physical limitations in the current technology, and monitor developments which can remove or circumvent these limitations making new technology possible, we can receive advance warnings (Table 8.1).

8.3.5 Modal shift

Like many ports worldwide, land side accessibility is a major vulnerability for PoR, and the situation will worsen with further expansion of the port. Insufficient accessibility for the three modalities (road, rail, and inland shipping) because of shortage of capacity and/or vulnerability of the hinterland connections, also across the borders, presents a major risk. This requires, in addition to transport efficiency improvements and improvements in interconnectivity of intermodal networks, modal shift tactics. Within EU, modal shift is an important item on the agenda (Polo, 2009). Modal shift actions take freight off the roads and transfer it to other modes of transport. Transporting

Table 8.1: Monitoring technological changes

Questions to be raised	Uncertainty: ship size	Uncertainty: crane productivity
What are the factors limiting further developments in this technology?	Inadequate draft in most ports Physical limitations in technology	Quay and terminal concept Physical limitations in technology
What are the physical limits of the relevant technology or precursor technologies?	Propulsion power to be supplied by the ship engine is a limiting factor	Difficult to achieve large improvements in crane cycle time
Are there developments/ concepts which can circumvent the physical limits?	Slow steaming - lesser power is required	Use larger number of cranes (translated into FASTNET concept by APMT)
Conclusion	Bigger ships are possible	Increase in terminal productivity is possible
Action(s)	Examine technical and economic feasibility of bigger ships	Reassess port Master Plan, terminal design and hinterland connections

goods by rail, inland waterways or short-sea shipping not only decreases pollution and avoids congested roads, but can be a means of improving logistics. The accessibility

Table 8.2: Modal-split targets

Year	Road %(mln.TEU)	Barge %(mln.TEU)	Rail %(mln.TEU)
2006	48 (1.9)	39 (1.6)	13 (0.5)
2009	47.5 (2.1)	39 (1.7)	13.5 (0.6)
2035	35 (5.0)	45 (7)	25 (3)

problem is being tackled at all fronts (te Lindert, 2009; van Meijeren et al., 2009), e.g.: efficiency improvements and interconnectivity of intermodal networks, investing in new infrastructure for inland shipping, expanding road infrastructure, taking measures to divert traffic from road to rail and barges, investing in container transferia etc. Some recent investments are the Delta barge feeder terminal at the ECT Delta complex (2009). The planned investments include Container Transferium Alblasserdam (2013), and the Blankenburg and Oranje tunnels under the Nieuwe Waterweg. The target figures for modal split in PoR can be seen in Table 8.2. In order to judge if the pre-set targets will be achieved, the exogenous developments affecting the modal split, as well as the impact of various measures need to be monitored. The measurement of the modal-split itself is ambiguous and the historical data limited to a single measurement per year for each modality (only available since 2001). Also it is not possible to make reliable estimates for the reduction potential of the undertaken measures. For instance, modal shift tactics such as infrastructure expansion and subsidies will most

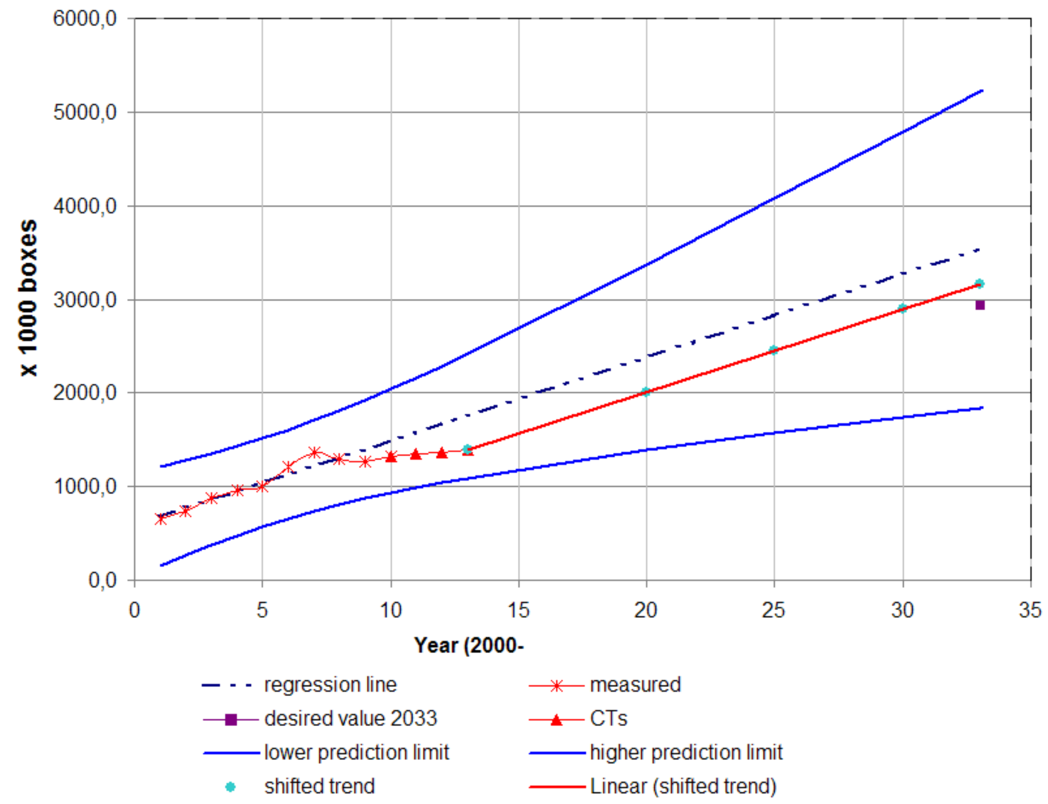


Figure 8.8: Container (road) transport trends

likely induce transport demand growth but the benefits of modal shift will likely be offset by growth in transport volumes (van Essen et al., 2009).

We can follow a simplistic approach and estimate the impact of each individual measure (disregarding all indirect effects) on the transport (TEU's) via each mode. This impact can be incorporated in the respective regression curve for each modality. Certain measures will cause dips or peaks without effecting the trend. For example, the container transferia are expected to divert traffic from road to barges, thus this measure only shifts the two trend-lines. However, lowered cost of barge transport will shift more cargo from road to barges, and probably bring about a structural change in trend. In this case a new trend-line, and corresponding prediction intervals can be determined. In this way, we can monitor the modal shift to see if extra intervention is required. Figures 8.8 and 8.9 show the extrapolated trends using simple regression, and the prediction intervals for the road and barge transport. It is assumed that in 2013 the share of road traffic reduces due to the exploitation of the Container Transferium Alblasserdam by 130,000, and in 2014 by another 100,000 containers. From the trends shown, it can be seen that in order to reach the target values of 35% and 45% for road and inland shipping respectively, measures are required. Regular monitoring is required to check if the measured values lie in the prediction interval. The graphs can be updated yearly when a new measurement (data point) is available, and the new prediction interval can be used to monitor the measurement following year. Individual measures can also be included in these graphs.

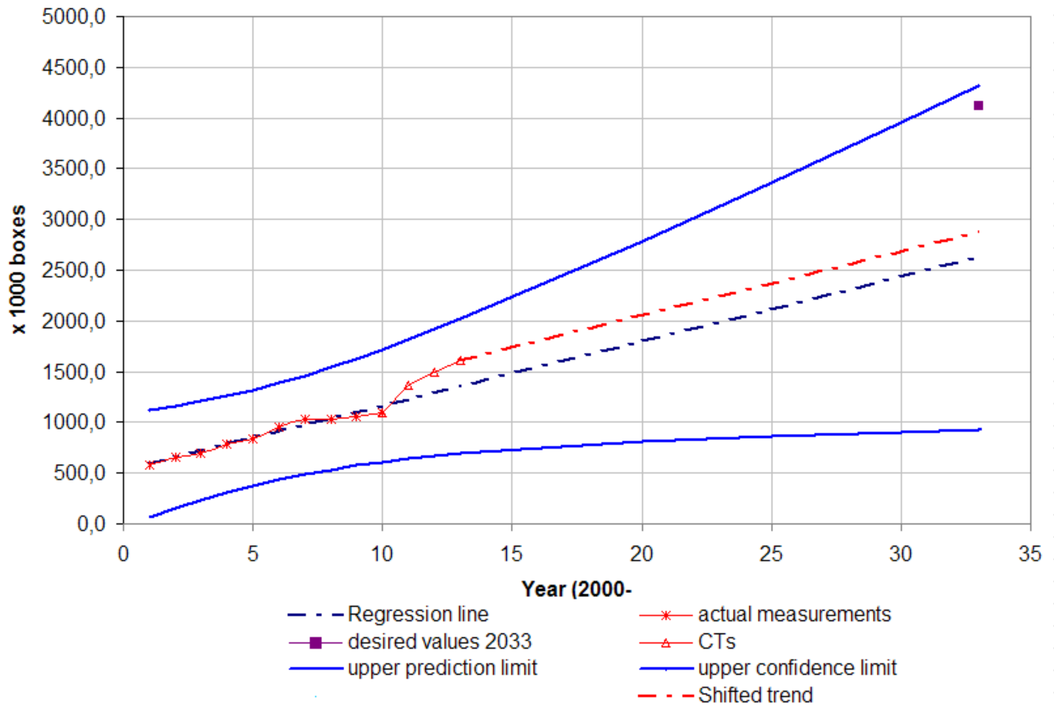


Figure 8.9: Container (barge) transport trends

8.3.6 Non-compliance with standards

Monitoring compliance with standards of sustainability, security, and safety, is carried out as routine by the Port Authority, and is not dealt with here. Vellinga (2010) discusses the environmental monitoring for the port expansion project Maasvlakte 2.

8.3.7 Dealing with wildcards

Of course, not all exogenous developments follow a trend: September 9/11 attacks on the WTC, volcanic eruptions all represent trend-breaks or wild cards. As said earlier, wildcards are low probability, low impact events; we cannot meaningfully quantify either the intensity or frequency of these events. They cannot be captured by exploratory scenarios, or meaningfully ordered or ranked. It would be largely a matter of guesswork, not an exercise based on frequency of past events. In a model, these can produce a short-term transient effect or a long term change in a model structure.

When large changes are expected, it is better to draw upon methods that incorporate causal reasoning. If the anticipated changes are unusual, judgemental methods such as Delphi eliciting expert opinion would be valuable. If the changes are expected to be large, and the causes are well understood, and if one lacks historical data, then judgemental bootstrapping[2] can be used to improve forecasting (Armstrong and Green,

[2]Judgemental bootstrapping converts subjective judgements into structured procedures. Experts are asked what information they use to make predictions about a class of situations. They are then asked to make predictions for diverse cases and the resulting data converted to a model, the assumption being that a model applies the rules more consistently.

2010).

Intervention analysis and Bayesian forecasting are two methods which can deal with outliers. Intervention analysis or event study is used to assess the impact of a special event on the time series of interest (Box and Tiao, 1975). The Bayesian approach to inference, as well as decision-making and forecasting, involves conditioning on what is known, to make statements about what is not known (Geweke and Whitman, 2006). Still, in some situations it may be wiser to accept that there is no sensible way to model an event or a process. Even if the information for a future change may be known, it may still be difficult to incorporate it formally into a mathematical model. In the absence of such information it would be most unwise to try and produce forecasts at all (Chatfield, 2001).

We cannot meaningfully quantify either the intensity or frequency of wildcards (Smil, 2008). Aside from the corrective, capitalizing, and defensive actions included in a contingency plan, we recommend that planners come up with a workaround plan to reduce the impact of these wildcards. Contingency reserves or resources are normally held aside for anticipated risks, but over time, as signposts trigger off risk responses, resources get depleted. Seldom are reserves set aside for unanticipated risks or wildcards. However, having a workaround or fall-back plan (with or without mobilized resources), for dealing with low probability – high impact events can sometimes mean survival instead of failure.

8.4 Conclusions

Monitoring, an important step in Adaptive Port Planning, aims at evaluation of events or developments as they occur or just after. It involves activities like measuring, analysis, assessing and forecasting. We recommend the simplest statistical techniques for forecasting using univariate, deterministic and linear methods, so that the data can be processed routinely and quickly. Extrapolation is sufficient if we assume that the same trends, causal forces, and same types of actions will persist into the future. When large changes are expected, one should draw upon methods that incorporate causal reasoning. If the anticipated changes are unusual, judgemental methods such as Delphi would be appropriate. If the changes are expected to be large, the causes are well understood, and if one lacks historical data, then judgemental bootstrapping can be used to improve forecasting. Even when the monitoring techniques are unsophisticated, the potential value of monitoring can be very significant.

Change in markets leading to fluctuations in the flow of goods, change in policies leading to new physical, performance, and sustainability requirements and changes in technology that could make current plans and designs obsolete, all present vulnerabilities that need to be monitored to safeguard a port development plan. Economic indicators such as GDP are useful in predicting trade volumes. Environmental scanning, media monitoring, and getting advance warning of changes to come through expert opinion can help to track changes in policies. Technological forecasting is more of an art than a science.

Changes in technology, when they represent breakthrough events, can have a drastic, or even disastrous impact on port design and operations. However, breakthroughs in technology do not come as 'bolts from the blue'. Through identifying physical limitations in a current technology (or precursor technologies), and monitoring developments that can either remove or circumvent these limitations, we can get sufficient warning of a possible breakthrough. We have presented a simple framework for monitoring breakthrough technology and illustrated this through two examples. Firstly, the current trend of slow steaming of ships which circumvents the requirement of engines with larger propulsion power, has made larger ships viable. Secondly, increasing the number of cranes per ship through circumventing the space requirements (by providing a horizontal guide rail on which crane booms can travel) allows a radical increase in crane and terminal productivity.

Monitoring is useful only if we can respond by either limiting the excessive detrimental impact of a development or reducing its probability through taking timely measures. We have only illustrated the method; a port should use systematic procedures for scanning the environment to be sure that they do not overlook variables that have large impact on their planning, operations, and markets.

Chapter 9

Some illustrative cases from the port sector

Our goal is to demonstrate that an adaptive approach to port planning can deliver flexible and robust solutions that can better withstand the vagaries of the future.

9.1 Introduction

In this dissertation we have put forward the hypothesis that adaptive approaches for port planning and design will result in flexible and robust solutions that can better deal with the challenge of uncertainty. In this chapter we introduce case studies to test the above hypothesis. A secondary objective of conducting the case studies is to identify the problems encountered during execution of the cases. If the problems are of a general nature (thus not specific to the case under study), addressing them would be worthwhile. The choice of the cases is based on two requirements:
Firstly, we should be able to test our hypothesis for short, medium, and long-term planning. In this way we can illustrate the ability of APP to accommodate different kinds of planning needs.
Secondly, the cases should address current issues in the port sector, which will further help to establish the usefulness of the framework in the eyes of a potential user.

Yin (2009) investigates case study research, and proposes that criteria be set up to evaluate the findings of case studies. Due to the diverse nature of our cases, we choose to compare for each case, the solution through using APP, with the solution that would have resulted from a traditional approach (thus with limited uncertainty considerations). This comparison will help us to draw general conclusions over the efficacy of the method. We would like to mention, that sometimes, the cases have been simplified, and for confidentiality reasons some names omitted, and data altered (this has not influenced the results).

9.2 Case 1: Planning the Europort area for 2045

9.2.1 Introduction

The Port of Rotterdam (PoR) operates within the framework of the European Union's transport policies and programmes as well as the Netherlands ports policy and legislative regulatory frameworks relating to port governance, operations and environmental, safety and security. In future, when the world is likely to place greater stress on reducing carbon intensity, fossil fuel use and CO_2 emissions, a balance between efficiency and profitability, and environmental impacts and sustainability will be required. Whether the outcomes will favour PoR to the same extent in the future, will depend on the path it opts for now (OECD, 2010).

In acknowledgement of the volatility and the growing complexity of the environment, PoRA seeks ways and means of addressing uncertainty. Recently, a new paradigm for the treatment of uncertainty has emerged – from trying to reduce uncertainties, towards accepting and anticipating them, and from finding an optimal plan to developing a robust plan (Lempert et al., 2003; Dewar et al., 1993). In this section we present a case study dealing with long-term strategic planning for a valuable port area, based on this paradigm.

9.2.2 Step Ia: Project description and objectives

The world stands at the brink of an 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. The future demand for oil-based products is expected to come mainly from Asia, an emerging market. This will stimulate the refining of crude at the drilling locations, closer to the future markets and end users, and result in reduced transport time and costs. For Europe it will mean a decline in the refining and in the production of basic chemicals (PoRA, 2011c). Some refineries in the Europort area of PoR may close, so valuable space in the port will become available for a new function.

In view of the recent investments in infrastructure and facilities by companies in the port by companies such as Shell, Esso, and BP, a smaller and older facility X owned by company Y is likely to close down first (Figure 9.1). The company Y has a site of 152 ha in the Europoort area where a refinery and tanks are located. The refinery processes the crude oil and produces products such as LPG (Liquid Petroleum Gas), naphtha, petrol, kerosene, diesel, lubricating oil, etc. Even if the company closes their refinery installation, they are likely to maintain their storage facilities. The soil at X terminal is heavily polluted due to the refining activities, but its exact extent is unknown. It is assumed that the polluted soil is mainly located under the refinery, therefore Company Y will retain this area to avoid expensive remediation of the soil and relocate the existing tanks here. A 63 ha area will become available next to the tank storage facilities.

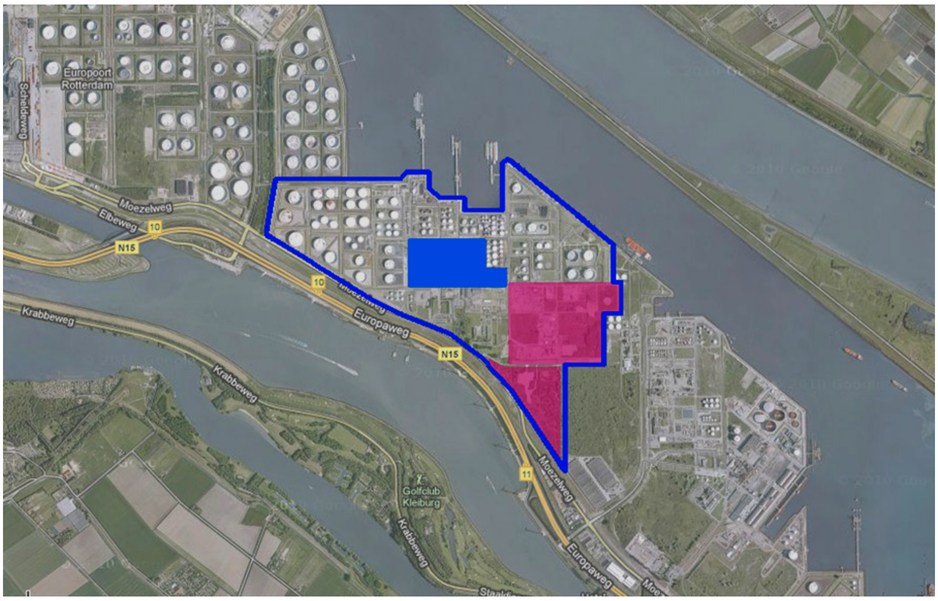


Figure 9.1: Layout of the port showing X terminal (source: PoR)

The objective of the PoRA is to find a new profitable and sustainable use for this space, which fits in with its vision and the overall spatial planning of the port. Numerous uncertainties exist:

- Which market segments will be commercially attractive in the future?
- Will these also be desirable in view of sustainability or other considerations that have priority in the future?
- Will the future change so much that the requirements of the future users will change drastically?

In short, the problem involves long-term planning beset with deep uncertainties (i.e., it can include discontinuities and surprises). Our planning objective will have been met if we can identify a use for the space that will be commercially viable in all plausible futures and also be in line with the vision and goals of PoRA.

9.2.3 Step Ib: Define strategy and formulate alternatives

We have presented various planning strategies in Chapter 5.2.4. In this case, we employ Scenario Planning (see Section 5.2.4 and Section 5.3.2) as a tool within APP, which recognizes that it is not possible to define the future as one picture, and we need several alternatives that all together describe the range of plausible futures (Meristo, 1986).

Scenario planning simplifies the avalanche of data into a limited number of possible states. Each scenario tells a story of how various elements might interact under certain conditions. A detailed and realistic narrative directs attention to aspects otherwise overlooked. Scenarios explore the joint impact of various uncertainties. The objective is to see the world in terms of trends and uncertainties (Schoemaker, 1995). Having

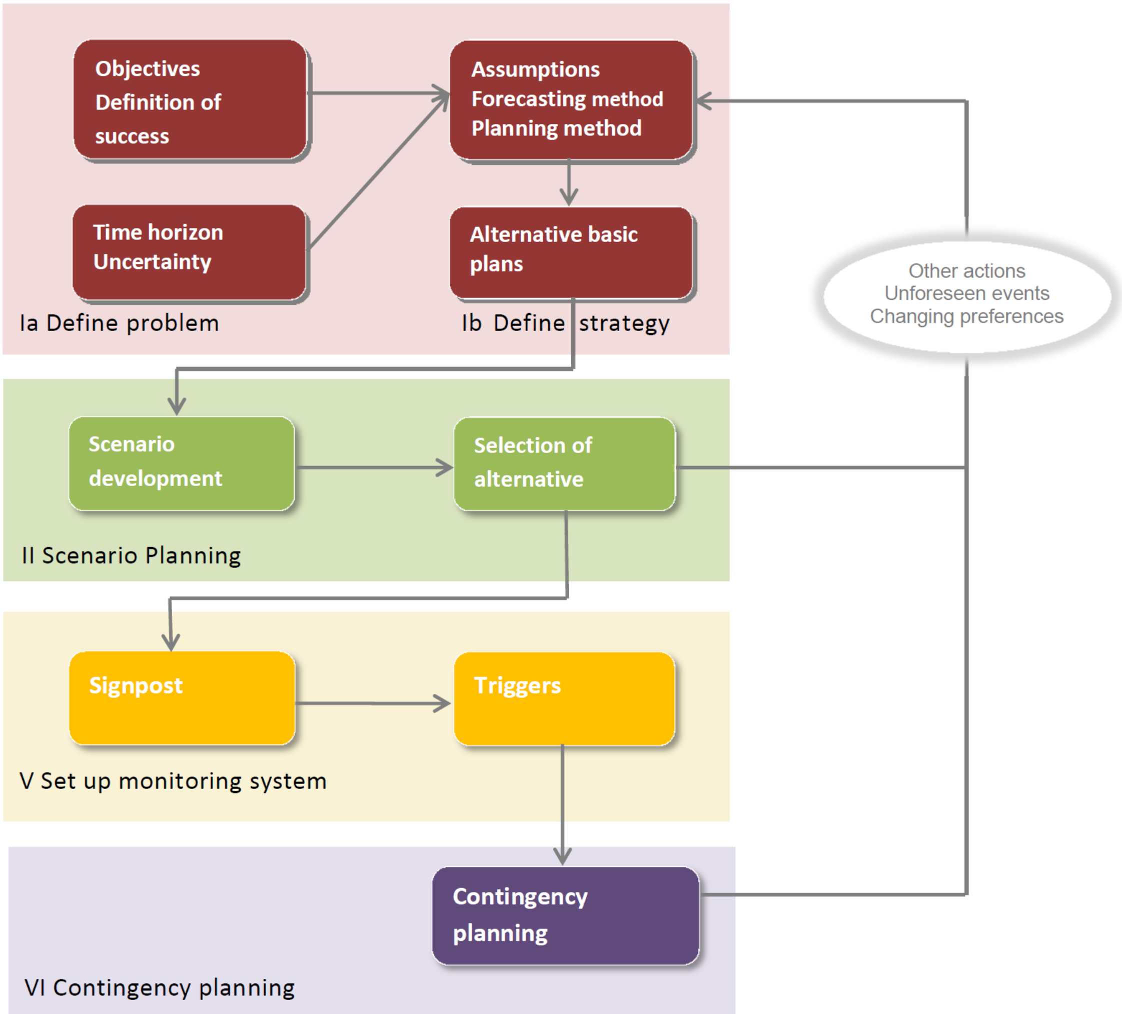


Figure 9.2: Steps in APP using scenario planning

identified a set of plausible scenarios, we will develop robust strategies to meet our objectives, and finally assess them in these scenarios (or multiple futures). This is also called Robust Decision Making (RDM) (Lempert et al., 2003). RDM characterizes uncertainty, and the relationship between near-term choices and long-term outcomes. It is an iterative, analytic process for identifying strategies that perform reasonably well compared to the other alternatives across a very wide range of plausible futures, and characterizing a small number of irreducible trade-offs inherent in the choice among robust strategies. Figure 9.2 shows the sequence of steps to be followed; Step II involves scenario development and selection of an alternative, while Steps III and IV are not required. Strategic plans are created on several levels by PoRA and updated regularly. Some of the relevant documents from the recent years are:

- Port Plan 2020;
- Business Plan 2011-2015;
- Commercial Plan 2011-2015;
- Spatial plans for various regions in the port (plan for Europort updated in November 2010);

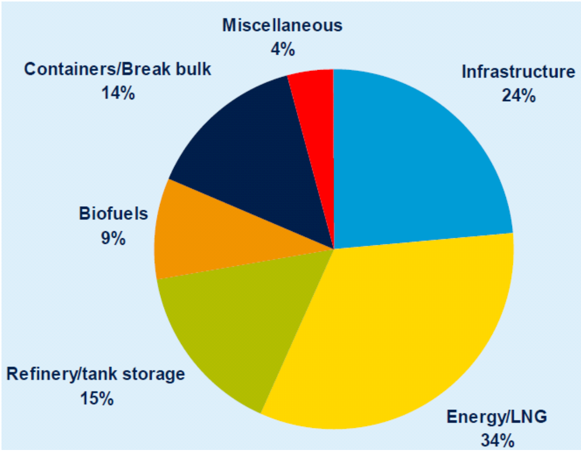


Figure 9.3: Investments Port of Rotterdam 2008-2015 (source: PoR)

– Port Compass 2030.

Each of these documents focuses on different aspects of planning, but there are substantial overlaps and interrelations. The forecasts in many of these documents are based on the econometric forecasts of CPB, which also employs scenarios for forecasting. Many studies focussing on developments in the energy sector have also been carried out in recent years (PoRA, 2007, 2010b). Port Compass 2030 (PoRA, 2011c) is a recent document that presents the long term vision of the port. None of the studies envisages a future beyond 2030.

PoR's new Business Plan (PoRA, 2010a) for the period 2011-2015 focuses on three themes: 'Rotterdam energy port', which favours LNG (Liquefied Natural Gas) and biomass energy facilities; 'Rotterdam fuel hub', which advocates strengthening of the liquid bulk sector and favours (mineral) oil and tank storage expansion, and 'Rotterdam container port' which favours the expansion of container handling. Figure 9.3 shows the share of PoR's investments in various sectors in the period 2008-2015. Based on various studies, and on discussion within PoRA, the growth sectors identified are: mineral oil, biofuels, LNG, biomass, CO_2 shipping hub, deep sea, and short sea containers. These represent the plausible alternative uses for site X under consideration.

9.2.4 Step IIa: Scenario development

The place of scenarios in an environment of complexity and uncertainty can be seen in Figure 9.4 (Zurek and Henrichs, 2007). Though many authors suggest techniques for generating scenarios, we use the scenario model of Global Business Network (RAND, 1997b) based on identifying pre-determined trends and critical uncertainties. The process involves creating a two-dimensional matrix based on identifying the two factors considered to be most influential for the issue at hand. If desired, the uncertainties can be structured by dividing them in themes such as social issues, technological changes, economic dynamics, environmental pressures and political dynamics (together termed by Global Business Network (2011) as STEEP). Expert opinion is valuable in this process. Scenario planning is carried out in the following steps:

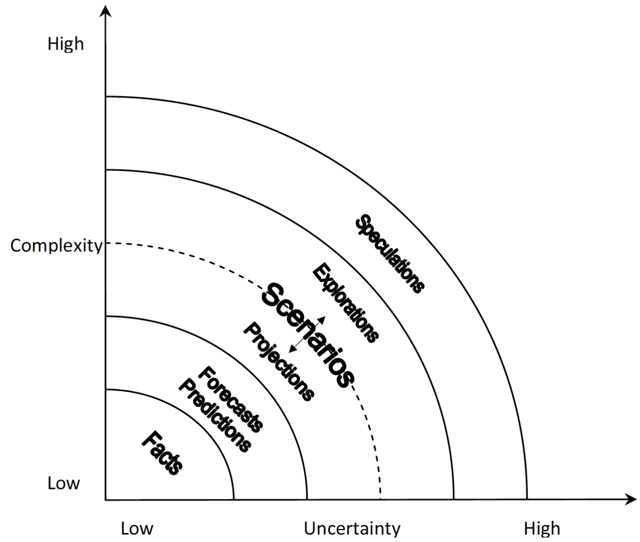


Figure 9.4: Place of scenarios among complexity and uncertainty

- Identify key driving forces;
- Categorized forces as predetermined or uncertain;
- Identify critical uncertainties through assessing their impacts and degree of uncertainty;
- Develop scenarios;
- Analyse scenarios and select a use for site X that is robust in all scenarios.

Some critical driving forces which are relevant to the issue at hand and may be important in a future beyond 2030:

1. Geopolitics and world trade
2. Economic growth
3. Environmental policies and regulations
4. Availability of fossil fuels and extent of their use which will depend upon process optimization and development in techniques of Carbon Capture and Sequestration (CCS)[1]
5. Costs of scarce natural resources and fossil fuels
6. Availability of renewable energy sources and extent of their use
7. Developments in biotechnology
8. Changes in the role of government
9. Investment climate

Some of these highly uncertain driving forces will be common to all scenarios (1-3), and the potential impacts of others (4-8) need to be examined in order to establish their relevancy.

There is no question that the future will bring scarcity of fossil fuels and lead to an energy transition. In the end we will be forced to become sustainable (any other option

[1]CCS is one of the critical technologies worldwide that will enable reduction of carbon dioxide emissions arising from large industrial sites. It allows the continued use of a diverse mix of energy sources, including fossil fuels, which can improve the sustainability of cost-effective electricity supply.

implies a doom scenario we prefer not to envision). Two vital questions that we cannot answer are:

– How long can we go on with 'business as usual'?
– Which alternative path will we follow?

Which activity and which cargo is profitable in the future (which is what we are trying to ascertain), will be in large part determined by future energy policies at the local, national and at the global level. This will depend on whether the world becomes green or grey, which is the transport mode preferred, and which fuels are used. Energy policies will be influential in determining the future trade patterns (what is manufactured where, and what is transported) and the transport costs. How carbon is priced, for example, could fundamentally alter many industries (Bisson et al., 2010). For the present exercise, the two key uncertainties we have chosen to be most influential in shaping the scenarios are:
– The degree to which the world is green as opposed to grey (sustainable as opposed to non-sustainable world)
– The trends of government intervention compared to private initiatives (government driven as opposed to market driven forces)

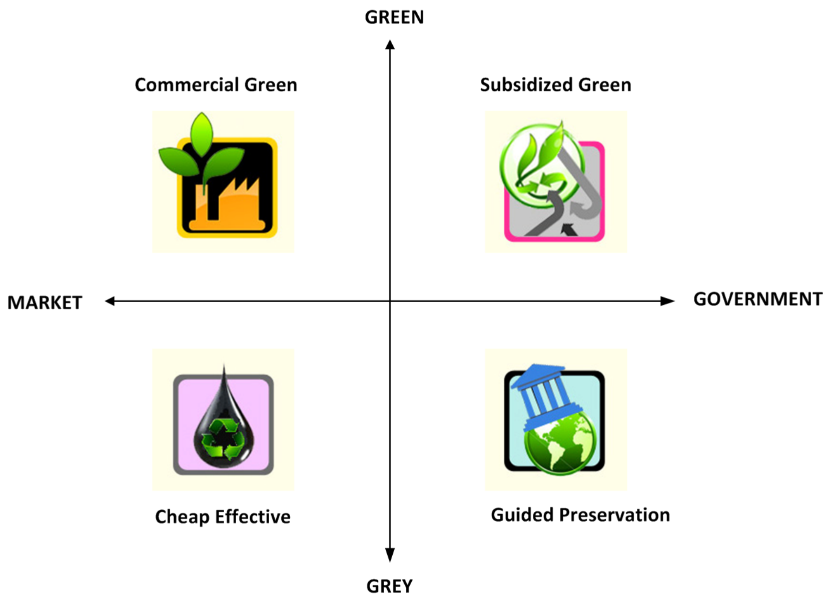


Figure 9.5: Four Scenarios

The two uncertainties give rise to four possible future worlds, as illustrated in Figure 9.5. On the horizontal axis, one extreme represents political regulation to attain specific environmental and social goals, while the other extreme represents market initiatives. The vertical axis represents the impacts on the environment: one extreme represents a state where fossil fuels are available and in use despite adverse impacts, while the other represents energy production and use that has less negative impact on the environment. The intersection of the driving forces creates four quadrants, each represents the scenario of a future world.

The bottom left, represents 'Cheap Effective' or business as usual, i.e., a world where fossil fuels are available and in use despite adverse impacts. The bottom right indicates 'Guided preservation', a transition towards a somewhat green world driven by a strict government legislation, while markets seek operational efficiency. The upper right quadrant represents 'Subsidized Green', a world with passive citizens and a reactive market. A proactive government is the driving force behind the transition to a green economy. The upper left quadrant represents 'Commercial Green', a desirable world with environmentally conscious citizens and a responsible proactive market.

Each of these four worlds are described in the following subsection. The various actors are: citizens or the public; government and intergovernmental organizations; markets (including shippers, operators, industrial corporations, port-related companies), and the port authority. There can be radical shifts in the way the actors will behave and interact in the worlds defined by our scenarios, sometimes assuming other than traditional roles.

9.2.5 Scenario narratives

(1) Cheap effective or 'business as usual'

Since there is no shortage of coal and unconventional hydrocarbons in this scenario, the economy is based on use of fossil fuels and there is worsening environment pollution. Sustainable energy sources are not attractive economically. Stricter measures have not been imposed by the government. The cost of environmental impacts and external productivity effects are not internalised due to absence of regulation. The focus of most organizations is more on minimum compliance than on long-term planning. They are prepared to resort to ad-hoc mitigation measures to continue non-sustainable mode of operations, and even pay heavy penalties. Initiatives due to enforced government regulations, such as CO_2 emissions reduction measures, wind turbine farms for renewable energy, and the co-firing of biomass within the existing power plants continues. It is business as usual and technological advancement is market-driven. As fossil fuels near exhaustion, fuel prices rise. The impact of a sudden energy transition can prove drastic for the port and the recovery can be slow.

(2) Guided preservation

Energy crisis is slowly becoming a fact. Biofuels and bio-based chemicals production technologies represent the only near-term alternatives to conventional gasoline, diesel-fuel, and petrochemical feedstock (since there is no approval for nuclear energy, and solar energy is insufficient). These are expensive and the transition from cheaper to expensive sustainable energy sources is slow. Political pressure in the form of strict environmental legislation is required to coerce the market towards sustainable solutions. The market (and the port) is reactive, instead of proactive in seeking solutions. There is no coordinated exploration for new resources.

As socio-economic and environmental stresses to deal with energy crisis increase, the government begins to be more active. Global and European legislations forces too begin to actively stimulate collaborative innovation. Public awareness for the dire need to shift to alternative energy sources increases. Increasing awareness will eventually demand a green supply chain – not only the products have to satisfy various end-user requirements at a competitive cost, but their entire lifecycle from conception, production, transportation to waste is required to be environmentally friendly. This will require innovative effort on a grand scale.

Markets in general focus on operational rather than sustainability goals. The ports throughput declines due to high oil prices. As they become targets for public environmental policy regulations, economic imperatives suffer.

(3) Subsidized green

A coordinated pro-environment policy framework including measures such as penalties, subsidies, fiscal incentives, and supporting activities for innovation and capacity building has been set up. Green taxes, strict environmental laws, polluter pays laws, and an emphasis on 'reducing, reusing, and recycling' has improved the quality of local and regional environments. The government supports sustainable initiatives and innovation related to sustainability technologies, but not much else. Global energy policy favours production closer to markets, driven by the rising cost of freight transport due to higher fuel costs and the impact of new environmental regulations.

Certain port activities such as container handling suffer and either disappear, reduce, or shift to a country with more lenient regulations. The port is slow to react. The government responds positively through providing aid, a favourable investment environment, encouraging collaborations between public-private sector, and setting up innovation related policies. Favourable developments take place in renewable energy such as wind, water, geothermal, and hydrogen fuel cells, which become cheaper. Though PoR suffers initially, timely investment in all-around innovation helps it to recover.

(4) Commercial Green

Public opinion is the driving force towards low-carbon transport. The international nature of port management has stimulated investment in global solutions and development of international policies. Green House Gas (GHG) monitoring is a part of the regulatory regime. European Union has included transportation in it cap and trade schemes for controlling emissions from a group of sources while providing flexibility in how they comply. This is proving a competitive advantage for ports that were ahead in carbon management and contribute least to the GHG burden. New development paradigm emerges in response to the challenge of sustainability. Corporate and social responsibility, and more equitable values are the norm.

The market forces dominate the political agenda, as globalization and liberalization continue to give an impetus to the world trade. Industries become more efficient with energy. There is a climate of environmental awareness, which stimulates accountability and transparency in corporate behaviour, and leads to sustainable governmental policies. All these factors reinforce each other so that technological development is rapid, and sustainable practices become cost-effective. This means most cargo sectors show growth in this scenario. There is an extra boost for bio-based industries as demand for renewable energy sources escalates.

Table 9.1: Scenario Characteristics

	Cheap effective	Guided preservation	Subsidized green	Commercial Green
Environmental awareness	Low-medium	Medium	Large	Large
Sustainability related innovation	Medium	Little	Large	Large
Energy demand/ prices	Stable/ low oil prices	Stable/ low-high oil prices	Medium/ High	High/ high
Energy sources	Fossil	Fossil	Renewable	Renewable
Regulation	Market	Government	Government	Market
(long-term) Economic impact	No growth, possible loss in competitive position	No growth without raising awareness and govt. aid	Not profitable, req. innovative solutions	Profitable, significant growth
Role of PoR	Enabler, facilitator	Enabler, facilitator	Enabler, facilitator	Leader, investor, innovator

Meanwhile, new trends have emerged: there is a shift to environmental friendly short sea and inland shipping that are subsidized, as is rail transport. The trend of large ships shuttling between offshore transport hubs and smaller ports is explored by alliances. Measures such as 'road pricing' stimulate the market to look into sustainable and innovative transport modes. Priority is given to intensifying resource use. Since port expansion is discouraged due to detrimental effects of a new land reclamation, the port authority and other stakeholders consider investment in innovative flexible infrastructure.

9.2.6 Step IIb: Scenario analysis

As a next step, we analyse the implications of these alternatives within scenarios, as well as compare these across our scenarios.

Table 9.2: SWOT analysis

	Cheap-effective	Guided-preservation	Subsidized-green	Commercial-green
Strength	Business as usual, Cheap and effective in the short term	Government aid	Not commercial, Govt. involvement can prove to be an advantage	Profitable, bio-based economy, cost effective practices

continued on next page

Table 9.2: *continued*

	Cheap-effective	Guided-preservation	Subsidized-green	Commercial-green
Weaknesses	Adverse environmental impacts	Little environmental awareness	Market not involved, Non-stimulating environment	Unregulated
Opportunities	Focus on other issues than sustainability, Short lived competitive advantage compared to countries with stricter regulation	Prepare for energy transition through guiding people into a green mind set	Policy tools such as subsidies and legislation can foster innovation	Stimulates co-operation, co-innovation, PoR leader in innovation
Threats	Fossil fuels are exhausted or too costly to extract, Global or National legislation concerning use of non renewable resources is increasingly stricter	The awareness comes too late. The government proves to be weak	Market cooperation required to translate research efforts into innovation is not forthcoming	Economic imperative becomes more important than sustainability

Table 9.1 lists the scenario characteristics, and a SWOT analysis of the scenarios is given in Table 9.2. These will provide insights while identifying alternative uses of the space in each scenarios.

Figure 9.6 lists the promising industries in columns 1 and 2 and the four scenarios in the top row. Tank storage and chemicals have been added to the list. The robustness of a sector is determined by its performance in all scenarios. For evaluating this performance, a scale from 1 to 5 has been used; the higher the number, more promising is the alternative. The industries have also been compared to each other within the same scenario using -, 0, + and ++ (indicating lower to higher performance). The input for the table has been supplied by experts at the port, or is based on earlier studies. The following conclusions as to a robust function for the space, can be drawn from this table:

LNG as industry fares well in all scenarios, and is also suited for deep sea. Small scale LNG, though a promising market sector (PoRA, 2010a), cannot effectively utilize large water depth available at this location. LNG is also proclaimed to be the key fuel in progressing to a sustainable energy future since it is a major source of safe, cleaner energy, offering the lowest emissions of any fossil fuel. (In fact, according to the LNG industry, it actually reduces global carbon pollution by displacing higher emission fuels.)

Containers will continue to be attractive for transporting cargo until an even better alternative can be found. According to forecasts, PoR is expected to reach its capacity

Alternative cargo sectors		Cheap Effective		Guided Preservation		Subsidized Green		Commercial Green		Total
Fuel	Mineral oil	++	5	+	4	+	2	+	1	12
	Bio Fuels	0	2	0	3	+	4	+	5	14
Energy	LNG	+	3	+	3	++	4	++	5	15
	Bio mass	0/-	1	0	3	++	5	+	5	14
	Co2 shipping hub	+	2	+	3	++	4	+	4	13
Containers	Deep sea	+	4	+	4	+	4	+	3	15
	Short sea	++	3	++	3	++	4	++	4	14
Miscellaneous	Tank storage Chemicals	+	3	+	2	+	2	+	2	9

Figure 9.6: Comparison of alternatives in four scenarios

in 2033. Due to sustainability considerations, reclamation of additional space is not likely to be an alternative in the future, thus X site could be used for containers. Figure 9.7 shows the layout of floating container terminal located close to the present X terminal in the port (Bijloo et al., 2010). This would provide temporary storage during the soil remediation activities and additional space for berthing vessels as well as for storage. (In the future, environmental threats could lead to population movements and wasted infrastructure investments. Floating infrastructure that can be relocated offers a flexible alternative).

The segments biofuels and biomass, together with bio-based industry can be clustered under a common heading, i.e., bio-refinery cluster. The bio-refinery concept is analogous to today's petroleum refinery, which produces multiple fuels and products from petroleum (Smith, 2007). IEA (2009) has defined bio-refining as the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bio-energy (biofuels, power and/or heat). Considering that many of the associated technologies are not developed yet, and many others are not cost-effective from the present economic feasibility point of view, this industry is not favoured. (However, our scenarios have revealed that in order to achieve a sustainable future, timely investments in sustainability are vital. PoR and other organizations should pay heed to this.)

Having identified LNG and containers as robust alternatives for site X, the following step is to investigate the feasibility of the selected functions, keeping in mind the technical and logistic requirements and the limitations imposed by the site characteristics. This requires a preliminary design of the facilities for each of the industries, followed by an economic evaluation. These steps do not form a part of the case study, though a quick scan indicates that the new function should utilize the deep draught available at the location.
As shown in Figure 9.2, Steps III and IV have been omitted.

Figure 9.7: Floating Container Terminal in the port

9.2.7 Step V: Set up a monitoring system

Having identified a use for the space that will be commercially viable in all plausible futures, we still need to carry out monitoring for two reasons. Firstly, to check if some of the assumptions based on which we have made a selection are failing. (This could refer to the critical uncertainties around which our scenarios have been developed or cargo sectors which were thought to be desirable at the time of planning.) In such an event, we may need to rethink our scenarios and go over to a reassessment of our plan. Secondly, we need to be able to respond timely to developments and initiate our plan. The adaptation of the existing facilities, or planning and realization of new infrastructure to accommodate the new function requires considerable lead time. Securing the environmental permits etc. can take up a lot of time, especially because the terrain at site X is polluted as a result of the refining activities.

Monitoring requires tracking the driving forces or precursor developments that will result in diminished refining activities in Western Europe. Some useful signposts are – higher oil prices, a shift to other fuel types, global energy policies, and change in trade patterns. It also requires following developments which can influence the desirability of certain cargo sectors. In addition are the ever-present risks of global shocks, conflicts and disasters that could affect the global and regional GDP projections. These and other trend-breaks have not been included in our scenarios.

Step VI involving contingency planning for the selected alternative, is not discussed here. It is suggested that just before going over to implementation of the plan, an assessment of the existing uncertainties (which have not cleared up, but could be critical) is carried out, and suitable actions prepared.

9.2.8 Discussion of the case

A new, profitable and sustainable use for a vacant space in the port, that is robust in multiple futures, and fits in with its vision and the overall spatial planning of the port, was investigated. These multiple futures were based around critical uncertainties related to energy transition – how long can we go on with 'business as usual' and which alternative path will we follow to reach a sustainable world. LNG and container handling activities were recommended.

An evaluation involving comparison of multiple alternatives in numerous scenarios is complex; this case study proposes a simple qualified manner to do so. Some issues related to the case are discussed here.

The scenarios in the case study have clearly identified a bio-refinery cluster as an essential market for the future. Through investing in research and development, and allocating reserve space for this activity during strategic planning, and supporting innovation friendly policies, we have a better chance of a smooth transition towards the desirable future, i.e., commercial green. (In this context we refer to Hinds (2008) who mentions five distinct stages that organization undergo: pre-compliance; compliance under regulatory pressure; beyond compliance where regulatory threat and a public relations crisis occurs; pro-active, integrated strategy, and purpose with a passion.) The message is that actively participating in the sustainability movement can increase port industry's ability to shape its destiny.

It is likely that not all scenarios (or key variables in these scenarios) have been accounted for during scenario planning. Also, black swans can negate the entire exercise. Therefore, we also advocate the strategy of flexibility to deal with uncertainty. Flexible solutions will help us adapt when conditions change.

9.3 Case 2: Planning for a quay wall construction project

9.3.1 Introduction

In a port, a quay wall forms an interface between land and water (Figure 9.8). It is a means for berthing ships and reliable handling of goods, in order to generate revenues. It should satisfy the need of the client and the user by providing capacity, durability, availability, and reliability, and comply to safety and environmental regulation. An investment in a quay wall is costly, irreversible, and because of the many uncertainties, risky. In this case study, we place a quay wall construction project in the framework of APP.

Figure 9.8: Quay wall for a container terminal (Port of Felixstowe)

9.3.2 Step Ia: Project description and objectives

We can distinguish distinct phases in the lifetime of a quay wall project: planning, realization, exploitation and demolition or reuse (Figure 3.4). The project risks in the realization phase (often related to site conditions or availability of material and equipment), are generally manageable through research and investigation and good management (permits and approvals on time, skilful workers, and sound contracts). However, the uncertainties that can appear during the lifetime of a quay wall must be accounted for through flexible and robust designs, which can be adapted at a later stage. These uncertainties generally concern future demand and new technology, e.g. future ships, equipment or transport, handling, and logistic concepts.

Here, we place the risks in the realization phase in the framework of APP. During this phase, the port authority requires (quality) construction within the planned budget and schedule. This is then also the objective of the contractor. Any event or development that threatens the budget or the schedule, forms a vulnerability for the project. Many of these vulnerabilities, some certain and others uncertain, are common to construction projects in a port. Three main actors can be identified – the future user or client, the port authority (generally represented by a consulting engineering firm), and the contractor (and sub-contractors) executing the works.

9.3.3 Step Ib: Define strategy and formulate alternatives

Our case study deals with the construction of a quay wall without taking into account the type of the quay wall. Therefore no alternatives are defined.

Table 9.3: Some certain vulnerabilities, and responses to them

Vulnerabilities and opportunities	Mitigating (M), Shaping (SH), and Seizing (SZ)Actions
Damage to the surroundings due to settlement behind the quay wall	SH: Construction methods that do not lead to soil displacement: piling from water towards land, pre-drilling upto a certain depth M: Construction all-risks insurance
Negative environmental impact	SH: Timely environmental impact assessment M: Planlogical adjustments to compensate for loss of natural reserves M: Sustainable construction materials and methods
Delay in environmental building permits due to and insufficient preparation	SH: Thorough inventory of necessary permits and procedures SH: Penalties for the consultant or contractor in contract SH: Sufficient attention for risks in the preparation phase
Quality of construction not satisfactory	SH: Detailed specifications and thorough supervision
Project scope not clearly defined due to insufficient communication	SH: Improve procedures
Delay in availability of site	SH: Better communication
Obstacles, foundation remains, pipes and cables, archaeological findings at site	SH: Thorough inventory, historical and archaeological research
Soil or site more polluted than expected	SH: Additional Investigations M: Risk reserve
Soil condition worse than expected leading to slope instability, unexpected settlement	SH: Extra soil investigation M: Alternative solutions for design and construction

continued on next page

Table 9.3: *continued*

Vulnerabilities and opportunities	Mitigating (M), Shaping (SH), and Seizing (SZ)Actions
Additional safety requirements from the surrounding	SH: Timely consultation with all stakeholders
Claims from the contractor due to extra work not covered in the contract	M: Uncertainty reserve
Error in judgement related to construction methods, supporting structures,	SH: Make provision in contract
project phasing, etc.	M: Risk for the contractor
Low grade quality work by contractor	SH: Specifications related to desired quality
	H: Penalty for the contractor to compensate for extra cost and schedule delay
High material prices due to market-effects	M: Financial instruments to insure against increase in prices of e.g. steel and oil
High tender prices due to market-effects	M: Good market orientation and hedging against critical elements
Bad climate conditions (frost over a long period or storm)	M: Provision in planning over workable days
Required equipment not available	SH: Timely market orientation
	M: Risk for the contractor
Late delivery of material	SH: Delivery of the material by the Project-owner procured in a separate tender)
Claims from the local government due to damage to the environment	M: Uncertainty reserve
Claims due to damage of buildings or industrial terrains	M: Uncertainty reserve
Claims due to damage during work not covered by insurance	M: Uncertainty reserve

9.3.4 Step II: Identify uncertainties

Table 9.3 lists some of the 'certain' vulnerabilities and Table 9.4 shows some of the 'uncertain' vulnerabilities identified in Step II. In the civil engineering sector, certain occurrences such as additional work outside the scope of the project, negative impact on the environment and bad weather causing delays, are 'fairly certain' and taken care of either contractually or through standard procedures[2]. Despite this, uncertainty pertaining to disputes between contractor and the client, mostly over cost overruns, are frequent. This arises mostly due to extra work outside the contract, and uncertainty around these claims is not accounted for in the risk analysis. The arbitration process for settling these claims can go on long after the completion of the project, which adds to the uncertainty. Which is why a separate risk category known as claims risks has been defined Vastert (2003).

As shown in Table 9.4, the uncertain vulnerabilities often deal with changes in client requirements, change in design assumptions due to new technology becoming available, or changes due to application of new materials or innovative construction methods. These can have a large impact on the project.

9.3.5 Step III: Make the plan flexible and robust

The appropriate actions devised in Step III for 'certain' vulnerabilities identified in Step II are listed in Table 9.3. Considering the short length of the construction period, timely market orientation, communication with the client over the project requirements and with the project team over construction related activities carried out in a framework of well defined procedures, will be generally adequate. The customary actions involve invoking the contract, or resorting to the uncertainty-reserve.

Table 9.4: Some uncertain vulnerabilities, and responses to them

Vulnerabilities and opportunities	Hedging (H) and Shaping (SH) actions
Changes in client requirements	SH: Discuss and take into account long-term planning of clients SH: If requirements are uncertain, postpone decisions as long as possible SH: Make flexible specifications and provide a robust or flexible quay wall design
Changes in design assumptions due to new technology	SH: Examine state-of-art developments while drawing up specifications, carry out technological forecasting SH: Draw up flexible specifications H: Adopt flexible designs
Changes in scope due to application of new materials or innovative construction methods	SH: Make provision in contract over sharing costs and benefits with the contractor, and applying for subsidies

[2] In the Netherlands, standard forms of contracts such as the UAV-GC 2005 (De Uniforme Administratieve Voorwaarden voor geïntegreerde contractvormen), RVOI 2001 (Regeling van de Verhouding tussen Opdrachtgever en adviserend Ingenieursbureau), DNR (Rechtsverhouding opdrachtgeverarchitect, ingenieur en adviseur) and the UAV 1989 (Uniforme Administratieve Voorwaarden) are well known and serve to lay down the client-contractor relationship in a construction contract.

The common approach is to treat the uncertainties as risks with associated probabilities. All identified risks are assigned a probability of occurrence and an impact, in terms of money as well as delay to the schedule. Next, a measure is devised either to reduce or remove the risk. The rest-risk (which is the irreducible part of the risk) and its probability is estimated. In this way, an overview can be created of the risks which despite measures have a rest risk. These can be prioritized and additional measures devised to make the plan robust.

We can prepare for the 'uncertain' vulnerabilities in the design phase through extensive research (not always effective) or postponing decisions till uncertainty clears up (not always feasible). By adopting flexible procedures, flexible specifications, and flexible or robust constructions, we can adapt to changed circumstances if required (Table 9.4). These considerations should be included while defining alternatives in Step I. The cost-effectiveness of any additional measures must be determined in Step III and can be carried out in the same manner as for 'certain' vulnerabilities.

9.3.6 Step IV: Evaluate and select alternative

In the present case, we have assumed a single alternative, therefore this step is not relevant.

9.3.7 Step V: Set up a monitoring system and Step VI: Contingency planning

After the construction of the quay wall is finished, and the necessary infra plus and the supra-structure have been put in place by the user (i.e. the terminal operator), the project goes over to the exploitation phase. Ships can be received and handled in order to generate revenue. Generally, the maintenance of the quay wall for a predefined duration is a part of the construction contract; the duration depends on the type of contract. After this period, the maintenance is taken over by the port authority (in case of a landlord port), or assigned to a third party.

Many of the vulnerabilities identified during Step II can appear during the exploitation phase. Step V involves monitoring the vulnerabilities listed in Table 9.4. Most of these deal with scope changes, which are a result of exogenous developments. The design phase, when the contract is formulated, is of utmost importance to be able to respond to these threats. The experience is, that adaptations at a later stage, in the form of corrective or defensive actions have enormous implications for the budget and schedule. These are not considered further.

Table 9.5 shows the general practice of monitoring for such a project. It includes inspection of visible damage, measurements of key parameters such as water levels, deformation of quay wall, settlement of soil, cracking of concrete, and corrosion of steel elements. In case these exceed acceptable limits, defensive actions can be taken to protect the design from adverse impacts of the developments, or corrective actions to adapt the design. As can be seen, only the physical state of the quay is monitored, and the exogenous developments do not form a part of the standard monitoring process. Even in larger organizations, market developments and other strategic risks are monitored at the corporate level (and not at the project level).

Table 9.5: Contingency Planning

Vulnerabilities and opportunities	Monitoring and trigger system	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP)) to be taken in implementation phase
Corrosion of combi-wall	Monitor wall thickness and evaluate structural safety	If safety factor decreases by 5% take DA-action If safety factor decreases by 10%, take CP-actions If safety factor decreases by 30%, take RE-action DA: Provide cathodic protection, induced current CP: Strengthen through steel plates at critical location RE: Reassess quay wall design concept for this location RE: Change functional use of quay wall
Settlement of crane beam	Monitor relative settlement	If less than 10% take DA-action If larger than 10%, take CP-actions If larger than 20%, take RE-action DA: Investigate cause and take action (inadequate soil compaction take CP-action, too large crane loads: spread crane loads over a larger area, inadequate design take RE action) CP: Stabilize soil under crane beam RE:Extensive repair and more thorough soil investigation and load assessment in next phase
Displacement of quay wall	Monitor terrain loads	If loads exceed design loads take CP action CP: Reduce terrain loads
	Monitor water levels	If ground water is higher than normal CP action CP: Repair drainage
	Check design assumptions	If assumptions are violated, re-evaluate safety factors If factor is less than 10%, take CP-actions If factor is less than 20%, take RE-action CP: Monitor displacement

continued on next page

Table 9.5: *continued*

Vulnerabilities and opportunities	Monitoring and trigger system	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP)) to be taken in implementation phase
		RE: Re-evaluate function of quay wall
Leaking of soil behind quay wall	Inspect quay wall for openings	Local problem due to poor construction take CP action, Overall degradation due the age of the wall take RE action CP: Repair openings RE: Replace quay wall
Long waiting times at quay	Berth occupancy or waiting times	If berth occupancy is greater than 50% take DA action If greater than 60%, take CP-actions If greater than 80%, take RE-action DA:Make plans for capacity expansion CP: Divert Cargo and make expansion plans RE: Implement capacity expansion plans

Though monitoring the berth utilization during the exploitation phase does not fall in the realm of project, it is of significance for both the port authority and the terminal operator. Low or high berth utilization can be indicative of abnormal demand levels or logistic problems, and is reflected in the waiting time and service levels for the ships. A trade-off between the desired service level and the investments required for capacity expansion determines the acceptable levels.

9.3.8 Discussion

A civil engineering project and its environment are subject to changes, not only during the design and construction phase, but also in the exploitation phase. The common practice of carrying out risk analysis, is limited to the planning and realization phase, and to dealing with the top 10 risks identified in a risk analysis (other drawbacks have been discussed in Chapter 3). In the exploitation phase, many of the vulnerabilities identified during Step II can appear. In the general practice of monitoring for such a project, only the physical state of the quay is monitored, and the exogenous developments do not form a part of the standard monitoring process. In larger organizations, market developments and other strategic risks are monitored at the corporate and strategic level (and not at the project level).

APP combines risk analysis and strategic planning into a single activity carried out in the same time frame over the entire planning horizon. Further, it includes and deals with the scope changes in a project (generally driven by exogenous changes, and not included in risk management as common practice). This means that the management is not taken by surprise: it has a contingency plan and reserves. A clear and complete picture of the status and the viability of the project at any given time is available. It advocates the strategy of flexibility and robustness to deal with uncertainties. It brings about a flexible mind set on the part of strategists and managers, who by the very nature of the exercise learn to think through contingency plans to every response to the strategy.

9.4 Case 3: Spatial planning for a strategic port area

9.4.1 Introduction

This case involves the long-term spatial planning for a port area that is valuable due to its strategic location, its nautical infrastructure and related services, as well as the synergistic opportunities with the established companies established (Taneja et al., 2012d). The planning requires the development and evaluation of alternatives dealing with profitable future uses of the area. We handle this case in the framework of APP.

9.4.2 Step Ia: Project description and objective

The Maasvlakte area is one of the most promising locations in the Port of Rotterdam, which gives it a significant place in the worldwide logistic chain. It is easily accessible nautically, has short sailing times to open sea, can accommodate the largest sea going vessels, and is well connected to the hinterland with respect to all modalities, i.e., inland vessels, feeders, rail transport, and pipelines. This is one of the few locations in PoR where LNG can be handled despite the strict regulations concerning this cargo. A state-of-the art container terminal currently used by an alliance, an LNG terminal, and one of the largest (mineral) oil storage complexes are located here (Figure 9.9). Thus in addition to excellent nautical infrastructure and related services, it offers great synergistic opportunities with the existing companies.

About 45 hectares is still available for future development (designated as Plots 1 to 5 in Figure 9.9). According to Dagnet (2010), the real core competency of a port authority is the land it owns – this resource is valuable, scarce, costly to imitate and non-substitutable. While choosing a location for (new) businesses in the port, efficient land-use is the key. 'The right company in the right place' is the motto of PoR. The factors that are taken into account when allocating businesses (PoRA, 2004) are the strategic value for the total port complex, accessibility, available environmental space and the employment potential.

The alternatives as to the clients and the market sectors that can be placed at this (or for that matter, at any other) location in the port are numerous and complex. Any port requires a balanced portfolio of segments in order to protect its incoming cash flows. Therefore, PoRA aims at limited dependency on a single segment, but creates and stimulates internal competition within sectors by contracting many, preferably worldwide players. Strategic decisionmaking, based on market considerations and regulative knowledge, is required to select the market segments that should be located on this scarce and valuable land. However, it is difficult to select between segments such as oil storage that are currently profitable, but possibly scarce in the future, and sectors such as LNG, which may have long term potential. The objective during planning is to make a robust choice based on the available information. If this choice can influence the future competitive position of the port positively, we can say that the planning exercise has been successful.

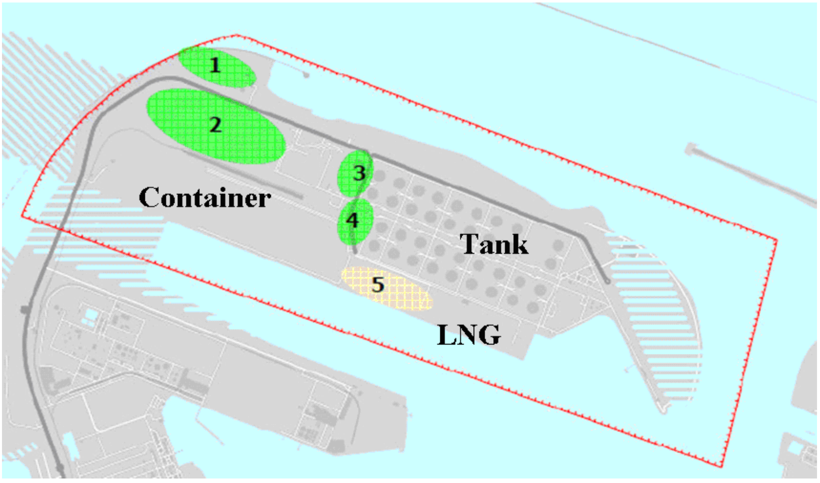


Figure 9.9: Available port area divided into 5 plots (source: PoR)

9.4.3 Step Ib: Define strategy and formulate alternatives

This is treated as a low to medium uncertainty planning problem, where the management objective is clear, but numerous alternatives may need to be examined to choose the best solution (Table 5.1). Of course, while defining the alternatives, long-term considerations have been duly incorporated.

As stated earlier, the Business Plan (PoRA, 2010a) for the period 2011-2015 focuses on three themes. In keeping with these themes, the following alternative uses are plausible for the area presently under consideration:

- expansion of the existing container terminals
- expansions of the existing LNG terminal
- expansion of the existing (mineral) oil and tank storage terminals
- empty depot terrain or
- other related services (including leisure)
  Carbon capture and storage is also an option.

The existing container, tank storage, and LNG terminals are also shown. The container terminal operator (CTO) has an option on the adjoining plot 5 as a reserve for future expansion, which will expire in 2016. Factors such as the plot location and layout, the length of the quay, available draught, connectivity, and the facilities required for a particular cargo sector, all play a role while allocating a market segment to a plot.

The future utilization of Plots 1, 3 and 4 has been determined (PoRA, 2011b) based on the criteria stated above. Plot 1 will be used for supporting services and facilities. Two areas are already leased out to a packaging firm and the fire department respectively. Plot 3 is designated for a liquid bulk storage tank. Plot 4 may be used for empty containers or liquid bulk. After numerous workshops and brainstorm sessions with experts, and based on commercial and strategic considerations, three alternatives have been selected for plots 2 and 5 (Table 9.6).

Table 9.6: Description of alternatives for Plot 2 and Plot 5

Alternative	Industry Plot 2 (plot size in ha)	Start contract (year)	Industry Plot 5 (plot size in ha)	Start contract (year)
1	LNG (10.5)	2020-2030	Containers (full plot)	2020
	Empty depot (10.5)	2020		
	Liquid bulk (10.5)	2015-2030		
2	Empty depot (10.5)	2020	LNG (full plot)	2015-2030
	Liquid bulk (10.5)	2015-2030		
	n/a (10.5)	2020		
3	LNG (10.5)	2015-2030	Containers + 1 LNG tank	2015-2020
	Empty depot (10.5)	2020-2030		
	Liquid bulk (10.5)	2020		

9.4.4 Step II: Identify uncertainties

A spatial planning and infrastructure development project faces many uncertainties over its lifetime Generally, the time between decisionmaking, and start of construction and operations, can vary from several months to years. In the meantime, the cost of investment can rise or fall in response to changes in material costs or to a policy change, such as granting or taking away of an investment or subsidy. Or new technology can appear requiring design changes. Also, scope changes in a project can be driven by factors such as introduction of new techniques or methods, regulatory changes, requirement changes, poor understanding of requirements, heuristic discoveries, financial circumstances, changes in leadership and more. Many of these uncertain developments can also crop up after construction, during the exploitation phase, requiring extra investments in adaptations, or leading to lowered revenues. Future demand or exchange rates too can fluctuate. The consequence is that the actual costs and revenues deviate from expected values in the business case set up at the beginning of the project. The major uncertainties in our case study are:

- Which market sectors show growth trends?
- Are there enough market sectors and suitable clients available for the 10 ha plot?
- Which market sector combinations create the most synergy?
- Will actual cargo flows follow forecasts?
- Will oil (or other) prices rise significantly during the realization period?
- Will the tariff structure of the port change significantly over the long term planning horizon?
- Is it possible to allocate a terrain for handling of LNG without direct access to the water front?
- Will the CTO use his option on the adjoining Plot 5? Does the CTO prefer to expand westwards on MV2 or will he insist on realization of a barge feeder terminal (BFT) at this location?
- To what extent will the absence of a BFT be a constraint for his operations?

9.4.5 Step III: Make the plan flexible and robust

Many of the uncertainties will clear up as more information is made available through research and investigation. Of the remaining uncertainties, some are acceptable (denoting that reserves will be built in the schedule and budget), yet others can be reduced, passed on (transferred), or eliminated through shaping, mitigating and hedging actions. The treatment of uncertainties as per the standard practices at PoR has been dealt with in Section 3.6.

The present and future cash flows of a project are considered a good measure for determining the financial feasibility of a project, thus a business case (essentially a spreadsheet model) which includes all three alternatives shown in Table 9.6. We choose to treat factors such as inflation, port tariffs, and discount rate as value parameters (mostly based on past projects), while future costs, future demand, and the timing of investment are treated as variables, indicating that a formulation of the uncertainty can be incorporated while quantifying them. The outcomes, for comparison between alternatives will include the uncertainty margins, which are likely to differ in each case, thus giving valuable insights for decisionmaking.

Keeping in mind the long lifetime of the civil infrastructure, PoR has chosen to built in flexibility through accommodating extra capacity, i.e. handle cargo and bring in extra revenues without the need of significant adaptations in the future. This represents flexibility (robustness) for the future. Flexibility can also be seen as the ability to attract additional or new cargo flows, and generate synergy with the existing clients; this can vary among alternatives, but is difficult to quantify).

We define three scenarios, whereby Scenario 0 represents the most likely scenario. In Scenario 1 we assume that flexibility is built in through investing in quay walls for handling deep sea ships at Plot 5 instead of a barge quay. This case assumes that the quay is used for handling deep sea ships in all three alternatives with the maximum capacity utilization (and CTO uses a common barge terminal, for instance, at MV2). The resulting quay productivity will be much higher (approx. 1750 TEU/m' as compared to 800 TEU/m'). In Scenario 2 we assume that the LNG tank utilization capacity has increased from 50% (in Scenario 0) to 75% in all three alternatives due to Rotterdam having established itself as a LNG hub.

A discussion of the input and results of the business case follows in Step IV where a selection among alternatives is made.

9.4.6 Step IV: Evaluate and select alternatives

Tables 1 and 2 in Appendix E list the variables included in the business case. For confidentiality reasons, the input figures have not been given. The business case is generally set up for a period of 25 years, but in the present case dealing with spatial planning, a longer period of 35 years has been considered. The input for the business case is derived from many sources. The engineering department estimates the investment costs, mostly using thumb-rules derived from historical data from similar projects. The commercial department carries out traffic forecasting, and the forecasts are used to determine the future revenues. The timing of an investment is estimated by the business manager. The formulation of the uncertainty margins is based on expert opinion.

Costs: In a deterministic business case set up at the feasibility stage of the project, investment costs include a margin of approx. 30% of the basic estimates for unforeseen costs. In the specifications phase, this is reduced to 10%. The uncertainty in such estimates is generally 20%. This is modelled as a uniform distribution in the business case. The ground price per square meter is modelled through defining a minimum, maximum, and most likely value in a Pert distribution, which is exclusively used for modelling expert estimates.

Future demand: The future demand will determine the revenues over the entire period of 35 years, can be seen to be a sum of the guaranteed and uncertain (variable) demand. The former is a fixed parameter while the latter is modelled as a discrete distribution in the model. The quantification of uncertainties is generally carried out through use of historical data, modelling exercises and expert opinion. Here, the distributions are based on the cargo estimates and the associated probability as given by experts (for an example, see Table 9.7 which applies to the demand at the planned barge feeder terminal).

Table 9.7: Expert opinion over extra cargo at BFT (tons)

Probability	10%	25%	30%	25%	10%
Extra cargo	400,000	500,000	600,000	700,000	800,000

Timing of investment: The timing of investment is dependent on external developments and the decision of the CTO to exercise his option on Plot 5. It is modelled as a discrete distributions, based on the expert opinion (for an example, see Table 9.8). This approach attempts to capture the available expertise while keeping in mind that the opinions are subjective and the sample size small.

Table 9.8: Expert opinion over timing of investment in BFT

Probability	30%	50%	10%	5%	3%	2%
Year of investment	2015	2016	2017	2018	2019	2020

Functional relationships between variables are incorporated in the business case. For instance, cost is a function of the created capacity (or infrastructure), the revenue is a function of the cargo handled (which in turn is a function of the capacity, productivity, and degree of utilization. Productivity itself is determined by the quay or terminal logistic concept, and often established during design through complex simulation studies involving numerous variables). Once the stochastic business case is set up in a spreadsheet, Monte Carlo simulations are applied to generate a large number of scenarios (10,000). All uncertainties can be taken into account simultaneously, and the result is a distribution of outcome of interest, which, in our case is the Net Present Value.

Table 9.9: Net Present Value (NPV) for various alternatives in million euros (M€)

Alternative	Scenario 0		Scenario 1		Scenario 2	
	Mean	Range	Mean	Range	Mean	Range
1	66.2	60.2-72.4	91.2	82.8-98.4	75.5	68.0-82.2
2	32.9	27.7-37.8	32.9	28.2-37.2	41.5	36.2-46.8
3	66.0	59.6-72.4	82.8	75.4-89.5	81.1	73.8-88.0

The results are presented in Table 9.9, where the mean as well as the 5% and 95% percentile values are given (together, these define the range within which 90% of the values lie). The difference between the maximum and minimum NPV is indicative of the spread or the risk – these values have been included in the analysis but have not been tabulated. A discussion of the results follows:

Scenario 0: In Alt. 1, where location 2 is fully utilised for container handling, the average NPV amounts to 66.2 M€. In Alt. 2 a single LNG tank is situated on location 2. The NPV is relatively low at 32.9 M€, since revenues from handling and storage of LNG tank are lower than from container handling on an equivalent plot. The NPV for Alt. 3 is comparable to Alt. 1 but it has a smaller spread between the minimum and maximum NPV (21.1 as compared to 23.9 M€). It appears to be less risky due to the diversification of the terrains (empty depots, liquid bulk, LNG and containers) and the associated cargo flows. In this scenario, Alt. 3 seems to be the best choice. Through use of a probabilistic business case we can compare the robustness of the alternatives under various scenarios, with very little extra computation effort:
In case of no growth, i.e. only fixed (or guarantee) cargo is included in the business case, a comparison of NPV for the three alternatives (61.5, 32.9, 62.8 M € respectively) shows that Alt. 3 still fares the best.

Scenario 1 represents a high container growth scenarios where the maximum quay capacity is utilized by sea going vessels. The business case results in a NPV of 91.2 M€ for Alt. 1 and 82.8 M€ for Alt. 3. The increase in NPV with respect to Scenario 0 represents the available flexibility of 25 M€ for Alt. 1 and 16.8 M€ for Alt. 3 (maximum values).

Scenario 2 represents a high LNG growth scenario where 75% capacity of the LNG tank can be utilized. The business case results in a NPV of 75.5 M€ for Alt. 1 and 81.1 M€ for Alt. 3. The difference represents the available flexibility 9.2 M€ for Alt. 1 and 15.1 M€ for Alt. 3. As expected, Alt. 3 fares the best in this scenario.

Scenario 2 and 3 represent extreme scenarios (and NPV's). But if nothing else, the process of thinking through scenarios is a useful exercise in thinking about the possible effect of extreme situations on the value of a risky asset. Natural calamities, bankruptcy of a client, radical regulatory changes concerning LNG handling, or a slump in container trade etc. can of course occur. We can also attempt to model such events in an excel spread sheet, but it will not give more information than a qualitative assessment. Some of the events have been a part of the overall strategic planning of PoR, and reasonable reserves have been allotted in the budget. The rest is not considered further. The indirect effects of various alternatives have not been quantified. However, when the alternatives are comparable (as in the present case), a qualitative estimate of the indirect effects can provide valuable input to support decisionmaking. The following indirect effects of different alternatives are of significance:

- The absence of a barge feeder terminal in Alt. 2 is likely to be a constraint for container terminal operator. Not only will this result in a less than optimum layout, but will also be a barrier to achieving the desired modal shift towards inland shipping. The negative impact is difficult to quantify.
- In Alt. 3, the creation of facilities for feeders and inland ships for LNG is feasible, which represents a growth option.
- In Alt. 1, the additional costs of setting up a cryogenic pipeline network for LNG are a big disadvantage for the client if only a single tank is constructed. Moreover, the space requirement for such a network is significant and the distance to the existing LNG facilities large.

Based on the NPV value and its distribution, as well as the indirect effects, Alternative 3 (a combination of LNG, liquid bulk, empty depots), seems to be the most suitable choice. Unexpected developments between now and the time of investment could easily change the picture.

9.4.7 Step V: Set up a monitoring system

Our objective as stated in Step Ia is to make a robust choice of the cargo sector for the given area, based on the available information. Thereafter, we need to periodically check if some of the assumptions, based on which we have made a selection, are failing. In that event, we may need to rethink our forecasts and defined alternatives and go and over to a reassessment of our plan. Monitoring will require tracking the driving forces or precursor developments which will have an impact on the investment costs and tariffs, or influence the desirability of chosen cargo sectors (e.g., new technology may lead to diminished demand for a cargo, or stricter policies may form a bottleneck for implementation).

9.4.8 Step VI: Contingency planning for the selected alternative

Step VI which involves contingency planning for the selected alternative is not discussed here. It is suggested that just before going over to implementation of the plan, an assessment of the existing uncertainties (which have not cleared up, but could be critical) is carried out, and suitable actions devised to protect the plan.

9.4.9 Discussion

The investments of PoR in infrastructure amount to about 175 million annually. In most ports, space is scarce and valuable, which means that the available land must be used strategically. The decisionmaking is generally based on a financial criteria, i.e., maximum return for the port authority that owns the land and invests in the infrastructure. This requires that an estimation of revenues over a long time horizon be taken into account.

The methodology for setting up a stochastic business case has been illustrated through a real life case study involving spatial planning of a valuable port area. A stochastic business case provides the possibility of including available flexible options in a project in the financial evaluation. Thus it is a more effective decision support tool for a complex investment project with many alternatives, uncertainties, and flexibilities. For the presented case study, this method provides added information that not only contributes towards responsible decisionmaking as to future use of the area, but also results in more accurate estimates for overall investment plans of PoRA. A probabilistic estimation of risks for all the projects in the portfolio, can provides an organization with a realistic risk map, that can influence their risk attitude, and allow them to timely steer their policies. The input for such a business case is provided by the business intelligence analysts, area managers, developers (project timing), business managers (commercial) and engineers (costs) during expert sessions and workshops.

In order to deal with uncertainty, PoR has chosen to built in flexibility through investing in quay walls that can handle deep sea ships at this location instead of barges. This represents a valuable flexible option that can be exercised if a high container growth scenario materializes, and the port reaches its capacity. This flexibility could be evaluated in the business case, and even a simplistic approach results in valuable extra information for selecting among alternatives. It was also possible to carry out a scenario analysis to test the robustness of various alternatives under different scenarios with little extra computational effort. When two alternatives were comparable, a qualitative comparison of the indirect effects (such as overall efficiency of the terminal or existing growth options) proved to be the determining factor.

9.5 Case 4: Flexible infrastructure for the temporary Inner Lake at MV2

9.5.1 Introduction

The Maasvlakte 2 (MV2) project, introduced in Chapter 5, is carried out in phases which means that in between phases, a large area of water, protected by an expensive sea-defence is not in use (Figure 9.10). This offers a unique opportunity for PoRA to generate extra revenues by carrying out commercial activities (of a temporary nature) in this area. This possibility was explored in a study, the details of which can be found in Ros (2011); Taneja et al. (2012b). The framework of Adaptive Port Planning, is used for this study which illustrates the incorporation of a flexible logistic concept as well as use of flexible infrastructure in the Master Plan.

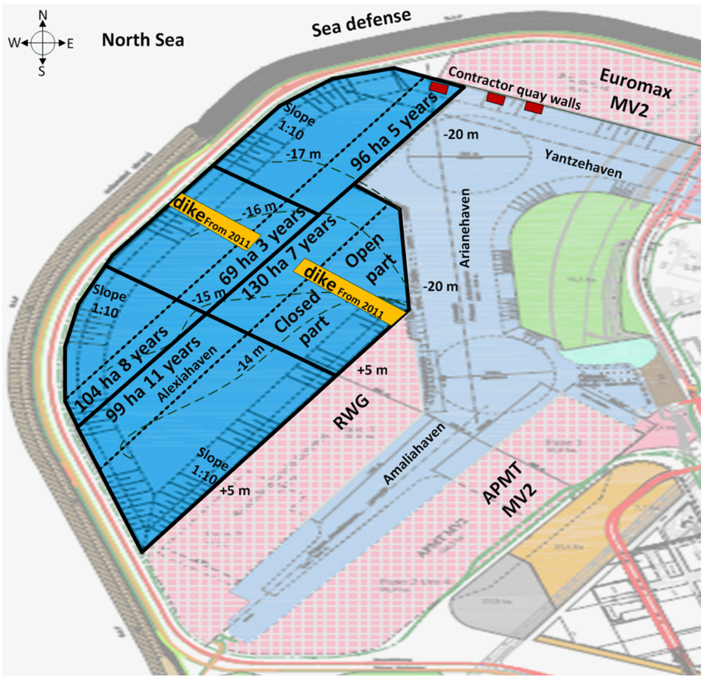


Figure 9.10: Inner Lake at Maasvlakte 2 (source: PoR)

9.5.2 Step Ia: Project description and objectives

Figure 9.10 shows the 500 hectare Inner Lake divided into parcels- the size, water depths and the approximate time that the parcel is expected to become available, are also indicated. The container terminals of RWG, APMT, and Euromax, presently under construction in phase 1 of the MV2 project, are also indicated. A temporary dike divides the area into an open and closed lake. Based on the Master Plan (PMR, 2010), which guides the development of MV2, the availability of Inner Lake is determined as being about 7 years. The water depth varies from 14 m in the south-east to 17 m in the north-west.

The planning objective is to select among various (commercially viable) temporary activities in this area. It is essential that the selected functions should fit within the policy of site allotment of the PoRA, and do not hinder other building or operational activities at MV2. Regulations related to safety and the environment, such as the European Bird and Habitat Directive, the Dutch spatial planning law, and the Dutch water law, limit the activities possible at the Inner Lake. The requirements set out in the zoning plan (IGWR, 2008) and the Environmental Impact Assessment reports (PMR, 2007) are also applicable.

9.5.3 Step Ib: Define strategy and formulate alternatives

The strategy is to approach it as a short term planning problem in the following sequence of steps: First, carry out an inventory of suitable activities and propose infrastructure design concepts for each of the activities. A cost analysis can be applied to select among the design concepts for each activity. The activities can then be examined for their financial viability in different scenarios. The activities selected on basis of the chosen criteria are examined in detail.

In order to formulate alternatives, a brainstorm-session was organized with participants from PoRA, Delft University of Technology, and Municipality of Rotterdam. The objective was to carry out an inventory of potential activities in the Inner Lake. Innovative ideas and out-of-the-box thinking were encouraged. The activities were not limited to cargo handling even though these generate the largest revenues in the form of port dues and contract income for PoR). The Inner Lake offers a unique location for carrying out pilot projects of innovative character e.g., realization of flexible infrastructures or new activities. Some activities could be beneficial for the existing or future clients of PoR, others could benefit the image of the port, yet others could represent future opportunities for the port.

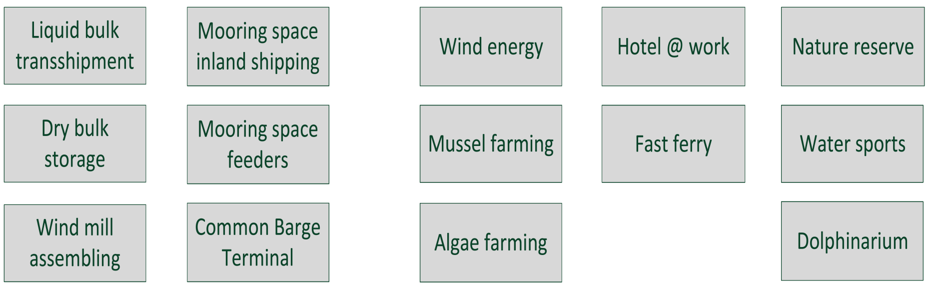


Figure 9.11: Potential activities in the Inner Lake: port related (left), others (right)

Figure 9.11 displays the seemingly most promising activities in the Inner Lake, which is a safer alternative than the North sea and also offers good hinterland connections):

- Ship to ship transshipment of liquid bulk using buoys or dolphins saves intermediate storage and requires cheaper facilities than ship-to-shore transfer, safer due to its mild wave conditions and patrol vessels nearby;
- Storage of construction materials e.g. granite blocks transported from Norway to the Benelux;

- Mooring facilities for inland vessels and feeders that have to wait since sea going vessels have priority generate more revenues and have service time agreements;
- A common terminal as a central (un)loading hub for inland vessels (barges), which obviates the need for hopping of inland vessels through the port;
- Assembly of structures such as caissons or offshore platforms;
- Assembly of offshore wind turbines which are transported in components to ports, assembled in ports and transported by sea, big market to meet European Union's renewable energy targets.

The Inner Lake could also be used for generation of wind energy, mussel farms, a pilot project for algae farming (algae can be used as biofuel in the future, high quality supplement in food and cosmetics), installing a hotel for the workers at MV2 (as many as 2500 workers are expected between 2010 and 2035), fast ferry for 10,000 commuters to MV2, a temporary nature reserve that can help the acclimatisation of flora and fauna, facilitate various kinds of water sports, and accommodate a dolphinarium.

9.5.4 Step II: Identify uncertainties

The major uncertainty facing the planners is the duration of availability of the Inner Lake, which will be for a limited time. Most traditional fixed infrastructure is capital intensive, and due to the long payback period on investment, financially non-viable for this situation. In addition, there are the usual uncertainties related to port projects such as future policies, growth markets, costs and revenues. In case of flexible infrastructures, the probability of reuse of a structure is the second major uncertainty.

9.5.5 Step III: Make the plan flexible and robust

Infrastructure facilities are required to carry out various activities. Some activities require nautical and land-side access and multi-modal connections. Others may require extensive berthing, mooring, (un)loading, or storage facilities, and yet others require no facility. The selected hedging action, to deal with the uncertain useful lifetime of infrastructure is to either select constructions that can be relocated and reused easily, or construct a relatively inexpensive structure that can be demolished without appreciable losses.

A traditional fixed design will result in the choice of a sheet pile wall, buoys or dolphins, which are relatively inexpensive, and can be reused. A jetty is also relatively inexpensive. Two alternative approaches to traditional design, which will result in a robust plan, are possible.

- Design for a shorter technical lifetime (in order to match the short economic lifetime): Containerland with a lifetime of 8-10 years is a possibility;
- Flexible designs that can be adapted for reuse: an L wall, Maxisteck, a barge, or a caisson can be employed.

Figure 9.12: Containerland (left)and Maxisteck (right)

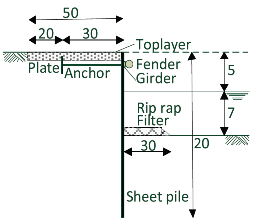
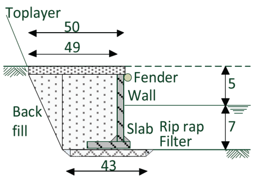
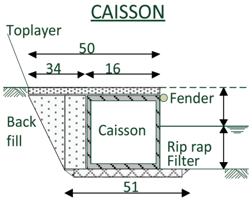
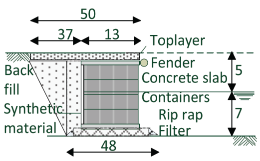
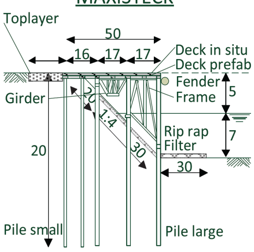
Structure	Port infrastructure	Other
SHEET PILE WALL 	- Quay wall	- Construction pit
L WALL 	- Quay wall - Crane foundation - Superstructure quay wall	- Abutment - Dry bulk storage - Landmark
CAISSON 	- Quay wall - Liquid bulk storage	- In a closure dam - Breakwater - Foundation wind mill
CONTAINERLAND 	- Slabs in crane track - Slabs terminal road	- Slabs in buildings
MAXISTECK 	- Jetty for liquid bulk transshipment - Piles as dolphin - Pile foundation	- Piles as props in a building pit

Figure 9.13: Reuse possibilities of selected infrastructure

The selection of a structure is based not only on the immediate functional requirements of an activity, but on long term considerations that include reuse. These structures can be seen in the first column of Figure 9.13, which also shows their reuse possibilities (in the port or otherwise). Most quay wall types, except for Containerland (Exalto, 2002; PoRA, 2002) and Maxisteck (IGWR, 2000) shown in Figure 9.12, are known (CUR, 2005a). These two innovative concepts were a result of an initiative of PoRA, whereby the market was encouraged to come up with flexible concepts for infrastructures (see Chapter 6). As mentioned earlier, these concepts have not been implemented.

Since the period of use is short, and revenues are not likely to depend on the type of structure, and lifecycle cost is used as a criterion for selecting the type of structure for each activity. This results in the following choices.

- Jetties are suitable for hotel at work and the fast ferry. A short jetty over a protected slope is cheaper than a longer jetty on a natural slope.
- Mooring structures are required for liquid bulk transshipment, as well as for mooring inland shipping and feeders. Piles are slightly more costly than buoys, but to be preferred.
- Common Barge terminal (CBT) requires a quay. Containerland is most cost-effective due to the short availability of the Inner Lake (at most 20 years). The containers, with a lifetime of about 10 years can be replaced, or alternatively they can be protected from corrosion.
- Wind mill assembling and dry bulk storage require a quay. The existing quay wall of the contractor, located next to the Euromax terminal (Figure 9.11) can be used instead of creating costly dedicated facilities.
- The technical lifetime of Containerland is assumed to be 10 years, a sheet pile 25 years, and for the remaining structures 50 years.
- Investment costs are based on reference projects. Rough assumptions are made over the demobilization, transport, demolition, storage and assembly costs.

Figures 1 and 2 in Appendix F show the alternative activities with required facilities and the proposed location based its logistic requirements. The preliminary designs i.e, dimensioning of the structures is carried out based on reference projects. The technical lifetime of the structures differs as do the investment, operational, demobilization, replacement and demolition costs. Reuse at another location is possible in all cases (in case of Containerland uncoated containers need to be replaced after 10 years).

9.5.6 Step IV: Evaluate and select alternatives

The financial viability of the activities needs to be examined in a business case. This requires an estimation of all relevant costs and revenues over the anticipated lifecycle, the rest value and the possibility of reuse. This is also given the name Life Cycle Analysis. The alternative with the highest net present value is commercially most attractive.

Not only the costs and revenues, but the useful lifetime of an alternative is uncertain. Various scenarios are developed by varying the number and duration of useful service

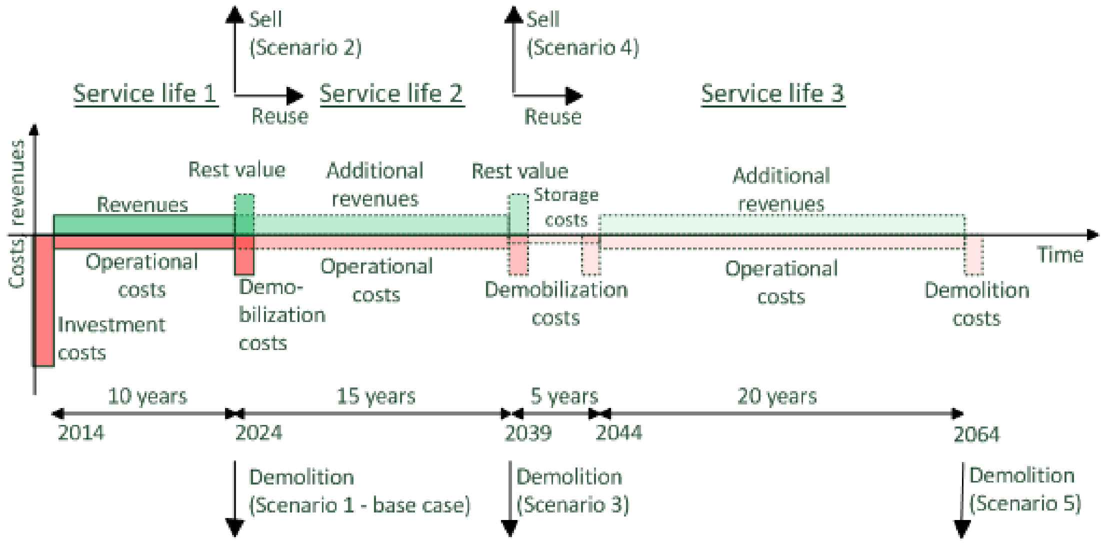


Figure 9.14: Scenarios for lifecycle analysis

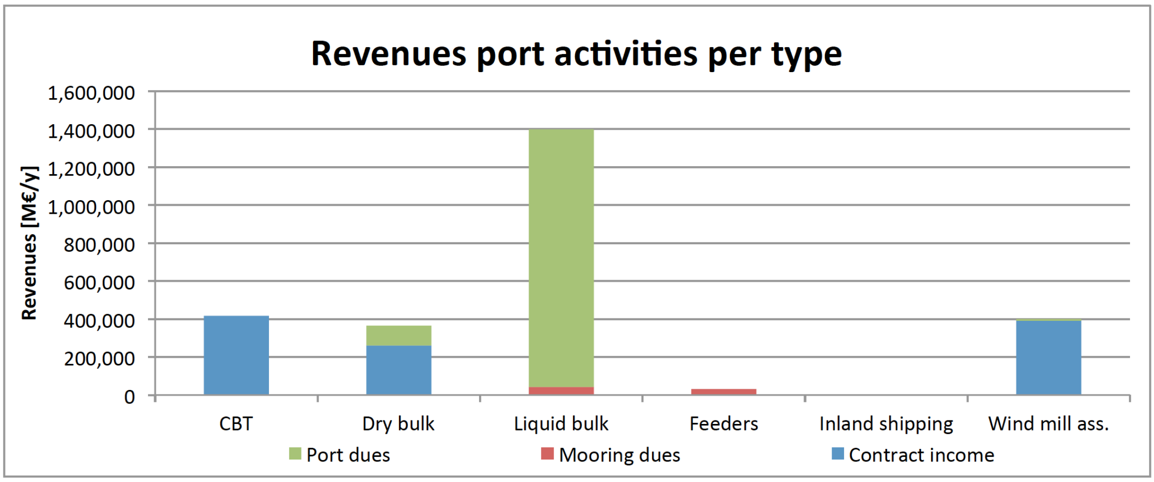


Figure 9.15: Revenues from port activities

life(s) of the infrastructure (Figure 9.14). It is assumed that the first service lifetime on the Inner Lake is 10 years. Structures can be demolished (Scenario 1), sold to another port (Scenario 2), or reused in PoR after 10 years. It is assumed that the second service life in PoR or another port lasts 15 years. Thereafter, the structures can be demolished (scenario 3), sold (Scenario 4) or reused once more (Scenario 5). Before the third service life of 20 years, the structure is stored for 5 years. The service life of the infrastructure, which will depend on development of MV2, is assumed to be 10 years, and activities with cancellation periods of 1-2 years are favoured.

We distinguish between two sets of alternatives: a) those employing structures with 50 year technical lifetime (revenues in Scenarios 2-5), and b) those employing no structures (no revenues in all scenarios).

In order to determine the revenues generated from each of the activities, consisting of port dues, contract income and quay dues, the average figures from the past year are

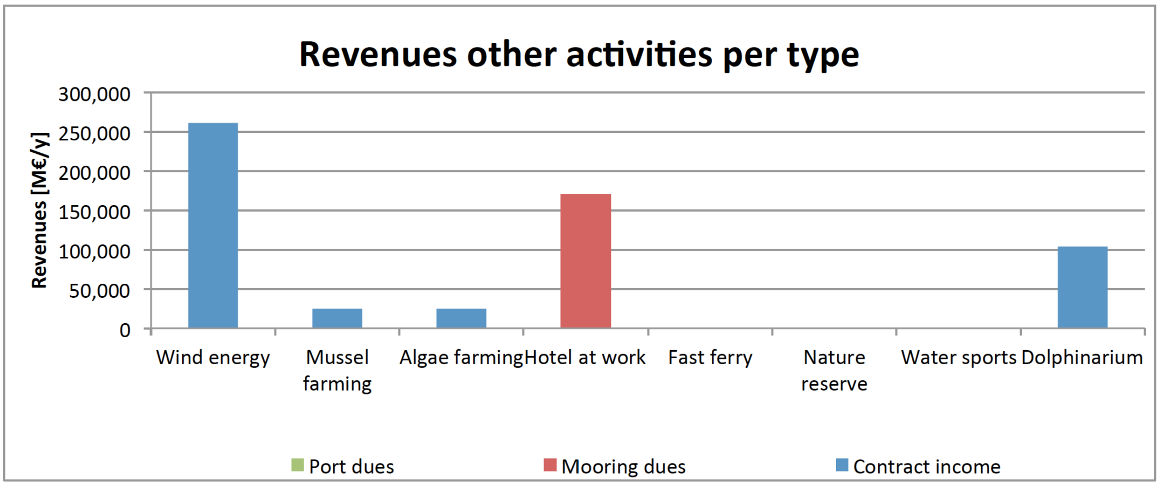


Figure 9.16: Revenue from non-core port activities

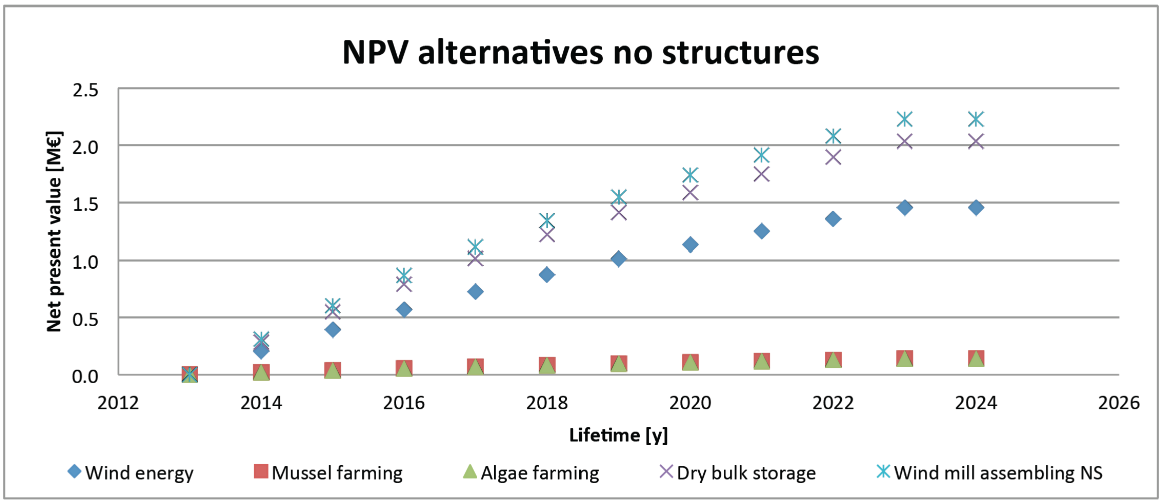


Figure 9.17: Net present value for activities requiring no structures

estimated. Figures 9.15 and 9.16 show the revenues generated through each activity based on these key-figures. The contribution of the port and mooring dues as well as the contract income can be distinguished for each activity in the figures.

Results from the business case

Figures 9.17, 9.18, and 9.19 show the net present value of the activities (using a specific structure) on the Y axis plotted against the life time of the activity. The figures show when the break even point is reached for each activity. For the activities requiring no structure, cash flow is positive in the first year itself. The activity with the largest NPV is Liquid bulk transshipment followed by dry bulk storage and wind energy generation. Wind mill assembling is also financially viable if the existing quay wall can be used. The CBT, evaluated on the same basis, was non-viable, but a more rational approach leads to a different result (discussed in the next section). A dolphinarium, fast ferry, mooring facilities for inland shipping and feeders are not financially viable.

Water sports do not generate revenues, but create a positive image for PoR. Hotel

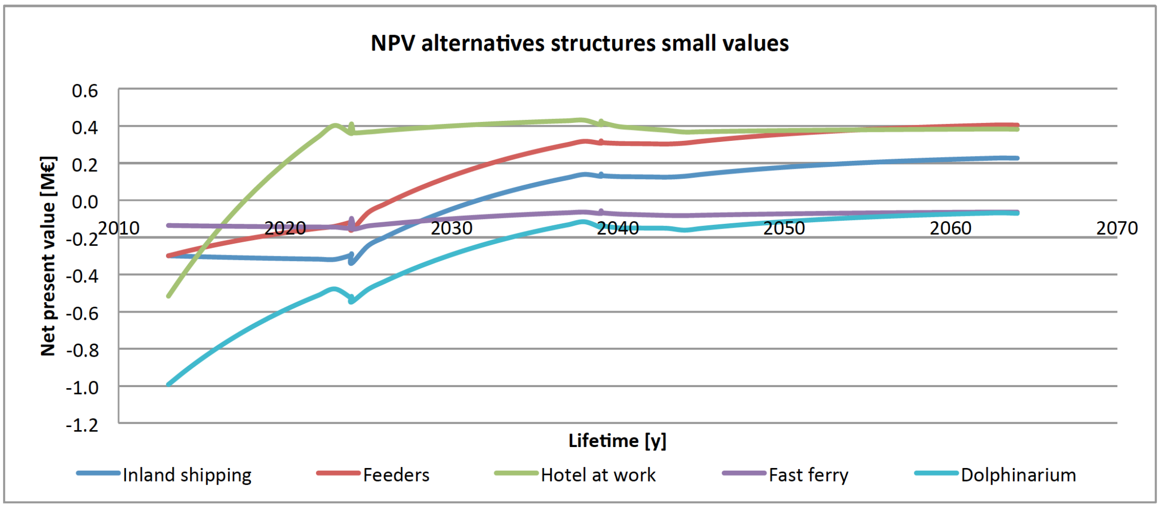


Figure 9.18: Net present value for activities requiring structures (1)

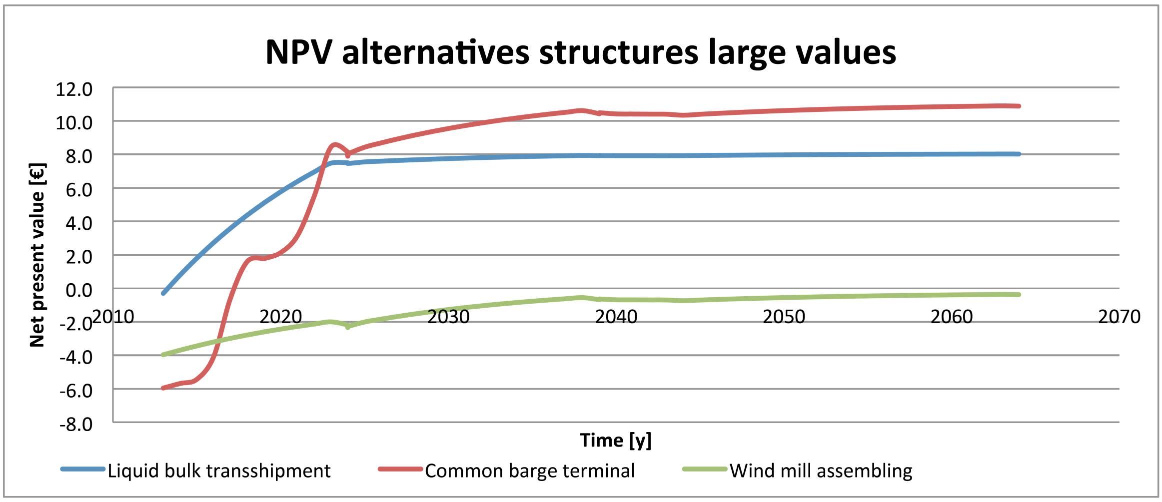


Figure 9.19: Net present value for activities requiring structures (2)

at work will generate small revenues, reduces commuter traffic, could and support other activities at MV2. A floating hotel requires seaside access as well as at a certain distance from port activities. The fast ferry generates small revenues, and is only useful with activities such as a dolphinarium, hotel at work or an amusement park. A nature reserve has a positive impact on the environment through an increase in biodiversity. Mussel and algae farming, both in the pilot project phase, require little investment and can generate small revenues. Hotel at work has a positive NPV.

Liquid bulk transshipment, with the largest NPV, and the Common Barge Terminal, a concept that provides flexibility for all the parties are discussed next.

9.5.7 Selected alternatives

Liquid bulk transshipment
In the North Sea about 264 liquid bulk transshipments took place in 2010. Most of them were carried out at Southwold (UK) and at Skagen (DK), areas that are free of port dues. Yearly about 20 transshipments take place at Skapa Flow (UK) at similar charges as the port tariffs of PoR (Port Authority of Orkney harbours, 2011). At MV2, the transshipment can take place with Suezmax vessels (150,000 DWT, 200 m LOA of about 200 m, a draft of 14.5 m). For larger vessels, the Inner Lake will need to be deepened locally, and Very Large Crude Carriers cannot be received in Yangtzehaven).

Most vessels that enter PoR are smaller than 60,000 DWT. For our estimate, we have assumed a 40,000 DWT vessel every week and that for 20% of the time the berth is occupied for transfer of liquid bulk for temporary storage. Under these assumptions, this activity has an NPV of 7.5 M€. Ship-to-ship transshipments are more costly at the Inner Lake, but safer than at the North Sea due to its mild wave conditions and the presence of patrol vessels. This activity requires a minimum safety distance from other activities. Also, it will create increased traffic on the Inner Lake resulting in a larger chance of encounters.

Ship to ship transshipment is a flexible solution, most suitable for unpredictable trading, and fast growing, but still uncertain markets. In general, this generate fewer revenues for the port authority than ship-to-shore transshipment. However, the occupancy rate of recently created facilities in the Calandkanaal (PoRA, 2006a) is high, even though other locations at the North Sea are free of port dues, which is favourable for this solution. The sheltered location at the inner lake and and presence of patrol vessel in the vicinity (in case of spillage) are additional advantages.

Common barge terminal
Figure 9.20 shows the Container Terminals (CT) at MV2 of RWG, APMT and Euromax run by three operators (CTO). The first phase of APMT and RWG are nearing completion, and the rest will be realized in phases as per market requirements. In the current plans, a barge feeder terminal is planned at MV2, still, a part of the deep sea quay will be used for handling inland ships. According to the current forecasts, even in the worst case economic scenario, an increase of 3.5% is expected, and on average 6% (PoRA, 2011c). When the sea terminals are nearing capacity, a Common Barge

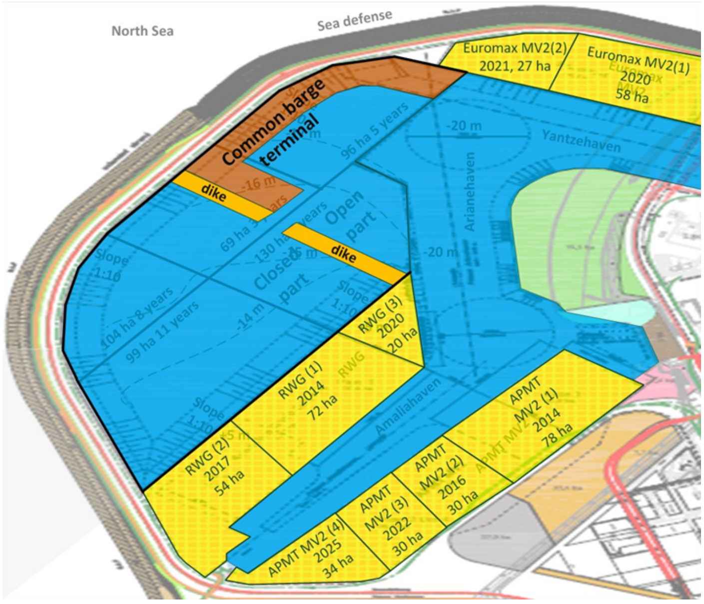


Figure 9.20: Planning of container terminals on Maasvlakte 2

Terminal (CBT) can be most efficient in reducing congestion, and taking the overflow of the terminals.

Moreover, the modal shift is expected to change in favor of inland shipping from 39% (2011) to 43% (2030.) From 2010 to 2035 inland shipping throughput is expected to increase by 5.6 MTEU (PoRA, 2011c). With a quay productivity of 800 TEU/m/year, about 280 m extra quay length will be required per year, necessitating capacity expansions.

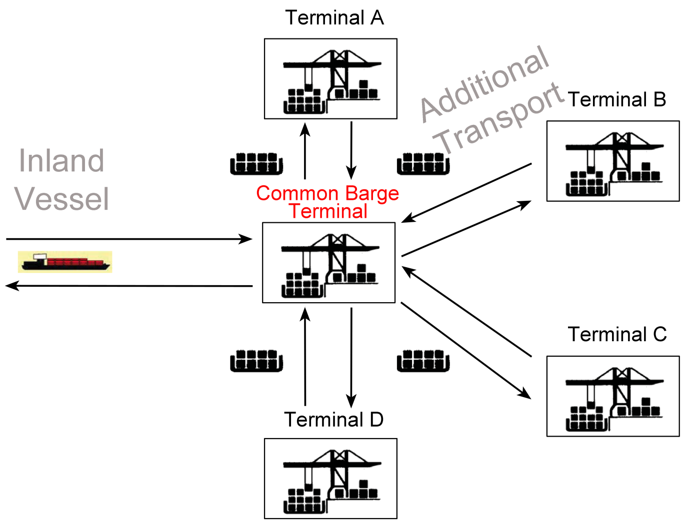


Figure 9.21: Logistics with CBT

A CBT is a central point for inland vessels to pick up and drop off cargo instead of at several terminals (Malchow, 2011). It has a quay to berth vessels and handle cargo and is required to be accessible via road for employees, suppliers, emergency services and internal transport of cargo to other terminals. The transport to and from the terminals is carried out by 25 TEU or 50 TEU vessels (shuttles). The concept is illustrated in Figure 9.21.

This logistic concept assumes that PoRA invests in the quay wall and infra plus at the CBT, his benefit is the postponement of investment in capacity expansion for the CTO (minus the loss of contract income from the new quay wall). CBTO invests in the equipment and additional transport. CTO incurs the cost for transport and handling of the barges at the CBT in order to relieve congestion at its terminals when they near capacity. Its benefit is postponement of investment in infrastructure expansions, without loss of cargo, and its competitive position. Another advantage is that a greater number of large call sizes and sea vessels can be handled at CT's by shifting small call sizes from the CT to the CBT. This results in increased productivity at the sea terminals (Zuidgeest, 2009), and is equivalent to creating extra capacity.

Table 9.10: SWOT analysis Common Barge Terminal concept

Strengths	**Weaknesses**
Increased efficiency and productivity at sea terminals (thus creating extra capacity in the terminal)	Initial capital investment by PoR and CBT operator (CBTO)
Faster loading/unloading of inland shipping by dedicated barge cranes	Requires co-operation among involved parties (CBTO, CTO, PoR)
Cost savings for PoR due to phased investment in civil infrastructure	New form of competitive transport (faster and environmentally friendly) appears
Cost savings for CTO due to phased investment in terminal equipment, no additional rent, personnel and operational costs	
Shorter sailing distances in the port	Logistics of barge transport need optimization
Opportunities	**Threats**
Delay investment in phase 2 MV2, use resources elsewhere	Conflicts between parties
Modal shift to inland transport due to available infra	Each party wants its own barge feeder terminal
Reduced congestion at terminals create better relations with CTO, better image for the port, attract more clients for phase 2 of MV2	Inland shipping rates rise making the concept non-viable (not enough transport via barges)
Pilot project for flexible structures	

A SWOT analysis of the CBT concept is carried out in Table 9.10 to evaluate the strengths, weakness, opportunities and threats of the concept. The market success of the CBT depends on the collaboration between the container terminal operators, the terminal operator of CBT (CBTO), and PoRA. The left column outweighs the right column, and is an evidence of the overall benefits of the concept. Such an analysis forms a part of Step II of APP, and is carried out for all the alternatives under consideration. These have not been included here.

The costs and benefits of this concept need to be monetized in a business case for all individual parties – the container terminal operators RWG, APMT and Euromax (CTO), the operator of CBT (CBTO), and PoRA. This financial analysis is based on many uncertain factors, e.g., container throughput and terminal productivity that together determine the capacity of the container terminals and when it is exceeded; call sizes of barges at the container terminals and the percentage of small call sizes; the logistic concept selected by the CBTO; the future port tariff structure; handling and internal transport costs etc. Assumptions were made in order to arrive at estimates of these variables in the business case, in consultation with experts.

The analysis concluded that the CBT was a viable option for PoR, if the business cases of CBT, the Container terminal operators, and PoRA are taken into account. Hereby, the eventual savings from postponed investment in container terminal expansions could be treated as income in the individual business cases of PoRA and CTO. The NPV is 8 M€ in Scenario where it is demolished after its service life and 11 M€ in case Containerland is reused (Scenario 5). The indirect benefits for PoRA in the form of greater efficiency at the sea terminals, were however not included. CTO benefits most from this concept, and a concrete business case helps in negotiations for mutual sharing of the benefits.

9.5.8 Step V: Set up a monitoring system & Step VI: Contingency planning

The future demand for transshipment facilities for various liquid bulk cargoes needs to be actively monitored. The required infrastructure (mooring dolphins) is not costly, and moreover flexible for reuse at another location in case of insufficient demand.

Any development that could have a significant influence on the parameters in the business case of the CBT (i.e., land prices, tariffs) needs monitoring so that corrective actions can be initiated in time. Similarly, the opportunities and threats identified in the SWOT analysis of the CBT, such as conflicts between parties, or each CTO wanting its own barge feeder terminal, pose a threat, and must be actively monitored. These can, to a certain extent be influenced through defensive actions on the part of PoRA. In case this is not possible, a reassessment of the strategy is required. A rise in inland shipping rates is unlikely due to increasing focus on sustainability that can make a case for governmental subsidy. If a new form of competitive transport (faster and environmentally friendly) appears, the plan will need reassessment. But this development will likely offer other opportunities. A detailed handling of Step V and VI of APP has not been included here.

In addition, the progress of MV2 project, which will determine the lifetime of the Inner Lake, also need to be monitored.

9.5.9 Discussion

Our case study examined the possibility of utilization of the Inner Lake at Maasvlakte 2 in Rotterdam for commercial purposes. A discussion based on the result follows.

- Constraints from the surroundings, such as ongoing construction and operational activities, limit the choice of activities and infrastructure for the Inner Lake. Similarly, institutional bottlenecks (such as the Master Plan of MV2 that forms the basis for Environmental Impact Assessment, and based on which the construction permits have been granted, also restrict the possibilities).

- In general, the selection of the structure is based on its functionality and its short-term financial viability. Traditional infrastructure designed to meet immediate requirements, are associated with minimum costs and risks (since the designs and construction methods have been optimized during multiple projects) and preferred. Long term viability is seldom examined. Therefore, a capital intensive concept has a small chance of being selected among available alternatives, despite the benefits that it may offer in the long-term future (for instance, CBT has a modular construction and offers the possibility of reusing the expensive deck resulting in lower lifecycle costs). Such flexible solutions could help PoRA seize many such opportunities in the future.

- When a non-traditional design concept is one of the alternatives (just as in the present study), our choices are limited to the existing concepts that have been well researched in pilot studies, through experiments or computer simulations. This highlights the need for collaborative research on innovative flexible concepts must continue, so that planners and designers have a variety of infrastructural solutions at their disposal.

- The study concluded that the CBT was a viable option for PoR, taking into account the business cases of other parties, i.e., CBT, the Container terminal operators, and PoRA. In this manner, the added benefits (such as savings resulting from deferred investment in container terminal expansions, and a significant increase in efficiency and productivity at the sea terminals) could be taken into account in individual business cases of PoRA and CTO. CBTO benefits most from this concept, and a concrete business case helps in negotiation with the CTO for mutual sharing of the resulting benefits.

- Thus, a CBT provides additional flexibility to phase investments in container terminal expansions, both by PoRA and CTO, and the value of this flexibility has been included in the business case to support decision-making over the commercial use of the Inner Lake. A valuable lesson from the exercise is that phasing infrastructure expansion offers monetary advantages for all the parties through deferring investment, and allows PoRA to keep their options open and reducing uncertainty.

- The focus should not be on the analysis of one single project to determine whether or not it is profitable or cost-effective. Instead the analysis should include related projects at any point in time, to determine the optimal strategy for the different possible scenarios. This is also the concept of portfolio management.

Table 9.11: Comparison of results using traditional and adaptive methods

Traditional method of planning	Adaptive planning method
Case: Masterplan Maasvlakte 2	
More or less static plan	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
Case 1: Planning for new use of an area	
Selection of future function for the area, based on short-term returns and a single future is likely to prove non-viable in a different future	Scenario planning is carried out to create four futures based on critical uncertainties & Robust Decision Making results in a selection of a function for the given area, that will be viable in multiple futures
Case 2: Quay wall construction project	
Only the top project risks during realization period are dealt with	A systematic approach that incorporates both short and long term uncertainties is applied
	It requires monitoring of precursor developments that can lead to scope changes in the project
	It proposes monitoring signposts such as berth utilization; this would signal a trigger for capacity expansion on time, thus avoiding negative effects such as congestion in the port and reduced service level
Case 3: Spatial planning for a port area	
Selection of alternative based on a single figure, i.e. maximum NPV	Selection of alternative for middle to long-term based on NPV and risk. The probability associated with the uncertainty around the NPV gives added insights on which to base investment decisions
	The robustness of the selected alternative is evaluated in multiple scenarios with relative ease
	Flexibility incorporated through investing in deep-sea instead of barge quays can be included easily in the evaluation
Case 4: Flexible infrastructure for MV2	
Most activities would be financially non-viable at the given location if a traditional quay wall construction was employed	Short term planning using minimum design approach for infrastructures in the framework of APP results in selection of an innovative flexible design alternative i.e. Containerland
	The selected activity i.e. a Common Barge Terminal can take the overflow from the container terminals at MV2 when they are nearing capacity so that investments in new quay wall can be postponed
	Including the added (indirect) value of this flexible logistic concept in the business case of the port authority makes it viable

9.6 Evaluation of the method

Case studies were carried out to illustrate Adaptive Port Planning and establish the feasibility of the approaches and methods proposed in this dissertation, for port planning projects. These dealt with short, middle, and long term planning in the framework of APP. In order to be able to draw general conclusions over the efficacy of the method, we compare for each case the solution arrived at using APP, with the solution likely to result from a traditional approach in Table 9.11. Included in the table is the case study over the port expansion Maasvlakte 2 (Chapter 5), in which an existing Master Plan was made adaptive by incorporating pro-active actions that aim at seizing opportunities and attempt to shape the external forces.

As can be seen from the comparison, incorporation of uncertainty and flexibility consideration have led to very different (flexible) alternatives on the table (instead of in the waste paper basket, as is mostly the case). Since the added value of these alternatives is made explicit (valuing flexibility is standard practice in APP), these are likely to be selected in place of the traditional solutions. The addition of adaptive actions to the plans has limited future surprises for the port authority. Solutions that are robust for a range of plausible futures than optimal for a single predicted future, have been favoured.
As has been demonstrated through the case studies, the value of APP lies in the creation of an awareness of uncertainty for the planner at every step, so that his focus does not shift from flexibility and robustness, whether it is during the selection of the logistic concept, design approach, or a design alternative.

Carrying out the case studies provided insights into the problems that planners encounter during planning and design. Arriving at a clear problem definition, data collection, and questioning experts regarding uncertainty estimates were the major issues encountered, in addition to the task of justifying the choice of non-traditional methods and solutions.

Chapter 10

Implementing Adaptive Port Planning

As with lots of good ideas, implementation is the key - Mitchell Reiss

10.1 Introduction

In today's turbulent, technology-driven, hyper-competitive, globalized economy, risks with new project investments are large. More than ever, large port projects denote thinking in terms of uncertainty, contingency planning, flexibility, and dynamic decisionmaking. We have introduced a method called Adaptive Port Planning (APP) that bridges the gaps identified in the traditional practices of port planning. APP recognizes uncertainties, accounts for flexibilities associated with a project, and can evaluate its investment potential with greater accuracy. This, in turn, helps to better evaluate the desirability of a long-term investment and leads to improved decisionmaking.

Having illustrated the varied applications of APP, and established its advantages over traditional methods, the next step is to incorporate and integrate APP into the practices of the organization(s) involved in port planning and design. The concepts underlying APP are not new and adaptive planning has been applied by the US Department of Defense for military planning (Klein, 2007), and it has recently been recommended for water management (Pahl-Wostl, 2005; Gregory et al., 2006), climate change management (RVW, 2009; Waardekker, 2011; Lempert and Groves, 2010; Walker et al., 2010), transport policies (Marchau et al., 2010), and Airport Strategic Planning (Rahman et al., 2008; Kwakkel et al., 2010). The application to infrastructure planning and design is still in its infancy.

The selection of APP over the traditional methods in the port sector will require surmounting many barriers. Once adopted, the successful implementation will place demands on the organizations involved in the planning or execution of plans, on the clients who have to frame the objectives, as well as the decisionmakers who have to assess the investment opportunities, finance the initiatives, and make a selection. When it comes to adopting new methods, economics play a major role for all commercial firms. However, the attitude of an organization to uncertainty, and its perceptions about flexibility, are as significant as available resources or capacity. In short, the strategies for dealing with uncertainty cannot be considered in isolation from the efforts made at the institutional level to incorporate and implement flexibility.

10.1.1 Some drivers, barriers, and enablers of flexibility

Since APP is closely linked to flexibility, going on to examine the barriers to APP, we list some drivers, barriers, and enablers of flexibility in the port sector in Figure 10.1. The list has been compiled during the research based on literature studies, interviews, and brainstorm sessions, and is by no means complete.

Increased volatility, limited space for port expansion, increased competition, higher productivity and efficiency requirements, and new technology leading to changed requirements are some of the drivers of flexibility. A lifecycle perspective, new design approaches, new technologies and innovation in many fields, new valuation methods that include flexibility all serve as enablers of flexibility. Clearly, the enablers of flexibility need a stimulus.

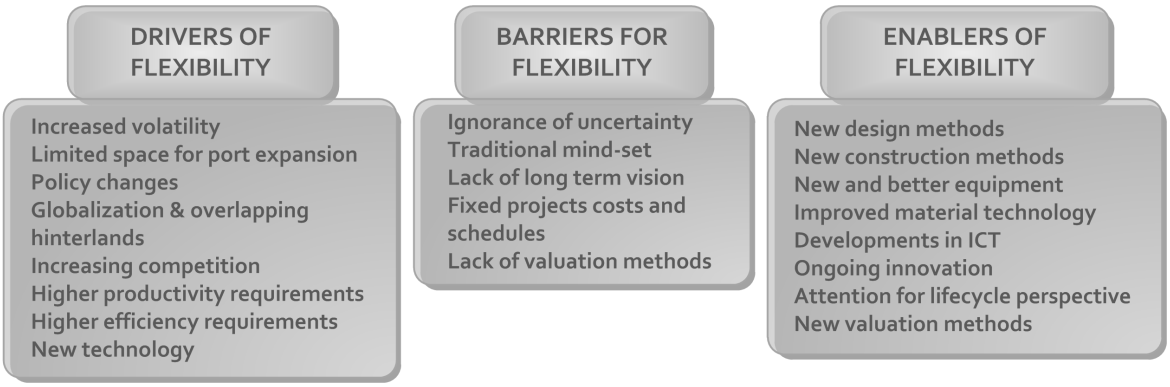


Figure 10.1: Drivers, barriers, and enablers of flexibility

10.1.2 Barriers to APP

The implementation of APP has to be carried out in a multi-actor and multi-disciplinary setting crossing social, economic, environmental, legal, and political boundaries. The APP method is based on three fundamentals: embracing uncertainty, acknowledging the role of flexibility, and actively pursuing innovation. The main barriers to these essential elements are stated here.

- The nature of port industry and port projects leaves little room for new techniques

- The practice of APP is at odds with the traditional methods

- Uncertainty and flexibility considerations add to the costs
- APP relies in many cases on (planned) innovation, which is a low priority goal for most organizations

In the following sections we examine these barriers to adoption and successful implementation of APP, and propose ways to address them. We focus considerable attention on two topics that we think are extremely relevant, i.e. the role of innovation, and the role of sustainability during the process of APP.

10.2 Port industry and port projects

10.2.1 Nature of port industry

The port industry is seen as a very traditional, sometimes old fashioned environment, and one that reflects the reactive approach that the industry has had towards the implementation of new concepts (Bellis, 1990). A retrospective look does reveal that ports have continued to evolve in response to the inevitable change in the environment, albeit reactively, so that we can distinctly identify four generations of ports and trace this evolution (UNCTAD, 1992). This speaks in favour of the port industry.

However, as we look around, we see that there is less opportunity today for port construction that does not satisfy established or agreed customer demand. This leaves less scope for speculative building and innovation. A tailor-made and optimized design for a single user or cargo, based on a fixed specification, has limited flexibility and adaptability for the future. This predilection for short term solutions, driven by a cost-benefit analysis and only sanctioned by a letter of intent of the investor, or better still, a signed contract, can be seen as a defensive approach on the part of port authorities.

Many organizations, also those involved in port planning, focus primarily on a consistent and efficient execution of internal tasks, processes, and procedures in a more or less institutionalized way. They are content to live with a more or less accepted version of the future, or ‘the official future’ (Schutte, 2008).

10.2.2 Nature of port projects

Ports affect the environment and natural resources. The vessel traffic and the activities related to a port development project translate into air quality, water quality, and noise issues, and often accessibility issues for the adjacent areas. A port development project can involve reclaiming land (thereby disturbing the eco-system), sometimes even causing displacement of the urban population. This is why infrastructure and spatial development projects need to go through environmental impact assessment procedures that provide the necessary legal basis for project approval. Such procedures aim at fixing the land-use plan and the scope of the project step by step. The fixing of the scope conflicts with an adaptive approach, which means keeping several choices open and possibly changing the scope in the future. Such projects are often realized in public-private partnerships, for instance in design-build-finance-maintain contracts. These are long term contracts that currently have little provisions for flexibility (Herder et al., 2011).

10.2.3 Traditional roles for actors

We have earlier discussed the distinct and separate role of planners (generally engineers) and managers in port planning. The former have a limited role in the whole process. Over the decades, the engineering profession has consciously taken the best practice results and results of empirical research and combined them into manuals of expertise. Engineers are expected to use their analytical abilities within the framework of these codes (standards and specifications), and produce outcomes that are constrained by the collective wisdom of past and present peers. Parkins (1996) rightly observes: "Engineering designers take pride in being the problem solvers – it is not for them to question the nature of those problems. The design engineer's quiet detachment is supported by a feeling that the performance of their duties, in accordance with the professional code of conduct and its physical embodiment in the standards and code of practice (particularly designed to protect the community from engineering risk), is sufficient to legitimize their role."

At present, few engineers are trained to consider the broader system or context. Engineers have a preference for detailed (exact or high fidelity) models, which are computationally heavy and cannot be used to explore alternative design configurations including flexibility and managerial decision rules under a wide range of uncertain scenarios. Absence of a broad view results in either suboptimal or wrong choices (Cardin and de Neufville, 2009). Duderstadt (2008) observes that despite the rapidly changing nature of engineering practice and technology needs of society, many aspects of engineering remain much as they have been for decades.

During a project, the managers rely on, and interpret the information documented by the engineer in a so called management summary, and often miss the detailed insights that the engineers have gathered during the planning process. This can lead to misguided decisionmaking and implementation. Defining actions to make a plan robust is generally the task of an engineer, though a multi-disciplinary team will probably work out the details. A limited role in the planning process means insufficient involvement and motivation for an engineer to seek flexible solutions.

10.3 APP and traditional practices

The standard practices in organizations involved in planning do not match APP principles which makes the implementation of APP problematic. Some examples:

In case of most projects, the objectives are rarely well specified at the outset of a project. The clients requiring the infrastructure have generally a short term vision – in fact, they also have a short term contract for the cargo they will handle (van der

Waarde and Jaquet, 2009). The terms of reference, on which the plans are to be based, is often finalized and authorized only after the project has been commissioned. Thus the very first step in APP is difficult to implement.

Generating a wide range of project alternatives is an important step in APP. These can represent varied approaches towards achieving the same objectives. But planners often let their thinking be constrained by cost factors, habitual thinking, or be guided by what the client wants to hear. Limiting or overlooking alternatives affects the quality of decisionmaking (Verhaege, 2007), and the result is a waste of valuable investment opportunity.

After the alternatives have been devised, the impacts of implementing these alternatives are imagined or estimated, taking into account the known constraints, and their projected implications used to re-examine the first formulation of objectives and introduce modifications (Miser and Quade, 1985). APP, in contrast, requires monitoring the environment and continually reassessing the objectives.

The traditional methods employ a top-down approach for corporate risks while a bottom up approach is applied for assessing project risks. This is also in contrast with APP approach, which does not distinguish between types of risks, but focuses instead on the critical vulnerabilities in the plan.

Adaptation is a key concept in APP. The traditional rigid contracts that lead to an early 'lock in', and linear organizational procedures are not in line with APP. Adaptations, the nature of which is not always known (and timing difficult to determine), are difficult to include in a contract. Administrative procedures are generally slow and can pose a big barrier to adaptation measures, if contract renegotiations are required for all changes, big or small.

The historical path that an organisation has followed, in relation to the people employed, the technologies and rules adopted, and its short or long-term strategy, influences its future behaviour. This makes it nearly impossible to switch from the old approach to a new approach such as APP. Contrarily, in situations of uncertainty, most are reluctant to add more uncertainty by introducing an approach that they do not understand and for which they require outside expertise. As van de Riet (2008) points out, decisionmakers look for unambiguous strategies in case of an unclear future.

Incorporating flexibility in order to exploit the upside potential while limiting the losses is also a key concept of APP. Paradoxically, the nature of flexibility presents a barrier to this. Increasing a system's flexibility generally introduces sub-optimality in the system, e.g., phasing a project offers subsequent flexibility in decisionmaking, but means losing out on economies of scale. Flexibility in one link of a supply chain can reduce flexibility in another, e.g., the added value of an innovative flexible infrastructural design is limited if no (or a single) contractor in the market has the skills and resources to realize such a design.

The varied perceptions of flexibility (often negative), by various stakeholders in a port development project add to the problem. Since project management is based on assuring conformity to time, budget, and scope constraints, a project manager sees flexibility as a threat to delivering the project on time and within budget. The general notion is that, in order to maximise efficiency, projects need to be clearly defined in the front-end phase and executed according to the plans. Too many design alternatives or changes in designs mid-way of a project due to scope change or unexpected situations are seen as risks. Moreover, in the eyes of a contractor, flexibility is not desirable, since it generally comes with a cost and added risks. This is also true for managers, who have to struggle to balance flexibility and continuity of a project, and to prioritise among different (and often conflicting) forms of flexibility.

10.4 Cost of uncertainty and flexibility

We have established in Chapter 7 that flexibility comes with an added cost. A port, however, is a commercial organization which has to generate economic value for its shareholders. The increasing competition and the volatility mean that the profit margins are smaller, and sensitive to disturbances. As a result, the designs, and the construction processes, can not be selected freely; costs rather than long-term considerations and innovation determine the choices. The pressure of short-term gains is at odds with longer-term uncertainty considerations that require investment in robustness and flexibility. Generally the short-term approach, directed at near-term solutions dominates. This also applies for contractors who are faced with short-term pressures, (e.g. to be the lowest bidders for a contract), so the long-term view takes a back seat. That the added value of an innovative design solution is not included in a standard tender evaluation, makes it difficult to convince the management of its superiority.

10.5 APP and innovation

An important step in APP is the identification and creation of flexibility in a system – which often requires 'planned' innovation. Conventional engineering practice often focuses on the expected value of future uncertainties, thus leaving the value of flexible designs unexplored (Yang, 2009). And even when new concepts have been proposed, they are considered high cost and high risk and do not find implementation.

A recent study carried out by Erasmus University in an assignment from the Port of Rotterdam and Port of Amsterdam to evaluate the innovation performance of port related industry in the two ports, revealed that port innovation is directed two thirds at efficiency and only one third at products and processes (evolutionary innovation). Even though 'planned' innovation is mentioned in the strategy of a company, the concrete translation into policy, personnel, organization structure and services mostly lags behind (INSCOPE, 2009). The following were the major barriers mentioned by the people interviewed: changeability of rules and regulations (38%), budgetary issues (32%), lack of competences and friction between partners, and resistance from the workers (20%). There has been an increasing appreciation of how important innovation is to the economy (Kin and Mauborgne, 1997; Dundon, 2002; Buganza and Verganti, 2006). And many claim that innovation is the only manner to survive since it offers a port resilience in future (Winkelmans, 2007; Chen et al., 2010; Haugstetter and Cahoon, 2010). A short discussion over innovation in the port sector follows.

10.5.1 Types of innovation

Innovation is the implementation of new ideas. Many believe that successful growth of a company can be achieved through dedication to breakthrough innovation and adoption of an innovation mind-set. Some organizations see innovation as the art of taking risks (Kuczmarski, 2003).

Table 10.1: Types of innovation in ports and their characteristics

Characteristics	Incremental innovation	Evolutionary innovation	Revolutionary innovation
Prime mover	Market forces	Market forces	Interplay between scientific advances, economic factors, institutional variables and unsolved problems (Goss, 2002)
Costs/ resources	Small	Large	Very large
Issues/ opportunities	Existing or predictable	Both existing and new	New
Associated uncertainty	Small	Small to large	Cannot be assessed
Routines/ Procedures	Routines or a variation/ combination	Changing trajectories, flexible use of routines	Routines mostly violated
Markets	Targeted at existing markets	Targeted at existing and new markets	Disrupts existing markets

A synthesis of views of various authors (Volberda, 1998; Dundon, 2002) results in the following classification of degrees of innovation which are summarized in Table 10.1.

Incremental adaptation (also called adaptive or efficiency innovation) focuses on improving what already exists, e.g., optimizing standard solutions for existing problems. This includes incremental changes such as cost reduction, and quality or productivity improvements. It requires small investments and delivers small gains.

Evolutionary innovation mostly addresses existing or new issues using state of the art approaches and techniques and is often targeted at new markets. The new issues can be a result of technology, or policy changes, new strategies, joint ventures or mergers, or customer feedback. Evolutionary innovation refers to distinctly better products and processes, but like incremental innovation, it is carried out within the existing structure of organizations.

Revolutionary or break-through innovation focuses on radically new and better ideas that may, in fact, transform or even dismantle the existing structure, technology and processes of the organization, as well as the marketplace. These innovative activities lead to the discovery of an intertemporal activity that cannot, even in principle, be said to actually exist before the opportunity has been created (Kirzner, 1985). Whereas incremental innovation addresses existing problems (and therefore can often prove limiting through shifting focus of an organization), evolutionary innovation is directed at anticipating new problems and issues as a result of long-term thinking about future developments. Revolutionary innovation is mostly a result of serendipity, though often triggered by inadequate solutions of existing problems. Which is why it can be termed unplanned innovation, while the first two can be classified as planned innovation.

In the port sector, containerization represented a break-through innovation. Manufacturing cranes that could handle extra wide post-panamax ships that did not sail yet on the Atlantic route in late 1980s, and building of the Sea-Land Delta terminal by ECT (now short for Europe Combined Terminals) in the early 1990s, first declared to be the logistic blunder of the century, but which later achieved the status of 3rd generation container terminal, exemplify revolutionary innovations. The ensuing developments, such as specialized cranes for container handling can be called evolutionary, and subsequent improvements in crane design (twin-lift and followed by quad-lift spreaders (Conquip, 2010)), or new types of containers, falls under the category of incremental innovation.

10.5.2 Innovation in engineering design

David Hughes (Tidd et al., 2005) states very aptly: "The characteristics of doing business today – rapid change, extreme volatility and high uncertainty – mean that traditional ways of managing technology need to be radically reappraised for any company that sees technical leadership as a critical business differentiator". Innovation is seen as a means for survival in this competitive age. Therefore, we find it useful to bring up a concept termed 'value innovation' (Kin and Mauborgne, 1997). It is a strategic logic that suggests designing a system by asking: what would we do if we were starting anew, even shaping industry conditions, and thinking in terms of total customer solution and satisfaction.

In addition to planned innovation as a part of APP, we need to apply the logic of value innovation to engineering design for dealing with the biggest challenge for the port industry – that is uncertainty. This requires a top-down approach that begins with specifying the global system state and requirements. Although more risky, it allows more room for creativity. On the contrary, the traditional bottom-up approach begins with specifying requirements and capabilities of individual components, and the global behavior is said to emerge – it is cheaper, faster, and less risky (Eshagh, 2012).

But first, we require a clear identification and prioritisation of challenges that can be overcome by innovation. The value innovation approach applied to engineering design suggests shifting attention from components and subsystems to systems, seeking new solutions and designs starting from performance criteria (Coates, 2002; de Neufville, 2003b). Such solutions might require adaptations in the rest of the chain, but the long-term pay-offs are also likely to be large. (For instance, the new break-through container handling concept of APMT discussed in Chapter 8, will require reassessing the design of the terminal and the hinterland connections to handle the peaks in cargo handling, but will double the terminal productivity and reduce the turnaround time of ships.)

In the new millennium, we are aware that we must use our resources in a responsible manner so that we do not deprive future generations. In the next section, we discuss how sustainability considerations are incorporated in APP.

10.6 APP and sustainability

The importance of sustainable infrastructure to a community is similar to the foundation the human skeleton plays in the overall structuring, functioning and health of the body (Dale and Hamilton, 2007). The three dimensions of sustainability (people, planet, and profit) need to be balanced in every endeavour. People refer to corporate social responsibility and regional social involvement. Planet refers to use of space, the air quality (emissions of PM10, NOx, SO2), nature, emissions of CO-2, water quality, soil quality, noise, and recyclable material use. Profit refers to the economic value created by an organization after deducting the cost of all inputs.

Sustainable development of a port requires designing, building, and operating port infrastructures in ways that do not diminish the social, economic, and ecological processes required to maintain human equity, diversity, and the functionality of natural systems. The benefits of incorporating sustainability considerations during planning, design, and construction are: efficient use of materials, lower costs, higher efficiency, application of lifecycle costing that can lead to other advantages, taking externalities into account, and nowadays, even attracting investors. Since sustainability has become a high profile objective, decisionmakers in governments and businesses are required to choose among different project alternatives that, in varying degrees, contribute to the three dimensions of sustainability. They also have to account for their choices to a large audience or a broad range of stakeholders (Sijtsma, 2006).

Sustainability has long been on the agenda at many companies, but for decades their environmental, social, and governance activities have been disconnected from their core strategies. Most still take a fragmented, reactive approach, launching ad hoc initiatives to enhance their ‘green’ credentials, to comply with regulations, or to deal with emergencies rather than treating sustainability as an issue with a direct impact on business results. Among the reasons given are: lack of incentives tied to performance and sustainability initiatives, lack of right capabilities and/or skills, lack of, or use of wrong key performance indicators (KPIs), insufficient resources, current organizational structure that does not support accountability for sustainable activities, and insufficient data or information to implement initiatives (McKinsey Global Survey (Bonini, 2011)). Needless to state, these issues need to be addressed.

While the APP framework recommends flexibility for dealing with uncertain vulnerabilities, it makes no explicit mention of sustainability. This is because it assumes that the sustainability requirements are included either in the objective or in definition of success of a project. Consequently, they are reflected in the terms of reference of a project – in terms of a long planning horizon, uncertainty consideration e.g. climate change, sea level rise and storm surges; environmental impact analysis including mitigation and compensation measures; requirements of energy efficiency, and use of tools such as lifecycle analysis. Sustainability can also be explicitly included in Step IV of APP, when the evaluation of alternatives takes place e.g. in a MCA or CBA. Nowadays, sustainability considerations are being included during tendering and contracting procedures which follow the planning stage. For instance, they are accounted for in the procurement criteria e.g. while selecting appropriate technology, or the construction materials, or the construction and management techniques that are consistent with local contexts. Broesterhuizen (2012) has gathered the various sustainability criteria considered during evaluation in port projects from various sources[1].

Many are realizing that sustainability is not an add-on criterion (Mulder, 2006), but that it should be about the characteristics that any design should meet, and in fact an overarching design principle for engineering systems (Cutcher-Gershenfield et al., 2004). In Section 10.7.4 we will examine how flexibility and sustainability are related.

10.7 Addressing the barriers

During our research, we assimilated many viewpoints related to the barriers to flexibility and the adoption of new methods. The major sources of information were – literature studies, surveys and brainstorm sessions, and interaction with individuals in the port sector while doing case studies. We go on to briefly discuss how these barriers can possibly be removed. The list is by no means complete, and since the proposed suggestions have not been researched, these can be seen as reflections.

- Changed mind-set
- New roles for actors
- Impetus to innovation
- Comprehending the relationship of flexibility and sustainability
- Formulating new objectives and criteria

[1]These criteria include: the extent of space required by the contractor, reduced land value due to division of land, additional traffic generated due to construction, deterioration of existing nature, emissions in air and in surface water and groundwater, nature compensation measures, creation of nature-friendly banks and slopes, implementation of an environmental management system, attention for energy demand, measures concerning disposal of waste materials, measures against noise during demolition, construction and operations, reuse of material, attention for ecological constraints, (e.g., amount of earth filling, soil quality etc.). In the Netherlands, the 5% rule (or social return agreement) is applicable, whereby 5% of the building sum is set towards employing long-time unemployed or trainees.

– Flexible organizational procedures and new tools

10.7.1 Changed mind-set

To start with, a change in the mind-set on part of the organization(s) involved in the planning and execution of plans, the clients, and other decisionmaking bodies is required. It begins with an awareness of uncertainty and its implications, requires thinking through the implications of these changes despite the bureaucracies and the cultural-political opposition; shifting the focus from short-term to long-term, and ultimately being willing to assume a role other than the traditional role. Childre and Cryer (2000) rightly state that flexibility and adaptability do not happen just by reacting fast to new information. They arise from mental and emotional balance, the lack of attachment to specific outcomes, and putting care for self and others as a prime operating principle.

The recent years have been a rich period for students of uncertainty, with many unanticipated events in the world that have been well broadcast thanks to modern technology. In the port sector, developments such as evolution in vessel size have made port master plans and equipment designs obsolete while still on the drafting table. The recent credit crisis that froze movement of money and cargo has been a wake up call. The recognition of uncertainty and its often dire consequences has penetrated most organizations. It has led to a willingness to open discussion on the subject, encouraged participation, and permitted addressing issues that were previously sensitive. Now the time is ripe to induce changes at the system level and prepare for uncertainty and its implications.

This mind-set will make it easier to convince the broader engineering and technical community that flexibility is a relevant issue (Cardin and de Neufville, 2009). And it will allow the planners and decisionmakers to embrace systemic approaches such as APP that lead to flexible and sustainable adaptive plans.

10.7.2 New roles

Not only do we require new approaches, but also new roles. We must realize that the role of a 'strategic' planner who can interact with the specialists in various disciplines and interpret and convey relevant information to the decisionmaker is vital. In many sectors, a similar function is assumed by a systems engineer, though the role of a strategic planner extends further. The many interactions are illustrated in Figure 10.2 based on Walker (2009) and explain why a planner needs to be be cross-trained.

For successful implementation of APP, a forecaster must not only communicate his forecast, but also the associated uncertainty. The planner must subsequently analyze design input and output for uncertainty considerations. He must consider flexibility early in the design phase, which is a departure from the traditional engineering paradigm. In addition to integrating such considerations in the engineering norms, standards, and guidelines, comprehensive long-term approaches that automatically steer a planner towards flexibility will prove invaluable.

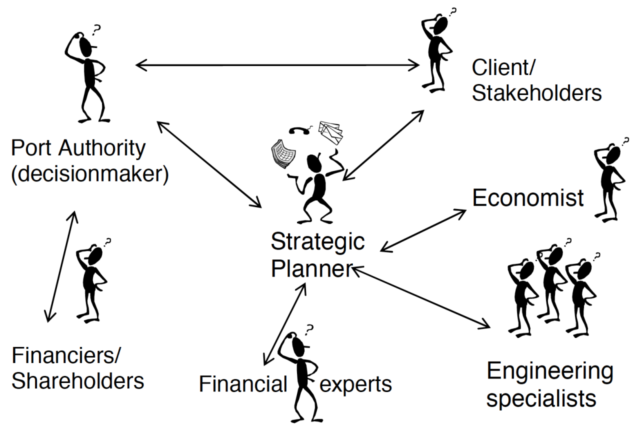


Figure 10.2: Role of strategic planner in the planning arena

A planner must use less detailed, and quicker analytical models to explore and value economically the universe of possible design configurations under uncertainty. He must learn how to integrate such considerations as functional and other stakeholder requirements, short-term goals and life-cycle costs, selection of materials and technologies, while convincing the client and decisionmaker of the wisdom of his choices. He would need to justify the incorporation of flexibility to the clients and the decisionmakers alike (the evaluation tools mentioned in the thesis could be usefully employed for this purpose). The best technical solution to a challenge is not always the one most acceptable for our planet and people. Therefore, he would need to strike a balance between economic, social, environmental, and political needs. As a practitioner in engineering systems he must be able to simultaneously navigate in the technical, managerial, and societal spheres (Hammond, 1996; Moses, 2004; Duderstadt, 2008; Cardin and de Neufville, 2009).

10.7.3 Impetus to innovation

We stated earlier that the identification and incorporation of flexibility plays a key role in APP. Technological development and advancing knowledge will make technically feasible tomorrow what today is a fantasy. And as new issues appear, a shift of focus and priorities will take place so that things not socially acceptable today may very well be in the future (and vice versa). Once need escalates and reaches a threshold, and initiative is taken to commonly address issues, promising ideas will find implementation. This understanding signifies that collaborative research in flexibility must continue, so that planners and designers have a variety of infrastructural solutions at their disposal. In short, we must have a structured approach to develop innovative solutions in answer to the challenge of uncertainty. The support of port authorities and the government is essential to developing such solutions.

10.7.4 Comprehending the relationship of flexibility to sustainability

Addressing uncertainty through flexibility automatically serves to enhance sustainability goals (de Neufville et al., 2006a) as illustrated in Figure 10.3. The recognition of this fact will give an impulse to flexibility. A flexible layout allows future expansion and permits re-configuration without expensive modifications, sometimes obviating the need for environment damaging land-reclamation. Flexibility in infrastructure helps to prolong the useful lifetime of an infrastructure through allowing adaptation, thus facilitating reusability. Reuse, in turn, concurrently optimizes use of natural resources and limits waste and pollution in the environment, thereby reducing the overall ecological impact. It also results in significantly lower lifecycle costs (despite the costs associated with incorporation of flexibility and subsequent adaptations) and conserves energy resources. The savings can be invested in improving social equity or the environment. Thus, flexibility helps achieve (long-term) financial viability in face of economic uncertainty, while reducing negative environmental and social impacts.

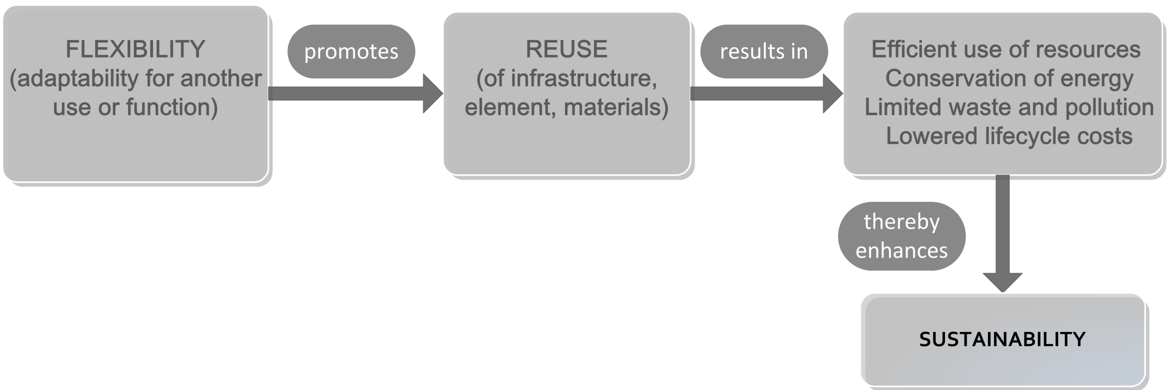


Figure 10.3: Relationship between flexibility and sustainability

10.7.5 Flexible organizational procedures and new tools

A successful implementation of APP would be greatly helped by flexible procedures. A degree of in-built contractual flexibility is required in port projects to allow for planned adaptation in response to unexpected developments at a later stage. The provisions in the contract should be able to accommodate small adaptations. Even though the timing of such just-in-time adaptations cannot be anticipated, the standard procedures for implementation must be established beforehand. If the nature of future adaptation is known, as is mostly the case in APP where actions have been defined, it is easier to define flexible contracts with in-built clauses that will ease implementation at a later stage. Substantial modifications will require a more elaborate procedure involving authorisation at many levels.

The wishes of the customers in the port sector are directed more and more towards flexibility. This is not only limited to the waterside of a port, but extends to flexibility in the whole supply chain/chain of goods transport. Moreover each customer has his own specific requirements to be accommodated that are not a part of a standard procedure. This trend also calls for flexible procedures.

Since flexibility is primarily useful to improve the effectiveness of projects rather than efficiency, and viewed as a threat to budget and schedule by contractors and mangers. Flexibility is more valued by the stakeholders that have a responsibility for the overall profitability or societal benefit of a project, compared to those who are only responsible for the cost side of the project (e.g., a contractor) (Olsson, 2003). This situation may change if stakeholders on the cost-side are given room to deploy flexibility as well as take advantage of it (by being allowed to keep a part of the benefits). Auctioning innovative concepts in order to attract participation of potential financiers should be considered by port authorities who can assume the role of a leader.

More recently, engineering-procurement-construction and turnkey contracts group these activities together to better align incentives between engineering and construction. Innovative contracts that make a single firm responsible not only for developing, designing, and building the project, but also for maintaining and operating it for a long period of time, is one way of aligning incentives of groups (with different motives and interests). The kind of participant selection procedures used, for instance, invited negotiation as opposed to an open and public call for bids, and innovative contract specifications are also part of this group of strategies (Floricel and Miller, 2001). This trend can facilitate the incorporation of flexibility in projects.

10.8 Role of actors

Because of the limited potential of forecasting techniques in anticipating rare events (Goodwin and Wright, 2010), there is a growing interest in flexibility and adaptiveness in plans where a strategic vision of the future is combined with short-term actions and a framework that can guide future actions (Walker et al., 2001; Albrechts, 2004; Walker et al., 2010). Fortunately, decisionmakers who generally regard uncertainty as negative are now beginning to realize that this very uncertainty can offer opportunities and competitive advantage. With the advent of tools for valuing investments under uncertainty, flexibility can be included in their projects and uncertainty can be exploited. Even if an organization acknowledges uncertainty, does not shy away from notions of (costly) flexibility, and is willing to employ new tools and techniques and adopt APP, it still requires support in order to successfully implement APP. This support can be provided by the government, port authorities, and even terminal operators, whose participation must be stimulated.

10.8.1 Government

In case of large investments in infrastructural projects, extensive government support is inevitable. But also innovative endeavours, especially with respect to sustainability, where the expenditure and the benefits accrue to different parties, need governmental assistance. Dekker et al. (2003) suggest that a justification for the public contribution for port projects could be found in the indirect economic impacts, which are outside the scope of the commercial exploitation but within the social welfare scope of the government. The government may contribute a portion in the investment equivalent to the discounted indirect economic impacts over the project's lifetime. There is, however, considerable controversy among analysts how indirect economic impacts should be accounted for.

Both (technological) innovation and sustainability endeavors need to be accompanied by institutional change to achieve the goal of sustainability, and the government has the authority to adapt or change regulations if required. The government can make available financial support at the beginning of a project in the form of state aid, through fiscal measures, or funding for research infrastructure and programs or apply regulation to stimulate alternative financing methods. Dale and Hamilton (2007) propose that mechanisms be considered to alleviate risks associated with the implementation of leading edge as well as proven state of the art technologies, such as 'guarantee' schemes, subsidized insurance and reduced pay-back periods. Internalization of environmental and social effects into cost of production, thereby generating revenue to support innovation, could be a possibility.

The government can foster public-private sector collaboration and networking and clustering of firms to create the necessary critical mass and synergy. Knowledge flows are the glue of the innovation system (Cowan and van de Paal, 2000), and the government can contribute by setting up data banks and performance indicators, as well as through policy and guideline documents.

Nowadays, many of the risks are passed by a landlord port authority to its terminal operators (through use of innovative contract-forms and risk alleviating mechanisms). These operators, who must increasingly satisfy stringent contractual demands, also need innovative solutions. Thanks to the ongoing vertical consolidation in the industry, many of these are now multinational enterprises that have the resources and leverage to contribute to innovative initiatives.

10.8.2 Port Authorities

Aside from the government, only a few organizations are likely to have a sufficiently broad perspective, capital and knowledge base, or the necessary leverage to bring about and manage change that accompanies innovative endeavours. Many have proposed this role of innovation leader for port authorities, citing reasons for doing so.

A port authority has wider responsibilities than other parties - e.g. for the sustainability of operations on which the port depends. It has a stake with innovation - improving operations, gaining competitive advantage, and nowadays, achieving and maintaining a 'license to operate' and a 'license to grow'. Having a secure capital structure and relatively robust sources of revenues mean that it is better placed than most other infrastructure owners and managers, particularly in the currently adverse economic times. With many small enterprises involved, the lead cannot really come from the market. On this basis, a port should be taking more of a lead, given the authority to influence or set down how things should happen (OECD, 2010). A port has a symbiotic relationship with key government strategies and programs, development organizations and industry and research institutes in the context of the transport infrastructure. And due to its unique position in the network at various levels, it is an ideal vehicle for leading innovation. Also, a port authority, located in an inter-modal hub, has many opportunities for capturing and integrating knowledge and learning (Chen et al., 2010; Haugstetter and Cahoon, 2010).

10.9 Conclusions

In this dissertation, we have proposed a method called Adaptive Port Planning (APP) that bridges the gaps identified in the traditional practices of port planning. Having illustrated its varied applications, and established its advantages over traditional methods, the next step is to incorporate and integrate APP into the practices of the organizations involved in port planning and design.

The APP method is based on the fundamentals of embracing uncertainty, acknowledging the role of flexibility, and actively pursuing innovation. The main barriers to these elements are: the conservative port industry; the inflexible nature of port projects, organizations, and procedures; the limiting traditional role of an engineer; and the organizational culture that leaves little room for new techniques. The concepts and steps in APP are at odds with the traditional methods, which is likely to create initial resistance in the organization. That fact that flexibility adds cost, while there is no guarantee that this flexibility will be utilized in the future, makes it difficult to justify its incorporation using tradition evaluation tools. Also, APP relies on planned innovation (to produce flexible solutions), but innovation is a low priority with most firms, especially in these uncertain times.

We think that unanticipated events in recent years, and the awareness that we must use our resources in a responsible manner so as not to deprive our future generations, has brought about a change in mind-set of individuals and organizations. Since sustainability has become a high profile objective, also in relation to infrastructural projects, the contribution of flexibility to sustainability must be made explicit (and preferably its value monetized). In that way, we can include it in project appraisal and during contracting.

The implementation of APP has to be carried out in multi-actor and multi-disciplinary setting crossing social, economic, environmental, legal, and political boundaries. Thus we need a 'strategic planner' – a generalist who can take a holistic approach, understand the tasks of an engineer, economist, manager, and a policymaker, and is able to communicate with the many disciplines in his planning team. He must be able to integrate their knowledge so that he can incorporate uncertainty considerations in standards and projects, seek new innovative flexible solutions, and justify them to the authorities.

The large scale of infrastructural projects and the need for institutional change concomitant with technological innovation or sustainability initiatives requires support from the government that has the capital base, as well as the authority to adapt regulations. A port authority can play the role of facilitator in setting up collaborations, stimulating initiatives, and creating a knowledge base, due to its unique position in the network. Thanks to the ongoing vertical consolidation in the port industry, many terminal operators are now multinational enterprises, with resources and leverage to contribute to innovative initiatives.

Once adopted and successfully implemented, APP can make a significant contribution by producing flexible, robust, and sustainable Master Plans and infrastructures.

Chapter 11

Conclusions and reflections

A flexible or adaptable port has the capability to change so as to be functional under new, different, or changing requirements, with minimal extra investment, while maintaining its service quality.

11.1 Introduction

Infrastructures, including ports, are the basic services and facilities necessary for an economy to function. They also require major investments. Since they have a design life of several decades, they need to accommodate today's needs as well as tomorrow's. The shifting function of a port, as well as the many logistical, technological, and economic uncertainties under which it must operate, make its planning and design very challenging. The sheer scale and complexity of a port project, and the fragility of the global trading network around it, add to the challenge.

The traditional methods of port planning are inadequate in present volatile times. They result in infrastructures that cannot cope with new or changing demands without costly adaptations. The subjects of uncertainty, flexibility, and adaptability have only recently received attention in the port sector due to recent developments such as the massive boom in container transport, and now the downward turn in container throughput due to the financial crisis.

Though sporadic research on a multitude of issues in the port sector is being carried out, resulting in remarkable innovations in products and processes, the issues why, how, and where with respect to uncertainty and flexibility have not been dealt with in an integrated manner. As a result, an easy to use tool-kit for port planners in times of uncertainty is missing. Therefore, this dissertation is about planning under uncertainty, which requires us to leave behind the ideas of permanence and stability in relation to developments affecting ports on all fronts, whether technological, political, environmental, or social.

We have built our research upon works initiated by the researchers at the RAND Corporation on adaptive planning (Walker, 2000; Walker et al., 2001) and on robust policymaking (Lempert et al., 2003). We have also built upon the work from the Engineering Systems Division at MIT on engineering systems design (de Neufville, 2000, 2003b; de Neufville et al., 2006a; Roos et al., 2004; Cutcher-Gershenfield et al., 2004; Hansman et al., 2005; Scholtes, 2007; Cardin and de Neufville, 2009; de Weck et al., 2011), and particularly flexibility (Ramirez, 2002; Greden, 2005; Cardin et al., 2008; Nilchiani, 2005). And, we have derived inspiration from recent studies on uncertainty (Walker et al., 2012), adaptive planning (Kwakkel, 2010), and flexibility (de Neufville and Scholtes, 2011).

We have addressed the issues of uncertainty and flexibility in a systematic manner in the context of ports, provided useful definitions of flexibility-related concepts, and presented frameworks that can be utilized while preparing strategies for flexibility. Port planning is a multidisciplinary effort, which is why this research also encompasses multiple disciplines. We have applied proven methods and techniques from the fields of engineering, finance, and management, all towards the single objective of achieving flexibility in port planning and design, in the framework of a method called Adaptive Port Planning (APP), which is based on several existing adaptive planning approaches.

We first present our research questions framed at the beginning, followed by the answers that we have found. We also present the lessons learned from our case studies, which not only serve to illustrate APP, but address significant issues in the port sector. Following this, we summarize the advantages of APP, and what we think to be the contributions of this research. Reflections on our research and its limitations, lead to suggestions for further research.

11.2 Research questions

In this dissertation we set forward the following hypothesis:

The port industry is in a state of radical change and the biggest challenge confronting it is uncertainty. Since uncertainty is here to stay, we need to recognize it, manage it, and even try to profit from it. This requires new approaches for port planning and design.

Our main research question was framed as follows:

How can we plan and design our port infrastructures under conditions of uncertainty?

This required us to answer the following research sub-questions:

1. What is one of the major challenges facing ports?
2. What are the drawbacks in the traditional methods of port planning with respect to handling uncertainties?
3. What is a good manner to deal with the uncertainties in port planning?
4. Which planning method(s) can remove the drawbacks identified in the traditional methods?
5. Where can we incorporate flexibility in port infrastructure?

6. How can we value flexibility in a project appraisal (and justify its extra costs)?
7. How can we monitor major uncertainties in order to initiate timely action?
8. How can we stimulate the adoption and successful implementation of the proposed planning method?

11.3 Answers to the research questions

 # 1 What is one of the major challenges facing ports?

Large-scale engineering projects are capital intensive, have a long lifetime, uncertain future requirements, and are characterized by indivisibility and irreversibility. This makes the task of planners very challenging, and the major challenge is how to deal with the uncertainty in the external environment. In support of this statement, we presented a multitude of cases from the port sector highlighting the implications of uncertainty. If port infrastructures or layouts have to undergo drastic adaptations long before their design lifetime has been reached, it not only means costly adaptations, but also a loss of cargo and revenue in the period that the facilities cannot be used. Container shipping companies (especially those with transshipment cargo) will not be loyal to a single port, but move on to other ports that provide adequate capacity and service levels. Loss of client and a tarnished image can be followed by obsolescence.

Port are dynamic, open, and complex engineering system subject to external influences and multiple uncertainties. Uncertainty can be defined as a plea for information. We found it essential to explore the different dimensions of uncertainty, i.e. its nature, its location, and its levels) in the context of ports, in order to deal with it. Notwithstanding its level or severity (which can range from deterministic knowledge to total ignorance), it is common practice to express uncertainties about variables or underlying functional relationships among key variables in the form of a probability distribution. This is not always appropriate. Deep uncertainty is most significant during infrastructure planning, and can be defined as the situation in which the decisionmaker does not know, or multiple decisionmakers cannot agree on, the system model, the prior probabilities for the uncertain parameters of the system model and/or the value function. Many uncertainty handling methods have emerged over the recent years to address different types of uncertainties; an overview has been included.

An understanding of the plausible future changes in the world is an essential element of planning. The prevailing and emerging trends in the port and shipping sector can influence how we approach port planning and design, our planning objectives, and the solutions we select. These trends include: continuing globalization and containerization; changing functions of ports and scales of port projects; changing actors in the port arena; changing technology; and increasing attention for the environment and safety.

 # 2 What are the drawbacks in the traditional methods of port planning and design with respect to handling uncertainties?

We examined the traditional planning approaches and observed that, due to inadequate uncertainty considerations (or a focus on the wrong uncertainties), the objectives and sub-objectives of a port development are often not correctly defined. There is often no clarity in the short-term and long-term visions, which can lead to conflicting performance criteria requiring paradoxical solutions. The designers do not habitually think in terms of uncertainty, and opt for inflexible Master Plans or infrastructure designs. There are long distances between the economist carrying out the demand forecasts (on which the plans are based), the engineer doing the planning, the investment manager who sets up the business case, and the decisionmaker (which could be the port authority, the future user, or even an investor). The linear planning approach followed for most port development projects means that the decisionmaking cannot benefit from new information that reduces uncertainty. Consequently, we have port layouts and infrastructures that prove inadequate under changing requirements.

The traditional methods of investment appraisal are based on a financial evaluation in a business case, using standard DCF methods. The decisionmaking is based on the most likely outcome of a situation, e.g., expected value of investment. Due to the many uncertainties surrounding the planning, implementation, and operating environment of a project, it is neither feasible, nor desirable, to express the value of project or project alternative in a single monetary value, and base our decisions on it. Current techniques do not value flexibility in projects, so that its costs are difficult to justify.

The organizations executing a project in the civil engineering sector, often implement a risk management program in addition to project management. Even so, the two are treated as independent activities, and practised in different time frames. The risks pertain mainly to project risks. Scope changes in a project are often responsible for the failure of a project, but are not a part of standard practice of risk management. When ad-hoc risk reduction measures are applied at a later stage, and lead to extra budget and time, it often comes as a source of surprise. A systematic and integrated approach to planning a (port) project is missing.

The prevalent volatility and the rapidly changing economy have led to the realization that project valuation depends on (highly uncertain future) expectations. It is also being acknowledged that under uncertainty, the project value is driven by the flexibility it provides to create options. Due to the inadequacy of the present decisionmaking tools for addressing these issues, project evaluation needs to shift from traditional techniques to methods that consider uncertainty and value flexibility. The root of the problem is that we are struggling with the same attitude, behavior, and mindset while the world around us has changed. We are still trying to predict the future using linear tools for complex non-linear systems, and then basing our plans on this future. It is clear that we need to revise best practices.

 # 3 What is a good manner to deal with the uncertainties in port planning?

A literature study pertaining to engineering system designs substantiates that flexibility is a suitable strategy for dealing with uncertainty. Recently, various ‘adaptive’ planning approaches that embrace uncertainty and flexibility have been put forward that are also relevant for infrastructures. We suggest that port planning too, needs to move from optimal designs to flexible designs, from anticipating risks to monitoring the environment, from operative Master Plans to directive planning, from strategic planning (aided by risk management) to an integrated method such as Adaptive Port Planning.

We have defined some relevant terms. A *flexible or adaptable port* 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 (which essentially means, to maintain, or even improve service levels, with minimal extra investment). An *option* is the right to carry out a strategic action, without the obligation to do so, now, or in the future, for a predetermined condition. When applied to real systems and projects, options represent (a type of) flexibility in the system and are termed as *real options*. We illustrated various types of real options mentioned in literature with examples from the port sector. We also depicted the port as a layered infrastructure system, where three layers are formed by the physical infrastructure, operations and management, and the product and services provided.

Using the layered infrastructure system model as a framework, we listed plausible flexibilities in each layer. Also, in order to help planners identify options in each layer, we presented a series of questions. Using these, a planner can systematically define strategies for each vulnerability (and opportunity) in his infra system.

 # 4 Which planning method(s) can remove the drawbacks identified in the traditional methods?

We presented an integrated planning approach called Adaptive Port Planning (APP). It is a method that offers a unified approach for strategic planning and risk management, and guides planners to systematically deal with uncertainties that appear over the lifetime of an infrastructure project. It results in a flexible plan – i.e., a plan that anticipates and adapts (flexibility is embedded in the plan for facilitating adaptation). This plan will perform well no matter what future occurs. APP is an approach that systematically guides the user through a planning process from the time of setting up a plan through to its implementation. It provides a framework for the planner to first identify critical uncertainties (vulnerabilities and opportunities) in the system; then, to explore, value, and incorporate flexibilities for handling these uncertainties, taking actions either in the planning stage, or by preparing actions in advance that can be taken if required. The actions are taken in response to triggers from a monitoring system (which monitors the external environment for new developments and alerts planners of the need to modify or reassess the plan). The chosen strategy depends on the level of uncertainty. We discussed these strategies in detail, and investigated suitable tools and techniques to be used in the framework of APP.

The question as to who should implement the various steps in APP presents a dilemma in case of civil engineering projects. Should the owner of the infrastructure set up a flexible design, or should he pass on this task to the market? We proposed how APP can be applied in case of a traditional contract form, where the port owner produces a robust plan, and a 'Design and Contract' contract, where this task is assigned to the contractor.
APP raises awareness about the notion of surprise and equips the organizations with new mental categories of radical change, as well as a set of new policies to mitigate their extreme effects. The idea of committing to a first set of actions while preparing

others in advance is of specific importance in infrastructure planning and development, because of the time it takes to build new infrastructure.
In order to illustrate APP, we use a case study in which an existing Master Plan was made adaptive by incorporating pro-active actions that aim at seizing opportunities and attempt to shape the external forces. Although extreme and 'black swan' events cannot be predicted, addressing them during planning is important. In some cases, survival of the organization can depend on doing so, and at other times they can reveal hidden opportunities.

 # 5 Where can we incorporate flexibility in port infrastructure?

The strategy of flexibility for dealing with unanticipated developments is a fundamental concept in APP. Therefore, we carried out a survey at the Port of Rotterdam to gain the perspective of various stakeholders in the port (related) industry about flexibility. Since perceptions drive actions, insights into the viewpoints of stakeholders can be helpful in promoting flexibility. We followed this up with a brainstorm session about promising flexible solutions for infrastructures.

The view that flexibility in port infrastructure is an effective tool for dealing with future uncertainties was unanimous. Among the favoured strategies for flexibility in physical infrastructures were: design modularity, standardization, generic, and robust designs. Surprisingly, the issues related to implementation of flexibility, such as approaches to planning, design, and project appraisal as well as the institutional barriers, were a focus of attention throughout the session. Following the suggestions of the participants, we proposed modifications to the current design approaches. The four alternative approaches to (physical) infrastructure design are: design for fixed specifications and resort to ad-hoc adaptation, design for obsolescence and demolish, design for robustness through building-in margins, or design for flexibility. Though the first is commonly practised to produce a client specific design, the participants agreed that all approaches must be considered at the beginning of each project, followed by a trade-off of the conflicting system attributes.

The traditional project appraisal procedure does not include flexibility, and moreover, is based on evaluating individual business cases (as a result, the indirect benefits are ignored during evaluation). This was thought to be the main reason why flexible design alternatives are not chosen over solutions requiring smaller initial investments. The evaluation should include (the costs and value of) flexibility, and consider a portfolio of related projects.

Flexibility facilitates reuse, concurrently optimizes use of natural resources, limits waste and pollution in the environment, can result in significantly lower lifecycle costs (despite the costs associated with incorporation of flexibility and subsequent adaptations), and conserves energy resources. Our investigation into flexible infrastructures at PoR, or of reuse of infrastructure in general, revealed that the instances are few and far between. The practices related to reuse have been limited to down-cycling materials into low-grade applications. Flexibility and sustainability considerations, which include designing for deconstruction and reuse, must be incorporated into all designs. Therefore, we presented a framework that guides adaptation and reuse.

Though many innovative logistic and infrastructural concepts have been proposed in recent times, despite intensive engineering effort and investment in pilot projects or feasibility studies, none have been implemented. We found it relevant to analyze the factors underlying failed and successful innovative endeavours through tracing some innovations at PoR. This corroborated that innovation is shaped by the interplay of need, economic, and institutional factors. An important lesson is that the strategies for flexibility cannot be considered in isolation from the efforts made at the institutional level to incorporate and implement flexibility.

 # 6 How can we value flexibility and adaptability in a project appraisal?

APP recognizes that under uncertainty, the value of a project (or a design alternative) is driven by the flexibility it provides to adapt its function and use. The valuation of this flexibility is mostly beyond the reach of traditional tools of financial analysis. Nevertheless, before flexible solutions can be implemented, the management and the stakeholders need to be convinced of their superiority, and their financial viability. Therefore, we investigated several valuation methods in order to select one that was appropriate for valuing flexibility 'in' projects. The method was required to meet certain criteria – it must be able to deal with the multiple (market and non market) uncertainties and flexibilities as they appear in port systems; it must be amenable to the characteristics of port projects and applicable for the port market being considered; the results must have transparency and the communicative power to convince the management of the superiority of flexible solutions. We should be able to employ the intricate knowledge of the port system and its processes acquired during planning and design, while setting up the evaluation model.

We found that the tools of traditional economic analysis – such as (stochastic) discounted cash flow and decision tree analysis – are adequate to achieve a useful and consistent comparison of alternatives. While simulation is suitable for continous risks, a decision analysis is recommended in case of clear investment alternatives and contingent decisions. Simulation can be applied using a simple spreadsheet model, which can incorporate uncertainties and flexibilities. Such an analysis requires practitioners to make explicit the uncertainty inherent in all estimates going into the analysis, which is already a significant advantage of the method over the traditional NPV methods. It results in a range and distribution of the possible outcomes, together with the likelihood of their occurrence. It enhances decisionmaking on marginal projects by providing additional information on risk.

A real options analysis (ROA) based on financial option theory was found unsuitable for our purposes. Many of the assumptions implicit in the method are not valid for port projects and markets (though further research in this rapidly growing field may find methods to relax these assumptions). Its inherent complexity, limited applicability, and non-transparency further limit the use of ROA. Real options thinking, however, compels decisionmakers to take into account a lifecycle perspective and consider flexibility that will decrease economic exposure to risk. In acknowledgement of its tremendous value, we proposed a qualitative framework to be used in combination with a traditional quantitative method. Its use will show management the added potential of a project due to the flexibility it incorporates; this will become easier as such thinking becomes ingrained in standard practices.

We made suggestions about the applicability of the selected evaluation methods to some real-life cases in PoR. We also presented two case studies that examined the value of flexibility in port infrastructure. The first case illustrates how standardization and modularity can prolong the economic lifetime of mooring dolphins and result in lower lifecycle costs. The second case dealt with uncertainty over the size of vessels to be handled at a quay wall. We estimated, using stochastic methods, the break-even point, i.e. the time after which the cost of acquiring flexibility (extra investment in a deeper quay wall for future larger ships) is exceeded by its value (extra revenues generated if bigger ships do appear on the scene). Such an analysis provides a decisionmaker with new insights on which to base his investment decision.

 # 7 How can we monitor uncertainties in order to take timely action?

Building a competitive advantage in a volatile environment in which the markets are uncertain, rate of technological change is rapid, and the competition intense, requires continuous vigilance and monitoring of the internal as well as external environment. APP too relies on monitoring of the environment. Monitoring aims at evaluation of events or developments as they occur or just after, and involves activities like measuring, analysing, assessing, and forecasting. Specifying appropriate triggers to warn when external developments require changes to the system is far from easy. We demonstrated, using the simplest class of forecasting techniques employing statistical methods, that it is possible to monitor developments that represent major vulnerabilities for port projects so that timely actions can be initiated.

Change in container markets can be monitored using economic indicators, such as GDP. Environmental scanning, media monitoring, and expert opinion can help to track changes in policies or get advance warning of changes to come. Technological forecasting is still far more an art than a science. Through identifying physical limitations in a current technology (or precursors technologies), and monitoring developments that can either remove or circumvent these limitations, we can get sufficient warning of a possible breakthrough, which can form a vulnerability for the port. We cite the cases of recently announced triple E class of ships (2010) and the Fastnet concept of APMT (2011). Our analysis showed that these breakthrough developments were not ‘bolts from the blue’, but could have been anticipated. We have presented a simple framework for monitoring breakthrough technology and illustrated this through two examples.

A port should use systematic procedures for scanning the environment to be sure that they do not overlook variables that have large impacts on their markets and operations. However, monitoring is only useful if we can respond by either limiting the excessive detrimental impact of a development or reducing its probability through taking timely measures. Hence, APP requires the organization to be proactive in developing strategies to hedge against future uncertainties.

 # 8 How can we stimulate the adoption and successful implementation of the proposed planning method?

Having shown the advantages of APP over traditional methods, we needed to find ways to integrate it into the practices of the organizations involved in port planning and design, and ensure its successful implementation. However we may expect many barriers, such as the conservative port industry, the nature of port mega projects constrained by legal procedures that limit flexibility, the traditional role assigned to an engineer (doing the planning), and the organizational culture that leaves little room for new techniques. The fact that most steps in APP are at odds with traditional methods is likely to create initial resistance with the practitioner. That flexibility costs extra, while there is no guarantee that it will be utilized in the future, makes it difficult to justify its incorporation using tradition evaluation tools. Also, APP relies on innovative flexible solutions and strategies that have a low priority with most firms, especially in times of crisis.

Unanticipated events such as the credit crisis, SARS, hurricanes, and volcanic eruptions, with their global impacts has made us question our way of living. The depleting resources and the threats of climate change impacts are leading to an awareness that we must use our resources in a sustainable manner. All this has instigated a change in the mind-set of individuals and organizations, which might make them open to new approaches and methods. Successful implementation will require a greater role for a strategic planner. Providing him with necessary tools and skills to work closely with specialists in the field of finance, economics, and diverse engineering disciplines and communicate with the decisionmaker effectively, is essential. Greater involvement will motivate him to take upon himself tasks of incorporating uncertainty considerations into design guidelines, pursue innovation, and justify his choice of an innovative solution (above the traditional solution) to the decisionmaker.

Since sustainability is becoming a high profile objective, also in relation to infrastructure projects, the contribution of flexibility to sustainability must be made explicit and its value monetized if possible. In that way, we can include flexibility in the project appraisal and during procurement. The large scale of infrastructure projects and the need for institutional change concomitant with technological innovation or sustainability initiatives, require support from the government, which has the capital base and the authority to adapt regulations. A port authority can play a role in setting up collaborations, stimulating initiatives, and creating a knowledge base, all due to its unique position in the network. Nowadays, many of the risks are passed by a landlord port authority to its terminal operators through use of innovative contract-forms. Because of the ongoing vertical consolidation in the industry, many of these are now multinational enterprises, which have the resources, leverage and the motivation to contribute to innovative initiatives.

11.4 Case studies and lessons learned

The process of research required us to investigate the existing and emerging trends in the port industry, as well as the urgent issues related to the industry and the solutions proposed for them thus far. This was not only helpful in identifying suitable cases to illustrate APP, but the added knowledge has proved invaluable in identifying solutions for the problems in the case studies.

The illustrative cases to demonstrate the application of the proposed method, and the tools and techniques it employs, were selected because they either deal with significant issues in the port sector (e.g. energy transition, spatial planning under uncertainty), or important flexibility related features (e.g. flexible infrastructures, flexible logistic concepts, phasing or flexibility in decisionmaking). The cases also serve to highlight problems planners face during planning and design. Though not always directly relevant to our research questions, we include here some of the important conclusions from the cases.

Case 1: Planning the Europort area for 2045

The first case dealt with long-term planning for a site at PoR that is likely to become vacant due to future developments related to energy transition. Scenarios were employed to include a wide range of futures (and the threats and opportunities they hold), and to identify functions that would be robust in all of them. These were LNG and containers, though in the future a bio-refinery cluster may also become cost-effective. The exercise in scenario development also established that we need a coordinated effort involving governments, international organisations, port authorities, and markets, to design and implement policy frameworks and strategies that will effectively support the transition to alternative-fuel sources. The additional insights into the plausible futures can help us avoid pitfalls, and steer us towards a (desirable) sustainable future. Ports too, need to join in the sustainability movement to avoid losing their 'social' license to operate.

The case study brought attention to the fact that developments related to future energy prices and policies will affect many industries and may even influence the overall global trade patterns. This emphasizes the importance of monitoring our environment and already preparing suitable responses. Ports would do better to invest in flexible, adaptable infrastructure that can accommodate the unanticipated future changes instead of investing in fixed (over)capacity – hence the urgent need for research and innovation into flexible solutions.

Case 2: Planning for a quay wall construction project

This case dealt with planning of a quay wall construction project in the framework of APP. A civil engineering project and its environment are subject to changes, not only during the design and construction phase, but also in the exploitation phase. The common practice of carrying out risk analysis is limited to the planning and realization phases, and even then, identifying and dealing with the top 10 risks following from a risk analysis suffers from drawbacks. APP, however, combines risk analysis and strategic planning into a single activity over the entire planning horizon. (Therefore, monitoring the berth occupancy is included during planning, so that capacity expansion plans can be triggered at the right time to avoid the negative impacts of congestion.) Further, it includes and deals with the scope changes in a project (generally driven by exogenous changes, and not included in risk management as common practice). 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 at any given time is available. Reassessment and proactive stopping of the project are also a part of the planning cycle.

Case 3: Spatial planning for a strategic port area

This case involves the long-term spatial planning for a port area that is valuable due to its strategic location, its nautical infrastructure, and synergistic opportunities with the companies located there. The planning requires development and evaluation of alternatives as to a profitable future use of the area, and is carried out in the framework of APP.

An economic evaluation of the alternatives was carried out by setting up stochastic business cases that included multiple uncertainties (related to future costs, revenues, and timing of investments). The resulting distribution of NPV provides an estimate of the risk in the alternative. Also, PoR has chosen to build in flexibility through investing in deep sea quay walls (instead of cheaper quays for inland shipping). This represents a valuable flexible option in case a high container growth scenario materializes and the port reaches its capacity. The stochastic model made it possible to test the robustness of various alternatives under different scenarios with little extra computational effort. The added insights contribute towards responsible decisionmaking as to future use of the area, but also results in more accurate estimates for overall investment plans of the port authority.

Case 4: Flexible infrastructure for the temporary inner lake at MV2

This case study deals with utilization of the Inner Lake at MV2, which has a temporary existence in between the two phases of the project, for carrying out a commercial activity employing flexible infrastructural facilities. After an inventory of plausible port and non port-related activities, a few were selected based on their commercial potential. Suitable infrastructures were designed for these activities, and locations were based on logistic and other requirements. A stochastic business case that included the lifecycle costs and revenues was set up to evaluate the alternatives under different scenarios. LNG transshipment and a Common Barge terminal (CBT) turned out to be the most profitable activities under the given assumptions. A detailed business case of the CBT established that a CBT employing the innovative design concept Containerland would be financially viable for all parties, provided the indirect benefits of the concept were included in the business case of PoRA. The case study illustrated the following aspects, which have been raised in earlier chapters:

– the application of design approaches proposed in the thesis, i.e. design under assumed certainty, design for demolition or minimum design, and design for reuse;
– the application of an innovative design concept, i.e., Containerland;
– the application of flexible logistic concepts, such as ship to ship transfer, and a Common Barge terminal (CBT). A common facility such as a CBT provides flexibility to phase investments in container terminal expansions, resulting in monetary advantages and allowing time for uncertainty to clear up;

- the use of scenarios for a lifecycle analysis;
- during appraisal, returns should not be evaluated for an individual project but include related projects in a portfolio. In this way, the indirect benefits of a solution (i.e. benefits for a related project), will be included in the project appraisal. This will help promote an innovative concept above traditional solution.

11.5 Evaluation of the proposed method

11.5.1 Characteristics

We find it useful to summarize here the characteristics of APP as well as the tools and techniques it embraces, as demonstrated in this dissertation. APP:

- considers a range of plausible futures;
- calls for multi-stakeholder deliberation at the beginning of a project for collective reflection, learning, and holistic decisionmaking;
- takes into account the full range of uncertainties, including those external to the system, those with respect to the system model, and those associated with stakeholder valuation of outcomes;
- includes pro-active actions for responding to expected and unexpected changes (before and during the project);
- systematically guides the planner or decisionmaker to look for flexibility;
- distinguishes among different types of actions, creating a systematic typology for the planner;
- includes monitoring the external environment for new developments as well as the impact of actions taken to reduce the uncertainties (likelihood of occurrence or impacts);
- includes a method for valuing flexibility, so that the cost-effectiveness of a flexible option can be demonstrated;
- reduces surprises with respect to time and budget;
- helps to increase the speed of decisionmaking, thus working as an enabler of flexibility;
- demonstrates the cost-benefit of the risk management effort;
- forces decisionmakers to be more explicit about the assumptions underlying their plans;
- provides a way to handle complexity;
- guides the planner as to the timing of actions;
- provides structure in the preparation, implementation, and exploitation phases of a project;
- routinely examines assumptions on the basis of new knowledge from the strategic environment;
- is a systematic approach, and
- is a continuous and dynamic management tool.

11.5.2 Applicability

Infrastructures have a common purpose of serving society, and also exhibit similar characteristics, in that they are large scale, have long lifetimes, and are capital intensive with long payback periods. Infrastructures, however, differ as to ownership and governance, the services they provide, and the type of value they create. The ability to create direct economic value (unlike public infrastructures) is a special characteristic of ports. The uncertainties confronting infrastructural projects are often similar – either related to demand or new technology, though the rate of these developments may differ for different sectors.

The adaptive planning approach is relevant for all infrastructures, even though its application may vary. The planning may have different objectives and sub-objectives, and may be driven by another definition of success[1]. The selected tools and techniques within the framework of APP will depend upon the objectives, the planning horizon, the available data, the stakeholders and actors. The actions and strategies for making the plans and designs robust and also the provisions of flexibility will be sector-specific. As to the evaluation, a government funded project might employ a cost-benefit tool for evaluation; a project involving an innovative design may need a model based on physical performance of the system, and yet another may require a qualitative multi-criteria analysis. The utility functions, and value parameters are likely to be firm-specific or even project-specific. The trade-offs between conflicting design specifications, or conflicting requirements during implementation will also be led by very different motives and criteria.

Nonetheless, we hope the illustration of the proposed approach for the port sector, will make a case for its applicability and effectiveness for many other areas of infrastructure planning.

11.6 Future research

A reflection on the unresolved issues during this research leads to recommendations for further research.

We are well aware that during infrastructure planning we are dealing mostly with anticipated risk, and our plan can still encounter surprises or black swans. This is why we advocate the strategies of robustness and flexibility, which will help to adapt to changed circumstances. We therefore recommend that further research into flexibility, at all levels of the port infrastructure system (physical, operational, and products and services) continue. A practitioner can then have a variety of solutions at his disposal while planning under uncertainty. Research and innovation must also focus on new flexible infrastructural solutions at macro-level, in view of the new uncertainties such as climate change, sea level rise, and a large scale cyber-terrorist attack. Flexibility in operations, and in fact flexibility in the global supply chain, is a subject of avid

[1] As per thinking behind APP, the overall objective in each case is the same: to devise a system that performs reasonably well across a variety of plausible futures instead of optimally in one future.

research as the waterside and land-side dynamics change and the burden of cost in the value chain shifts to land side. This research too must continue.

Our focus has been on planning under uncertainty. However, the contracting and procurement procedures in a project also require careful attention. The project owner, i.e. the client, must formulate his requirements in a manner that results in flexible solutions. During tender evaluation, the specified evaluation criteria should also lead to the selection of flexible alternatives. Research is required to investigate how flexibility requirements can be incorporated in the design specifications as well as in various forms of contracts. One way could be to explore plausible methods in consultation with the clients and subsequently test their effectiveness in pilot projects. In the Netherlands, the Port of Rotterdam and the Ministry of Infrastructure and Environment have already shown active interest in such an endeavour.

Sound decisionmaking during planning requires a rational procedure for quantifying the direct and indirect impacts of port development projects and including them in a project appraisal. In spite of ongoing efforts, such procedures are not currently available in a port planner's tool-kit. Research into this important aspect must go on. We also recommend that ongoing developments in real options analysis methods and tools be closely followed. Tools that can more accurately estimate an investment opportunity (especially of innovative character), preferably with little additional effort and cost, can be very helpful in decisionmaking.

We have described a number of simple tools and techniques that can be applied during various steps of APP. Many sophisticated tools for modelling complex engineering systems, screening tools for exploring flexible strategies in these systems, and quantitative tools for assessing the value of flexibility, are under development. Their application to different infrastructure domains should be investigated.

We have suggested that the successful implementation of APP will require a greater role for a strategic planner who can understand the tasks and communicate with an engineer, economist, manager, and a policymaker; is able to integrate the knowledge of multiple engineering disciplines in a social, environmental, economic and legal context; and innovates to keep pace with the new challenges in a rapidly transforming global economy. How to equip him with necessary knowledge base and competencies to assume such a central role, is a thought provoking question. Research into this aspect may reveal that engineering education today needs to add elements to its curriculum.

We have suggested that establishing the relationship of flexibility in infrastructures to sustainability will help to promote flexibility. Furthermore, the significance of innovation in a volatile world characterized by disruptive technology should be brought home to individuals and organizations. How to bring these matters to realization needs to be researched.

11.7 In conclusion

This dissertation is about planning under uncertainty. Uncertainty is here to stay; we must recognize it, prepare for it, adapt to it, manage it, profit from it. We must replace our traditional approach with an adaptive approach to planning to create Master Plans and infrastructure designs that can stand the test of time. We must build in flexibility so that later generations can adapt them to their own needs.

Adaptive Port Planning, as recommended in this dissertation, is so designed that a port planner following this approach in a systematic manner does not accept anything on the premise of uncertainty. Instead, he questions assumptions, does thorough research, uses expert opinion to reduce uncertainty, regularly scans his environment to anticipate developments and their impact on his plans, expands his solution space and innovates instead of adopting traditional solutions. He makes visible the value of flexibility for the decisionmakers, thereby convincing them to opt for flexibility in times of uncertainty.

Planning infrastructures for an uncertain future requires contribution from many. A task is set out for policymakers to stimulate formulation of norms and guidelines that embrace uncertainty considerations and lead to flexible infrastructure designs and solutions. The task set out for a port authority is to initiate collaborative efforts for innovation. Both the terminal operators and the port authorities need to be pioneers (risk-takers) in implementing new solutions if we are to successfully confront the challenge of uncertainty. The government is expected to play the role of a facilitator, at least up to the time that the market acquires a new mind set and becomes pro-active in innovation.

List of Publications P. Taneja

Aartsen, M. E. (2006). *Raamwerk rendementseis investeringsprojecten HbR (in Dutch) [Framework for Investment returns on PoR projects]*. Port of Rotterdam.

Abt, C. (1970). *Serious Games*. New York: The Viking Press.

Agerschou (1983). *Planning and design of ports and marine terminals*. UK: Telford.

Agusdinata, B. (2008). *Exploratory modeling and analysis: A promising method to deal with deep uncertainty*. PhD thesis, Faculty of Teachnology, Policy, and Management, Delft University of Technology, The Netherlands.

Ahmed, P., Hardaker, G., and Carpenter, M. (1996). Integrated flexibility - Key to competition in a turbulent environment. *Long Range Planning*, 29(4):562–571.

Albrechts, L. (2004). Strategic (spatial) planning re-examined. *Environment and Planning B: Planning and Design*, 31(5):743–758.

Alderton, P. M. (2004). *Reeds Sea Transport: Operation & Economics*. London: Thomas Reed Publications.

Alessandri, T., Ford, D. N., Lander, D. M., Leggiod, K., and Taylore, M. (2004). Managing risk and uncertainty in complex capital projects. *The Quarterly Review of Economics and Finance*, 44:751–767.

Ali, A. (2005). *Floating Transshipment Container Terminal*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Aligica, P. D. (2005). Scenarios and the growth of knowledge: Notes on the epistemic element in scenario building. *Technological Forecasting and Social Change*, 72(7):815–824.

Almodovar, L. and Chang, W. (2010). Economic Impacts of US Corps of Engineers Navigation Infrastructure. In *Annual Conference of the International Association of Maritime Economists, 7-9 July 2010, Lisbon, Portugal*.

Alterman, R. (2000). Adaptive planning. *Cognitive Science*, 12(3):393–421.

Amram, M. (2002). *Value Sweep: Mapping Corporate Growth Opportunities*. Boston, Massachusetts: Harvard Business School Press.

Amram, M. and Kulatilaka, N. (1999). Disciplined decisions: aligning strategy with the financial markets. *Harvard Business Review, January 1999*, pages 1–10.

Anderson, C., Opaluch, J., and Grigalunas, T. A. (2009). The demand for import services at US container ports. *Maritime Economics and Logistics*, 11(2):156–185.

Annema, J., Koopmans, C., and Van Wee, B. (2007). Evaluating Transport Infrastructure Investments: The Dutch Experience with a Standardized Approach. *Transport Reviews*, 27(2):125–150.

APAA (1988). *Strategic Planning: A guide for the port industry*. American Association of Port Authorities.

Armstrong, J. and Green, K. (2010). *Strategic Marketing Management: A Business Process Approach*. UK: Cengage Learning.

ASME (2004). *Performance Based Codes and Standards - ASME*. Available at: http://cstools.asme.org/csconnect/pdf/CommitteeFiles/13525.pdf. Accessed 1 March 2011.

Aven, T. (2008). *Assessing Uncertainties beyond Expected Values and Probabilities*. West Sussex, England: Wiley.

Axson, D. (2009). *Succeeding in a volatile world: How the best managers and organizations are adapting to the new economic realities, Innovation in Action Series*. Available at: http://www-935.ibm.com/services/no/cfo/pdf/succeed_in_volatile_world.pdf. Accessed 1 May 2012.

Baird, A. (2000). *Privatisation and deregulation of transport*, chapter Privatisation and deregulation in seaports, pages 397–412. London: MacMillan Press.

Baird, A. (2002). Privatization trends at the worlds top-100 container ports. *Maritime Policy and Management*, 29(3):271–284.

Baldwin, C. Y. and Clark, K. B. (2003). *Modularity in the Design of Complex Engineering Systems, Working Paper*. Available at: www.people.hbs.edu/cbaldwin/DR2/BaldwinClarkCES.pdf. Accessed 1 April 2011.

Bartolomei, J. (2007). *Qualitative Knowledge Construction for Engineering Systems: Extending the Design Structure Matrix Methodology in Scope and Perspective*. PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Bekebrede, G. (2010). *Experiencing Complexity: A gaming approach for understanding infrastructure systems*. PhD thesis, Faculty of Technology, Policy and Management, Delft University of Technology, The Netherlands.

Bekebrede, G. and Mayer, I. (2006). Build your seaport in a game and learn about complex systems. *Journal of Design Research*, 5(2):273–298.

Bellis, A. (1990). A new approach to port engineering. in *Ports into the next century Hull*, c.r. ford (ed.). gb: Thomas telford limited.

Ben-Haim, Y. (2001). *Information-Gap Decision Theory: Decisions Under Severe Uncertainty*. UK: Academic Press.

Bendall, H. and Stent, A. F. (2003). Investment strategies in market uncertainty. *Maritime Policy & Management*, 30(4):545–561.

Bettis, R. and Hitt, M. (1995). The new competitive landscape. *Strategic Management Journal*, 16(7):7–19.

Bijloo, E., Breukink, J., Donker, J., and Paquel, C. (2010). *Design of a floating structure for container terminal activities. Student group work report.* Delft University of Technology, The Netherlands.

Bisson, P., Stephenson, E., and Viguerie, S. P. (2010). *Global forces: An introduction, The McKinsey Quarterly*, June 2010. Avaialable at: https://www.mckinseyquarterly.com/Global_forces_An_introduction_2625. Accessed 11 January 2012.

Black, F. and Scholes, M. T. (1973). The pricing of options and corporate liabilities. *Journal of Political Economy*, 81(3):637–654.

Blanchard, B. and Fabrycky, W. J. (2011). *System engineering and analysis*. NJ, USA: Prentice Hall.

Blank, S. and Brooks, M. R. a. (2006). *Moving forward on the Atlantic Gateway: Context and Key Questions*. Available at: http://citt.management.dal.ca/Files/Gateway/Working_Papers/Blank_3.pdf. Accessed 1 February 2012.

Bonini, S. (2011). *The business of sustainability: McKinsey Global Survey results*. Available at: https://www.mckinseyquarterly.com/PDFDownload.aspx?ar=2867&srid=17. Accessed 18 October 2011.

Bonney, J. (2010). *Carriers Move Full Speed into Slow Steaming*. Available at: http://www.joc.com/maritime/carriers-move-full-speed-slow-steaming. Accessed 1 Febrauary 2011.

Bonte, P. (2007). *Structural design of a sandwich wall as the quay wall for the future*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Borison, A. (2005a). A Response to Real Options: Meeting the Georgetown Challenge. *Journal of Applied Corporate Finance*, 17(2):52–54.

Borison, A. (2005b). Real options analysis: where are the Emperor's clothes? *Journal of Applied Corporate Finance*, 17(2):17–31.

Boskalis and van Hattum and Blankvoort (2001). *Caisson quay wall, Brittainiehaven*. Technical report, Boskalis, Papendrecht and van Hattum and Blankvoort, Woerden, The Netherlands.

Box, G. and Tiao, G. (1975). Intervention analysis with applications to economic and environmental problems. *Journal of the American Statistical Association*, 70(349):70–79.

Bradley, A., Duan, H., Elion, W., van Soest-Vercammen, E., and Nagelvoort, R. K. (2009). Innovation in the LNG industry: Shell's approach. Available at: http://www.igu.org/html/wgc2009/papers/docs/wgcFinal00535.pdf. Accessed 1 February 2011.

Brealey, R. and Myers, S. (2003). *Principles of Corporate Finance*. NY: McGraw Hill.

Briscoe, G. and Hirst, G. (1973). An appreciation of alternative sales forecasting models: Recent techniques based on historical data. *Long range planning*, 6:79–89.

Broesterhuizen, E. (2012). *Sustainability as procurement critera for port projects*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Brolsma, J. U. (2006). *Havens, kranen, dokken en veren. De Gemeentelijke Handelsinrichtingen en het Havenbedrijf der gemeente Rotterdam, 1882-2004*. Utrecht: Stichting Matrijs.

Bruun, P. (1989). *Port engineering Vol. 1. Harbor planning, breakwaters, and marine terminals*. Houston: Gulf Publishing.

BS 6349 (2007). *Maritime structures: Code of Practice*. British Standards Institution.

Buganza, T. and Verganti, R. (2006). Life-cycle flexibility: How to measure and improve the innovative capability in turbulent environments. *Journal of Product Innovation Management*, 23(5):393–407.

Burghouwt, G. (2007). *Airline Network Development in Europe and Its Implications for Airport Planning*. Burlington, USA: Ashgate Publishing Company.

Byl, R. (2002). Strategic planning using scenarios. In *Annual Conference of the International Association of Maritime Economists, 13-15 November, 2002, Panama City, Panama*.

Cann, R. A. (2010). Planning navigation infrastructure for an uncertain future. In *PIANC MMX Congress , Liverpool 2010*, Liverpool.

Cardin, M. A. (2007). *Facing Reality: Design and Management of Flexible Engineering Systems*. Master's thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Cardin, M. A. and de Neufville, R. (2008). *A Survey of State-of-the-Art Methodologies and a Framework for Identifying and Valuing Flexible Design Opportunities in Engineering Systems*. Available at: http://ardent.mit.edu/real_options/Real_opts_papers/WP-CardindeNeufville2008.pdf. Accessed 1 January 2011.

Cardin, M. A. and de Neufville, R. (2009). Direct interaction approach to identify real options in large-scale infrastructure systems. In *Real Options Conference 2009, Massachussets Institute of Technology, Cambridge, MA*.

Cardin, M. A., de Neufville, R., and Kazakidis, V. (2008). *A Process to Improve Expected Value in Mining Operations*. Available at: http://ardent.mit.edu/real_options/Real_opts_papers/Cardin_deNeufvillle_Kazakidis_MT2008_v1.pdf. Accessed 1 April 2011.

Cardin, M. A., Nuttall, W., de Neufville, R., and Dahlgren, J. (2007). Extracting value from uncertainty: A methodology for engineering systems design. Available at: http://ardent.mit.edu/real_options/Real_opts_papers/Cardin%20CSER.pdf. Acessed 1 April 2012.

Carlsson, B. and Jacobsson, S. (1997). *Technological Systems and Industrial Dynamics*, chapter In search of useful public policies: key lessons and issues for policy makers. Dordrecht: Kluwer Academic Publishers.

Chapman, C. and Ward, S. (1997). *Project risk management, processes, techniques and insights*. West Sussex, UK: Wiley.

Charoenpornpattana, S., Minato, T., and Nakahama, S. (2004). *Government Supports as bundle of Real Options in Built-Operate-Transfer Highways Projects*. Available at: http://www.realoptions.org/papers2003/CharoenMinatoNakahama.pdf. Accessed 1 April 2011.

Chase, R. B., Jacobs, F. R., and Aquilano, N. J. (2006). *Operations Management for Competitive Advantage*. New York: McGraw-Hill/Irwin.

Chatfield, C. (2001). *Time-Series Forecasting*. Florida: Chapman and Hall/ CRC Press.

Cheah, C. Y. and Liu, J. (2006). Valuing governmental support in infrstructure projects as real optionsusing Monte Carlo simulation. *Construction Maangement and Economics*, 24(5):545–554.

Chen, S., Cahoon, S., and Haugstetter, H. (2010). A regional ports role in innovation: The regional development platform method. In *Annual Conference of the International Association of Maritime Economists, 7-9 July 2010, Lisbon, Portugal*.

Cheung, J. (1993). Managerial flexibility in capital investment decisions: Insight from the real-options literature. *Journal of Accounting Literature*, 12:29–66.

Childre, D. and Cryer, B. (2000). *From Chaos to Coherence: The Power to Change Performance*. UK: HeartMath.

Clements, M. and Hendry, D. (2000). *Forecasting Economic Time Series*. UK: Cambridge University Press.

Co, H. C. (2010). *Technology forecasting*. Available at: www.csupomona.edu/~hco/MoT/03aTechnologyForecast.ppt. Accessed 17 January 2011.

Coates, J. S. (2000). Scenario planning. *Technological Forecasting and Social Change*, 65:115–123.

Coates, J. S. (2002). Innovation in the future of engineering design. *Technological Forecasting and Social Change*, 64:121–132.

Coates, V., Coates, J., Jarratt, J., and Heinz, L. (1985). *Issues identification and management: The state of the art and methods and techniques. Research Project 2345-28*. Palo Alto, California: Electric Power Research Institute.

Cobb, B. R. and Charnes, J. M. (2007). Real options valuation. In *Proceedings of the 2007 Winter Simulation Conference, Washington D.C.*

Collingridge, D. and James, P. (1991). Inflexible energy policies in a rapidly-changing market. *Long Range Planning*, 24(2):101–107.

Conquip, B. (2010). *Ship to shore twin-lift spreaders*. Available at: http://www.bromma.com/show.php?id=1016100. Accessed August 31 2011.

Copeland, T. and Antikarov, V. (2001). *Real Options: A practitionerś guide*. New York : Texere Publishing Limited.

Cornelius, P., Van De Putte, A., and Romani, M. (2005). Three Decades of Scenario Planning in Shell. *California Management Review*, Nov 01, 2005:19.

Cowan, R. and van de Paal, G. (2000). *Innovation Policy in a Knowledge-Based Economy* June 2000, Publication no. EUR 17023. Technical report, Commission of the European Communities, Luxembourg.

Cox, J., Ross, S., and Rubinstein, M. (1979). Option pricing: A simplified approach. *Journal of Financial Economics*, 7(3):229–263.

CPB (2003). *Twee jaar ervaring met OEEI: De discussie over indirecte effecten (in Dutch). [Two years experience with OEEI: The debate on wider economic Impacts]*. CPB and Ministerie van Verkeer en Waterstaat and Zaken, Ministerie van Economische Zaken.

CPB/NEI (2000). *Evaluatie van Infrastructuurprojecten; leidraad voor kostenbatenanlyse*. Netherlands Bureau for Economic Policy Analysis/ Netherlands Economic Institute.

Creswell, J. W. (2003). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Thousand Oaks, CA: Sage.

CROW (2002). *Wat kost dat? Standaardsystematiek voor kostenramingen in de GWW, Publicatie 137 (in Dutch) [Standard system for cost estimates]*. Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek (CROW).

CROW (2011). *RISicoMANagement voor projecten (in Dutch) [Risk management for projects]*. Available at: http://www.risman.nl. Accessed 1 June 2011.

Cullinane, K. and Panayides, P. (2000). The Use Of Capital Budgeting Techniques Among UK-Based Ship Operators. *International Journal of Maritime Economics, October 2000*, 2:313–330.

CUR (2005a). *Handbook Quay Walls.* CUR 211.

CUR (2005b). *Handbook Sheetpile Structures.* CUR 166.

Cutcher-Gershenfield, J. F., Field, F., Hall, R., Kirchain, R., Marks, D., Oye, K., and Sussman, J. (2004). Sustainability as an organizing design principle for large-scale engineering systems. Available at: http://esd.mit.edu/symposium/monograph. Accessed 1 April 2008.

Dagnet, F. (2010). The cube: A comprehensive tool for port management. In *Annual Conference of the International Association of Maritime Economists, 7-9 July 2010, Lisbon, Portugal.*

Dale, A. and Hamilton, J. (2007). *Unsustainable Infrastructure: Implications for Canadas Future*. Available at: www.crcresearch.org/files-crcresearch_v2/File/SI_Final_Report.psf. Accessed 29 March 2012.

Damodaran, A. (2000). The promise of real option. *Journal of Applied Corporate Finance*, 13(2):29–44.

Damodaran, A. (2002). *Investment Valuation: Tools & Techniques for Determining Any Asset.* New York: John Wiley and Sons.

Damodaran, A. (2011). *Probabilistic approaches: Scenario analysis, decision trees and simulations*. Available at: www.stern.nyu.edu/~adamodar/pdfiles/papers/probabilistic.pdf. Accessed 1 April 2011.

de Gijt, J. G. and van der Toorn, A. (2007). Future trends in quay wall design. In *MTEC 2007, Singapore.*

de Langen, P. (2004a). Governance in seaport clusters. *Maritime Economics & Logistics*, 6(2):141–156.

de Langen, P., van Meijeren, J., and Tavasszy, L. A. (2012). Combining models and commodity chain research for making long-term projections of port throughput: an application to the hamburg- le havre range. *EJTIR*, 12(3):310–331.

de Langen, P. W. (2004b). Governance in seaport clusters. *Maritime Economics and Logistics*, 6:141–156.

De Monie, G. (2004). Mission and role of port authorities after privatisation. In *ITMMA PPP Seminar, Antwerpen.*

De Monie, G. and Peeters, C. (2006). Ports are more than piers - Liber Amicorum presented to Prof. Dr. Willy Winkelmans. pages 237–260.

de Neufville, R. (1990). *Applied Systems Analysis: Engineering planning and technology management.* New York, USA: McGraw-Hill, Inc.

de Neufville, R. (2000). Dynamic strategic planning for technology policy. *International Journal of Technology Management*, 19(3-5):225–245.

de Neufville, R. (2003a). *Lecture Notes: Engineering Systems Analysis for Design, Massachusetts Institute of Technology, Cambridge, MA*. Available at: http://ardent.mit.edu/real_options/ROcse_MIT_latest/coursemat.html. Accessed 1 April 2012.

de Neufville, R. (2003b). Real options: Dealing with uncertainty in systems planning and design. *Integrated Assessment*, 4(1):26–34.

de Neufville, R. (2004). *Uncertainty management for engineering systems planning and design*. Available at: http://esd.mit.edu/symposium/pdfs/monograph/uncertainty.pdf. Accessed 30 January 2012.

de Neufville, R. (2010). *Options concept* Presentation. Avaialable at: http://ardent.mit.edu/real_options/Common_course_materials/papers.html. Accessed 23 May 2012.

de Neufville, R., Hodota, K., Sussman, J., and Scholtes, S. (2007). Real options to increase the value of intelligent transportation systems. *Transportation Research Record: Journal of the Transportation Research Board*, Issue 2086:40–47.

de Neufville, R., Scholtes, D., and Wang, T. (2006a). Valuing Options by Spreadsheet: Parking Garage Case Example. *ASCE Journal of Infrastructure Systems*, 12(2):107–111.

de Neufville, R. and Scholtes, S. (2011). *Flexibility in design*. Boston, MA: The MIT press, MA.

de Neufville, R., Scholtes, S., ASCE, L. M., Scholtes, S., and Wang, T. (2006b). Real Options by Spreadsheet: Parking Garage Case Example. *American Soceity of Civil Engineers, Journal of Infrastructure Systems*, 12(3):107–111.

de Ridder, H. (2012). *Enkele opmerkingen over Toekomstvast ontwerpen (in Dutch) [A few remarks over future-proof designs]*, Presentation, Toekomstvaste Infrastructuur Workshop, 25 September 2012, Movares.

de Rooij, G. (2006). *A Very Large Floating Container Terminal*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

de Weck, O. and Eckert, C. (2007). A classification of uncertainty for early product and system design. In *International Conference of Engineering Design ICED 2007*. 28 - 31 August, Paris.

de Weck, O., Roos, D., and Magee, C. L. (2011). *Engineering Systems: Meeting Human Needs in a Complex Technological World*. Cambridge, MA: The MIT Press.

de Weck, O. L., Ross, A. M., and Rhodes, D. H. (2012). Investigating relationships and semantic sets among lifecycle properties (ilities). In *Third International Engineering Systems Symposium, CESUN 2012, Delft University of Technology, 18-20 June 2012*.

Dekker, S., Verhaege, R. J., and Pols, A. A. J. (2003). Economic impacts and public financing of port capacity investments: the case of Rotterdam port expansion. In *Transport Research Board Annual Meeting*.

Dempsey, S., Goetz, A., and Szyliowicz, J. (1997). *Denver International Airport: Lessons Learned*. New York: McGraw-Hill.

Dewar, J. A. (2002). *Assumption-Based Planning: A tool for Reducing Avoidable Surprises*. Cambridge, UK: Cambridge University Press.

Dewar, J. A., Builder, H. C., Hix, W. M., and Levin, M. (1993). *Assumption-Based Planning: A Planning Tool for Very Uncertain Times*. Report MR-114-A, RAND, Santa Monica.

Dewey, J. (1927). *The Public and Its Problems*. New York: Holt and Company.

Dijkema, G., Biesheuvel, S., IJsselstijn, S., Nikolic, I., Baggen, J., Stoop, J., and van de Riet, O. (2007). *Combinatie van Infrastructuren: Systematische verkenning van (on)mogelijkheden van ruimtesparende infrastructuur voor het Rotterdams haven industriegebied (in Dutch) [Combination of infrastructures]*. Port Research Centre.

Dijkema, S. and Willemse, O. (2008). *Ondergrondse opslag van delfstoffen (in Dutch) [Underground storage of minerals]*. Master's thesis, Hogeschool Zeeland, The Netherlands.

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

Dixit, A. and Pindyck, R. (1995). The options approach to capital investment. *Harvard Business Review*, 73(3):105–115.

DNB (2011). *Monetair beleid(in Dutch) [Monetary Policy]*. Available at: http://www.dnb.nl/rente-en-inflatie/monetair-beleid/index.jsp. Accessed 1 April 2012.

Dommershuizen, H. J., Ligteringen, H., van Schuylenburg, M., and Willekes, M. J. (2000). *Multifunctionele kademuur (in Dutch) [Multi-functional Quay wall]*. Technical report, Port Research Centre, Delft - Rotterdam.

Don, F. J. H. (2001). Forecasting in macroeconomics: A practitioner's view. *De Economist*, 149(2):155–175.

Dongen, A. (2003). *Adaptive Planning for Maasvlakte 2 (in Dutch) [Adaptive Planning for Maasvlakte 2]*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Dooms, M., Macharis, C., and Verbeke, A. (2004). *Proactive stakeholder management in port planning process: Empirical evidence fom the Port of Brussels*. Available at: http://www.ersa.org/ersaconfs/ersa04/PDF/271.pdf. Not found.

Dooms, M. and Verbeke, A. (2007). Stakeholder management in ports: a conceptual framework integrating insights from research in strategy, corporate social responsibility and port management. In *IAME 2007 Annual Conference 2007, Athens.*

Dowd, T. J. (1992). Considering Strategic Planning for Your Port? Port Management Series. Technical report, Washington Sea Grant; Maritime Advisory Services; Seattle WA 98105; January.

Dreyer, B. and Gronhaug, K. (2004). Uncertainty, flexibility, and sustained competitive advantage. *Journal of Business Research*, 57:484–494.

Duderstadt, J. J. (2008). *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education, The Millennium Project*, The University of Michigan. Available at: http://milproj.ummu.umich.edu/publications/engflex%20report/download/engflex%20report.pdf. Accessed 1 Juli 2012.

Dundon, E. (2002). *The seeds of innovation: cultivating the synergy that fosters new ideas*. New York: AMACOM.

EAU (2004). Recommendations of the Committee for Waterfront Structures - Harbours and Waterways.

ECT (2008). *Euromax Terminal, Fast Forward*, Summer 2008, Issue 42. Available at: http://www.ect.nl/public/static/newsdelta/FastForward_files/FastForwardsummer07.pdf. Accessed 1 June 2011.

Edquist, C. (1997). *Systems of Innovation, Technologies, Institutions, and Organisations*. Londone: Pinter.

EEA (2011). *About scenarios and forward studies*. Available at: http://www.eea.europa.eu/themes/scenarios/about-scenarios-and-forward-studies. Accessed 1 January 2011.

Egyedi, T. (2002). *Standards enhance system flexibility*. Available at: http://www.tudelft.nl/live/binaries/0b330c26-def4-45e3-a367-43b61bf0ae45/doc/mapping.pdf. Accessed 1 November, 2012.

Eijgenraam, C., Koopmans, C., Tang, P., and Verster, A. (2000). *Evaluatie van infrastructuurprojecten, leidraad voor kosten-batenanalyse (in Dutch) [Evaluation of infrastructure projects, guidelines for cost-benefit analysis]*. Netherlands Bureau for Economic Policy Analysis/ Netherlands Economic Institute.

Eschenbach, E., Lewis, N., Henrie, M., Baker, E., and Hartman, J. (2007). Real options and real engineering projects. *Engineering Management Journal*, 19(4):11–18.

Eshagh, E. (2012). *System Engineering Review Cliffnotes*. Available at: http://www.mind2b.com/component/content/article/9-info/5-system-engineer-review. Accessed 1 March, 2012.

Exalto, R. (2002). *Containerland: (in Dutch) [Containerland: De ontwikkeling van een business model (in Dutch)]*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology and HBG Civiel, The Netherlands.

Faludi, A. and Hamnett, S. (1977). Flexibility in Dutch Local Planning, Working Paper No. 28. *Oxford Polytechnic: Oxford, UK*, pages 1–7.

FAMAS.MV2 (2000). Towards a new generation of automated terminals on Maasvlakte 2. Technical report, FAMAS. 23-6-2000.

Fecken, F. A. (2001). *Universele verplaatsbaar kademuur (in Dutch) [Universal relocatable quay wall]*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Floricel, S. and Miller, R. (2001). Strategizing for anticipated risks and turbulence in large-scale engineering projects. *International Journal of Project Management*, 19:445–455.

Flyvbjerg, B., Bruzelius, N., and Rothengatter, W. (2003). *Megaprojects and Risk: An Anatomy of Ambition*. Cambridge, UK: Cambridge University Press.

Foster, R. N. (1986). *Innovation: The Attacker's Advantage*. New York: Summit Books.

Frankel, E. (1987). *Port Planning and Development*. New York: Wiley-Interscience.

Frankel, E. G. (1989). Strategic planning applied to shipping and ports. *Maritime Policy & Management*, 16(2):123 –132.

Gaur, P. (2005). *Port Planning as a Strategic Tool*. Master's thesis, Institute of Transport and Maritime Management, University of Antwerp, Belgium.

Gerrits, W. A. (2007). *Dynamic port planning under competetition*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Geweke, J. and Whitman, C. (2006). *The Handbook of Economic Forecasting, Volume 1*, chapter Bayesian Forecasting, page 78. Elsevier B.V.

GHR (1998). *2020: Integrale verkenning voor haven en industrie (in Dutch) [2020: Integral exploration for port and industry]*. Gemeentelijk Havenbedrijf.

Giglio, F. (2002). *Controlling environmental impacts in the dismantling phase*. Available at: http://www.irbnet.de/daten/iconda/CIB942.pdf. Accessed 1 July 2012.

Global Business Network (2011). *Plan tomorrows scenario's*. Available at: http://www.gbn.com/news/pdfs/Scenario%20Planning_ISM%20Feb2011.pdf. Accessed 01 January 2012.

Global Harbours (2008). *The Renewal of Old Ports Around the World, Global Harbors: A Waterfront Renaissance, Documentary*. Available at: http://www.globalharbors.org/. Accessed 1 April 2012.

Goodwin, P. and Wright, G. (2010). Technological Forecasting and Social Change. *Technological Forecasting & Social Change*, 77:355–368.

Goss, R. (2002). An early history of maritime economics. *International Journal of Maritime Economics*, 4:390–404.

Grant-Muller, S. (2001). Economic appraisal of european transport projects: the state-of-the-art revisited. *Transport Reviews*, 21:237–261.

Greden, L. (2005). *Flexibility in building design: A real options approach and methodology to address risk*. PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Gregory, R., Failing, L., and Higgins, P. (2006). Adaptive management and environmental decision making: A case study application to water use planning. *Ecological Economics*, 58(2):434–447.

Groenveld, R. (2004). Manual model Harboursim: A tool to estimate port capacities. Technical report, Delft Institute of Technology.

Grubler, A. and Nakicenovic, N. (2001). Identifying dangers in an uncertain climate. *Nature 412*, 6842:15–15.

Guthrie, G. (2009). *Real options in theory and practice*. New York: Oxford University Press.

Hall, P. (1980). *Great Planning Disasters, London, Weidenfeld, 1980*. London: Weidenfeld.

Hall, P. (2009). Container ports, local benefits and transportation worker earnings. *GeoJournal 74*, 74:67–83.

Hammond, K. R. (1996). *Human Judgment and Social Policy*. New York: Oxford University Press.

Hansman, R., Magee, J., de Neufville, R., Robins, R., and Roos, D. (2005). Research agenda for an integrated approach to infrastructure planning, design, and management. *International Journal of critical infrastructures*, 2 (2/3):146–159.

Haralambides, H. (2002). Competition excess capacity and pricing of port infrastructure. *International Journal for Maritime Economics*, 4:323–347.

Hastings, D. and McManus, H. (2004). *A Framework for Understanding Uncertainty and its Mitigation and Exploitation in Complex Systems*. Available at: http://esd.mit.edu/symposium/pdfs/papers/hastings.pdf. Accessed 1 April 2012.

Haugstetter, H. and Cahoon, S. (2010). Strategic intent: Guiding port authorities to their new world? *Research in Transportation Economics*, 27:30–36.

Hayashi, Y. and Morisugi, H. (2000). International comparison of background concept and methodology of transportation project appraisal. *Transport Policy*, 7:73–88.

HbR (2010a). *100e mega-containerschip in Rotterdam (in Dutch) [100th mega container vessel in Rotterdam], 26 august 2010*. Avaialble at: http://www.portofrotterdam.com/en/Business/containers/Pages/MegacontainershipsinRotterdam.aspx. Accessed 30 December 2010.

HbR (2010b). *Ramingsnauwkeurigheid vs investeringsbeslissing (in Dutch) [Estimation accuracy versus investment decision]*. Havenbedrijf Rotterdam NV.

Heaver, T., Meersman, H., and Van de Voorde, E. (2001). Co-operation and competition in international container transport: strategies for ports. *Maritime Policy and Management*, 28(3):293–305.

Heijden, M., Moerland, V., and Elbers, T. (2008). *Modulaire Kadebouw (in Dutch) [Modular Quay Construction]*. Master's thesis, Hogeschool Rotterdam, The Netherlands.

Hendriks, C. F. (2000). Quality in the production chain [Kwaliteit in de keten (in Dutch]. In *Nationaal congres Bouw- en Sloopafval, Nederlands Studiecentrum, Rotterdam, The Netherlands*. Nederlands Studiecentrum, Rotterdam, The Netherlands.

Herder, P., Dijkema, G., Stikkelman, R., and Weijnen, M. P. C. (2008). Designing infrastructures using a complex systems perspective. *Journal of Design Research*, 7(1):17–34.

Herder, P. M., de Joode, J., Ligtvoet, A., Schenk, S., and Taneja, P. (2011). Buying real options valuing uncertainty in infrastructure planning. *Futures*, 43(9):961–969.

Hertz, D. B. (1964). Risk analysis in capital investment. *Harvard Business Review*, Sep 01, 1964:95–106.

Heukelom, S. (2001). *Report Workshop 'Verdiepen bestaande kade' (in Dutch) [Deepening existing quay wall], 31 mei 2001*. Port of Rotterdam and Delft University of Technology, The Netherlands. Internal Report.

Hillier, F. and Lieberman, G. (2001). *Introduction to Operations Research*. New York: McGraw Hill.

Hinds, A. A. (2008). *Doing Well by Doing Good: Ports and the Sustainability Challenge, AAPA Port Finance Seminar, June 10-12, 2008*. Available at: http://aapa.files.cms-plus.com/SeminarPresentations/08FINANCE_Hinds_Aston.pdf. Accessed 1 March 2012.

Holling, C. (1978). *Adaptive environmental assessment and management*. London: John Wiley & Sons.

Hui, E. C. M., Seabrooke, W., and Wong, G. K. C. (2004). Forecasting cargo throughput for the port of Hong Kong: Error correction model approach. *Journal of Urban Planning*, 130(4):195–203.

Huisman, J. and de Waal, J. (1999). LNG terminals. In *Cursus Haven en Terminal Planning, 15 April 1999, Stichting Postacademisch Onderwijs*.

Huss, R. W. and Honton, J. E. (1987). Scenario Planning - What Style Should You use? *Long Range Planning*, 20(4):21–29.

HWWI and Berenberg Bank (2007). Strategy 2030: Maritime trade and Transport Logistics. Hamburg: Hamburgisches WeltWirtschafts Institut.

IAPH (2003). Biennial report on ship trends. Technical report, International Association of Ports and Harbours: Committee on ship trends.

IEA (2009). *IEA Bioenergy*, Task 42, Biorefinery. Available at: http://www.biorefinery.nl/fileadmin/biorefinery/docs/Brochure_Totaal_definitief_HR_opt.pdf. Accessed 1 January 2012.

IGWR (1978). *Havenverdieping kademuur EECV aan het Calandkanaal (in Dutch) [Deepening quay wall EECV]*. Technical report, Port of Rotterdam.

IGWR (2000). *Maxisteck: An innovative design for a quay wall in the Brittaniehaven*. Technical report, Port of Rotterdam.

IGWR (2001). *Verdieping Delt 1 en Delta 2 (in Dutch) [Deepening Delta 1 and 2, Europahaven]*. Technical report, Port of Rotterdam.

IGWR (2008). *Ontwerp Bestemmingsplan Maasvlakte 2 (in Dutch) [Zoning plan Maasvlakte 2]*. Technical report, Port of Rotterdam.

INSCOPE (2009). Haven Innovatie Monitor, Ports of Rotterdam and Amsterdam. INSCOPE research for innovation, Erasmsus school of Management.

IPC (2005). Israel Strategic Ports Development Plan 2006-2055, Internal Report, Israel Ports Company. Technical report, Royal Haskoning.

Ircha, M. (2001). Serving tommorrow's mega-size containerships: the Canadian solution. *International Journal of Maritime Economics*, 3:318–332.

ITR (2009). *Multi-User Terminals: Concept Plan van Aanpak (in Dutch) [Multi-User Terminals: Concept Work plan]*, Innovatie Team Ruimte, Havenbedrijf Rotterdam.

Johansen, R. S. (2007). The impact of technology on terminal design. In *PORTS 2007: 30 Years of Sharing Ideas 1977-2007*. American Society of Civil Engineers, San Diego, CA.

Jones, J. R., Qu, L., Casavant, K. L., and Koo, W. W. (1995). A spatial equilibrium port cargo projection model. *Maritime Policy and Management*, 22(1):63–80.

Jordan, M. A. (2001). *Future proof your crane*. Available http://www.liftech.net/Publications/Cranes/Procurement%20and%20New%20Development/Future-Proof%20Your%20Crane.pdf. Accessed 1 March 2012.

Jordan, M. A. (2002). *Quay crane productivity*. Available at: http://www.liftech.net/Publications/Cranes/Procurement%20and%20New%20Development/Quay%20Crane%20Productivity%20Paper.pdf. Accessed 1 March 2012.

Kalligeros, K. (1998). Real options in engineering systems design. in *Real Options in Engineering Design, Operations, and Management*, h. m. nembhard (ed.). crc press.

Kalligeros, K. (2006). *Platforms and Real Options in Large-Scale Engineering Systems.* PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Kamperlaan, E. (2005). Showcase megaproject management: Maasvlakte 2. *Project Manager Magazine*, March 2005:12–17.

Kaplan, R. S. and Norton, D. P. (1992). The balanced scorecard: measures that drive performance. *Harvard Business Review*, Jan - Feb:71–80.

Kaplan, R. S. and Norton, D. P. (1993). Putting the balanced scorecard to work. *Harvard Business Review*, Sep - Oct:2–16.

Kennisinstituut voor Mobiliteitsbeleid (KIM) (1997). *Nut en noodzaak: het afwegen van kosten en baten: Notitie met voorlopige resultaten (in Dutch) [Usefullness and need: weighing costs and benefits]*. Available at: http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2010/. Accessed 1 April 2012.

Khan, M. A., Rashi, A., and Henesey, L. (2011). Simulating Automated Guided Vehicle Dispatching Strategies in the Transport of Containers. In *Proceedings of the International Maritime-Port Technology and Development Conference,13 - 15 April 2011, Singapore.*

Kikuchi, S. and Perincherry, V. (2008). *Handling Uncertainty in Large Scale Systems with Certainty and Integrity*. Available at: http://esd.mit.edu/symposium/pdfs/papers/kikuchi.pdf. Accessed 31 January 2012.

Kim, H., Chang, Y., Lee, P. T. W., Shin, S., and Kim, M. (2008). Optimizing the transportation of international container cargoes in Korea. *Maritime Policy and Management*, 35(1):103–122.

Kin, W. C. and Mauborgne, R. (1997). Value innovation: The strategic logic of high growth. *Harvard Business Review*, January-February, 1997.

Kincaid, I., Tretheway, M., Gros, S., and Lewis, D. (2012). *Addressing Uncertainty about Future Airport Activity Levels in Airport Decision Making, ACRP Report 76.* Washington D.C.: TRB.

Kirzner, I. M. (1985). *Perception, Opportunity and Profit Studies in the Theory of Entrepreneurship.* Chicago: University of Chicago Press.

Klein, R. (2007). *Great Grandfathers Schlieffen Plan*. Available http://www.ndu.edu/inss/Press/jfq_pages/i45.htm.Accessedon19July2009. Accessed 1 March 2012.

Knight, F. (1921). *Risk, Uncertainty and Profit.* Boston, MA: Hart, Schaffner & Marx; Houghton Mifflin Company.

Kodukula, P. and Papudesu, C. (2006). *Project Valuation Using Real Options: A Practitioners Guide*. Florida: J. Ross Publishing, Fort Lauderdale: US.

Koksalan, M., Wallenius, J., and Zionts, S. (2011). *Multiple Criteria Decision Making: From Early History to the 21st Century*. Singapore: World Scientific.

Koontz, H. and O' Donnell, C. (1972). *Principles of Management: An Analysis of Managerial Functions*. New York: McGraw-Hill.

Koopman, C. and van Beek, F. (2007). *Toekomstvaste infrastructuur of flexibele opties? Omgaan met scenarios in het investeringsbeleid (in Dutch) [Future proof infrastructure or flexible options? Dealing with scenarios in investment policies]*. ed. Kennisinstituut Mobiliteits Management.

Koorengevel, R., de Vos, J., and Zoeteweij, R. (2010). *Demontabele LNG steiger (in Dutch) [Relocatable LNG steiger]*. Master's thesis, Hogeschool Rotterdam, The Netherlands.

Kroon, R., Hillebrand, J. F., and Vis, I. (2005). *Seriously Ceres?* Available at: http://dare.ubvu.vu.nl/bitstream/1871/10248/1/20050003.pdf. Accessed 31 January 2012.

Kuczmarski, T. D. (2003). What is innovation and why are companie not doing more of it? *Journal of consumer marketing*, 20(6):536–541.

Kuiper, J. C. and Vrijling, J. K. (2005). Nieuwe inzichten in het probabilistische ramen (in Dutch) [New insights in probabilistic cost calculations]. *Wegen*, 5 May.

Kwakkel, J. (2010). *The treatment of uncertainty in airport strategic planning*. PhD thesis, Faculty of Teachnology, Policy, and Management, Delft University of Technology, The Netherlands.

Kwakkel, J., Walker, W. E., and Marchau, V. (2010). Adaptive airport strategic planning. *European Journal of Transport and Infrastructure Research*, 10(3):249–273.

Labrut, M. (2009). Making history: Panama report. Technical report, Dredging and Port Construction Magazine, May 2009, pp.16-47.

Lansink, P. M. (1980). Verslag van parlementaire debatten 1979 -1980. Technical report, SDU, Den Haag.

Lei, D., Hitt, M. A., and Bettis, R. (1995). Dynamic core competences through meta-learning and strategic context. *Journal of Management*, 22(4):549–569.

Lempert, R. and Groves, D. J. (2010). Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American West. *Technological Forecasting & Social Change*, 77(6):960–974.

Lempert, R., Popper, S. W., and Bankes, S. C. (2003). *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Policy Analysis, MR-1626*. Santa Monica, CA: RAND.

Lempert, R. J., Popper, S. W., and Bankes, S. C. (2002). Confronting Surprise. *Social Science Computing Review*, 20(4):420–440.

Leslie, K. J. and Michaels, M. P. (1997). The real power of real options. *The McKinsey Quarterly*, 3:1–20.

Lessard, G. (1998). An adaptive approach to planning and decision-making. *Landscape and Urban Planning*, 40(1-3):81–87.

Leusink, A. and Zanting, H. (2009). *Naar een afwegingskader voor een klimaatbestendig Nederland, met ervaringen uit 4 case studies: Samenvatting voor bestuurders (in Dutch) [Towards a trade-off framework for climate proofing the Netherlands, with experiences from 4 case studies: Executive summary*. Available at: http://edepot.wur.nl/15219. Accessed 01 March 2012.

Levinson, M. (2006). *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger.* University Presses of California, Columbia and Princeton.

Ligteringen, H. (2010). *What's new? Farewell Address Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft.*

Ligteringen, H. and Velsink, H. (2012). *Ports and Terminals.* Delft, The Netherlands: VSSD.

Liu, Y. (2005). *Dealing with Uncertainties by Bouncecasting, Application in ISA Implementation.* Master's thesis, Faculty of Technology, Policy and Management, Delft University of Technology, The Netherlands.

Lloyds Register (2012). *Infosheet No. 30, Modern ship size definitions*. Avaialble at: http://www.lr.org/Images/30%20ship%20sizes_tcm155-173543.pdf. Accessed 30 August 2012.

Lorthiois, G. (2008). *Container shipping: impact of mega-containerships on ports in Europe and the Med*. Available at: http://www.mareforum.com/Marseille_Maritime_2008_papers/LORTHIOIS.pdf. Accessed 1 March 2012.

Luijten, C. J. L. M., Andriessen, C. J., de Gijt, J. G., Broos, E. J., Zwakhals, J. W., and van Ewijk, H. A. L. (2010). Preliminary results of a research into carbon footprint of port infrastructure, Port of Rotterdam. In *Port Infrastructure Seminar.* June 2010, Delft University of Technology.

Luo, M. and Grigalunas, T. A. (2003). A spatial economic multimodal transportation simulation model for us coastal container ports. *Maritime Economics and Logistics*, 5(2):158–178.

Lynn, L. and Salzman, H. (2006). Collaborative advantage. *Issues in Science and Technology*, Winter 2006:74–82.

Maas, G. (2011). *Comparison of quay wall designs in concrete, steel, wood and composites with regard to the CO2 emission and the life cycle analysis*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Maerskline (2011). *Berth productivity will have to keep up with shippings super-sized revolution, Port Technology International, Edition 50- Port Focus*. Available at: http://www.porttechnology.org/images/uploads/technical_papers/PT50-17.pdf. Accessed 24 January 2012.

Malchow, U. (2011). *Port Feeder Barge: Floating infrastructure for the intermodal connectivity of inland navigation in sea ports*. Available at: http://bluebox.bohmann.at/24/downloads/download_4624.pdf. Accessed 30 November 2012.

MAN Diesel A/S (2007). *Low container ship speed facilitated by Versatile ME/ME-C Engines*. Available at: http://www.mandieselturbo.com/files/news/filesof8410/5510-0038-04.pdf. Accessed 1 April 2012.

Marchau, V., Walker, W., and van Wee, G. (2010). Dynamic adaptive transport policies for handling deep uncertainty. *Technological Forecasting and Social Change*, 77:940–950.

Marien, M. (2002). Futures studies in the 21st century: a reality-based view. *Futures*, 34 (3/4):261–281.

Mauboussin, M. J. (2000). *Get Real, Using Real Options in Security Analysis*. Available http://www.capatcolumbia.com/Articles/FoFinance/Fof10.pdf. Accessed 30 March 2010.

Mauboussin, M. J. (2008). *More Than You Know : Finding Financial Wisdom in Unconventional Places*. New York: Columbia University Press.

Meersman, H., Van de Voorde, E., and Vanelslander, T. (2009). *Future Challenges for the Port and Shipping Sector*. UK: Informa Law.

Meredith, J. R. and Mantel, S. J. (1995). *Technological Forecasting*. NY: John Wiley & Sons, Inc.

Meristo, T. (1986). Not forecasts but miltiple scenarios when coping with uncertainties in the competetive environment. *European Journal of Operational Research*, 38:350–357.

Milis, K., Snoeck, M., and Haesen, R. (2009). *Evaluation of the applicability of investment appraisal techniques for assessing the business value of IS services*. Available: https://lirias.kuleuven.be/handle/123456789/247210. Accessed 1 April 2012.

Miller, R. and Lessard, D. (2001). *The strategic management of large engineering projects: shaping institutions, risks, and governance*. Cambridge, MA: The MIT Press.

Miser, H. J. and Quade, E. (1985). *Handbook of Systems Analysis: Overview of uses, procedures, applications, and practice*. NJ, USA: John Wiley and Sons.

Mittal, G. (2004). *Real Options Approach to Capacity Planning Under Uncertainty*. PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Moglia, F. and Sanguineri, M. (2003). Port planning: the need for a new approach? *Maritime Economics & Logistics*, 5:413–425.

Morgan, M. G. (2009). *Best Practice Approaches for Characterizing, Communicating and Incorporating Scientific Uncertainty in Climate Decision Making*. Available at: http://downloads.globalchange.gov/sap/sap5-2/sap5-2-final-report-all.pdf. Accessed 1 April 2012.

Moses, J. (2004). *Foundational issues in engineering systems: A framing paper*. Available at: http://esd.mit.edu/symposium/pdfs/monograph/framing.pdf. Accessed 1 April 2012.

MTG (2005). *Forecast of container vessel specifications and port calls within San Pedro Bay, Final Report, February 22, 2005. Mercator Transport Group*. Available at: http://www.portoflosangeles.org/DOC/REPORT_SPB_Vessel_Forecast.pdf. Accessed 1 April 2012.

Mulder, K. (2006). *Sustainable development for engineers: A handbook and resource guide*. Sheffield, UK: Greenleaf Publishing Ltd.

MultiCore (2012). *MultiCore pipeline bundle*. Available http://www.multicorerotterdam.com/en/bundle/Default.aspx. Accessed 23 February 2012.

Mun, J. (2002). *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions*. John Wiley & Sons: Hoboken, New Jersey.

Musso, E., Benacchio, M., and Ferrari, C. (2000). Ports and employment in port cities. *Maritime Economics and Logistics*, 2(4):283–312.

Myers, S. (1984). Finance theory and financial strategy. *Interfaces*, 14, Jan-Feb:126–137.

National Research Council (1987). *Infrastructure for the 21st Century*. Washington DC: National Academy Press.

Neely, J. and de Neufville, R. (2001). Hybrid real options valuation of risky product development projects. *International Journal of Technology, Policy and Management*, 1:29–46.

Nieuwsblad Transport (2005a). *Drijvende kraan heeft toekomst (in Dutch) [Floating crane has a future]*, 08 juni 2005. Available at: http://www.nieuwsbladtransport.nl/Archive/Article/tabid/409/ArchiveArticleID/95444/ArticleName/Drijvendekraanheefttoekomst/Default.aspx. Accessed 29 March 2012.

Nieuwsblad Transport (2005b). *Drijvende kraan stuit op logistiek bezwaar (in Dutch) [Floating crane encounters objection on logistic ground]*, 08 juni 2005. Available at: http://www.nieuwsbladtransport.nl/Archive/Article/tabid/409/ArchiveArticleID/95507/ArticleName/Drijvendekraanstuitoplogistiekbezwaar/Default.aspx. Accessed 29 March 2012.

Nijdam, M. (2011). Port economics. In *International Port Seminar, UNESCO-IHE, April-May-2011*.

Nilchiani, R. (2005). *Measuring Space Systems Flexibility: A Comprehensive Six-element Framework*. Phd, mit, Massachusetts Institute of Technology.

Notenboom, P. and Reijm, B. (2006). *Onderwater/ondergrondse opslag van LNG (in Dutch) [Underground storage of LNG]*. Master's thesis, Hogeschool Rotterdam, The Netherlands.

Notteboom, T. (2003). *Current issues in port logistics and intermodality*. Antwerp/Appeldoorn: Garant.

Notteboom, T. and Rodrigue, J. (2005). Port regionalization: Towards a new phase. *Maritime Policy and Management*, 32(3):297–313.

Notteboom, T. and Rodrigue, J. (2007). Strategic challenges to container ports in a changing market environment. pages 29–52.

Notteboom, T. and Rodrigue, J. (2008a). Containerisation, box logistics and global supply chains: The integration of ports and liner shipping networks. *Maritime Economics & Logistics*, 10:152–174.

Notteboom, T. and Rodrigue, J. (2008b). The future of containerization: Perspectives from maritime and inland freight distribution. *GeoJournal*, 74(1):1–9.

Nourse, K. (2009). *The Best of Times, the Worst of Times: Strategic thinking mind-sets and practices among seaport CEOs during the 2008-09 global economic crisis*. Available at: http://www.nourseleadership.com/Resources.html. Accessed 9 May 2012.

O3 (1999). Ondergrondse Olie Opslag (Underground storage of oil). Technical report, BAM Civiel B.V., Van Hattum and Blankevoort B.V., Haskoning Nederland B.V.

OCDI (2009). Technical Standards for port and harbour facilities in Japan. Japan Port and Harbour Association.

OECD (2010). *Transcontinental infrastructure needs to 2030 / 2050 North -West Europe gateway area - Port of Rotterdam case study*. Available at: http://www.oecd.org/dataoecd/12/54/48321781.pdf. Accessed 1 April 2011.

Olivier, D. and Slack, B. (2006). Rethinking the port. *Environment and Planning A*, 38(8):1409–1427.

Olsson, N. (2003). Flexibility in engineering projects: blessing or a curse? In *NORDNET 2004, International PM Conference, 29 September 1 October 2004, Helsinki, Finland.*

Olsson, N. O. E. (2006). Management of flexibility in projects. *International Journal of Project Management*, 24(1)(1):66–74.

Osborn, A. (1963). *Applied imagination: Principles and procedures of creative problem solving (3rd Ed.).* Amherst, MA: Creative Education Foundation, New York: Charles Scribners Sons.

Osborne, C. (2008). *Real Options Should Be a Part of Our Thinking*, Society of Petroleum Engineers 4(1). Avaialble at: http://www.spe.org/twa/print/archives/2008/2008v4n1/twa2008_v4n1_Economists_Corner.pdf. Accessed 1 April 2012.

Pahl-Wostl, C. (2005). Transition to adaptive water management: the new water project. Technical report, NeWater Working Paper 1, NeWater.

Paixäo, A. and Marlow, P. B. (2003). Fourth generation ports - a question of agility? *International Journal of Physical Distribution & Logistics Management*, 33(4):355–375.

Pals, H. and Ligteringen, H. (2005). Underground Tank Storage. In *International Conference on Port and Maritime Development and Innovation, Rotterdam.*

PAO (2005). Cursus Voorzien, onvoorzien of onzeker: Kostenramingen. In *Stichting PAO (Postdoctoral Onderwijs in Civiele Techniek).*

Parkins, J. (1996). *Management decisions for engineers.* London: Thomas Telford.

Paus, C. H. (2004). *De ontwikkeling van een drijvende kade voor het dubbelzijdig afhandelen van containerschepen (in Dutch) [The design of a floating terminal for double-side handling of container ships]*. Port Research Centre.

Penfold, A. (2005). *Changes in the Shipping Industry*, Ocean Shipping Consultant Ltd.

Peterson, G., Cumming, G., and Carpenter, S. (2003). Scenario planning: a tool for conservation in an uncertain world. *Conservation biology*, 17(2):358–366.

PIANC (2008). *Life cycle approach in Port Infrastructure: Recommended practice for implementation, Report no. 103*. Technical report, Brussels.

Pinder, D. and Slack, B. (2004). *Shipping and Ports in the Twenty First Century.* New York, London: Routledge.

PMR (2007). *Milieueffectrapport (Environmental Impact Assessment Report) MER A and B*. Technical report, Rotterdam Mainport Development Project.

PMR (2008). *Masterplan Maasvlakte 2, werkversie 8*. Technical report, Rotterdam Mainport Development Project, Port of Rotterdam.

PMR (2010). *Masterplan 6 Maasvlakte 2*. Technical report, Rotterdam Mainport Development Project.

Podevins, O. (2009). Container and terminal shipping industry from a banking perspective (20082015). In *Critical Issues in the Port and Maritime Sector, WCTRS, 7-8 May, Antwerp.*

Polo, M. (2009). *Marco Polo program: Modal shift actions*. Available at: http://ec.europa.eu/transport/marcopolo/in-action/modal-shift/index_en.htm. Accessed 1 April 2012.

Popper, S. (2009). *Natural Gas and Israel's Energy Future: Near-Term Decisions from a Strategic Perspective*. Available at: http://www.rand.org/pubs/monographs/2009/RAND_MG927.english.pdf. Accessed 1 March 2012.

PoRA (2000). *Negatief bouwen EMO kade (in Dutch) [Negative construction EMO quay wall]*. Port of Rotterdam.

PoRA (2002). *Evaluation Mini-Pilot Containerland*. Port of Rotterdam.

PoRA (2004). *Port Vision 2020*. Available at: http://www.havenplan2020.nl/html/uk/index.html. Accessed 1 April 2012.

PoRA (2006a). *Ligplaatsen Calandkanaal, Noordoever (in Dutch) [Mooring locations Caland Canal]*. Port of Rotterdam.

PoRA (2006b). *Multipurpose Kade Odfjell (in Dutch) [Multi-purpose quay wall Odjfell]*. Port of Rotterdam.

PoRA (2007). *Facts and figures on Rotterdams oil and chemical industry*, January 2007. Port of Rotterdam.

PoRA (2009). *Haven wil stoompijp voor CO2 reductie*. Available at: http://www.portofrotterdam.com/nl/actueel/pers-en-nieuwsberichten/Pages/20091120_11.aspx. Accessed 11 January 2010.

PoRA (2010a). *Business Plan 2011-2015*. Port of Rotterdam.

PoRA (2010b). *Facts and Figures Rotterdam Energy Port and Petrochemical Cluster 2010*. Port of Rotterdam.

PoRA (2010c). *General terms and conditions including port tariffs 2010*. Available at: http://www.portofrotterdam.com/nl/Scheepvaart/havengelden/Documents/general-terms-conditions-2010.pdf. Accessed 1 August 2010.

PoRA (2010d). *Havenvisie 2030: Potentieraming goederenstroom.* Port of Rotterdam.

PoRA (2010e). *PM@PoR Manual: A comprehensive overview of project management within the Port of Rotterdam Authority, Internal report.* Port of Rotterdam.

PoRA (2011a). *Center for European coal transhipment*. Available at: http://www.portofrotterdam.com/nl/Brochures/Coal-Eng.pdf. Accessed 1 January 2012.

PoRA (2011b). *Ontwikkelplan Maasvlakte (in Dutch) [Development plan Maasvlakte]*. Port of Rotterdam.

PoRA (2011c). *Port Compass 2030*. Available at: http://portcompass2030.com/. Accessed 17 Juli 2012.

PoRA (2012). *New contract for Container Transferium Alblasserdam*. Available at: http://www.alblasserdamsnieuws.nl/wordpress/tag/containertransferium/. Accessed 26 March 2012.

Port Authority of Orkney harbours (2011). *Ship-to-ship transfer*. Available at: http://www.orkneyharbours.com. Accessed 20 June, 2011.

Port of Portland Authority (2008). *Master plan Marine Terminals 2020*. Port of Portland Authority.

Porter, M. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance*. New York: The Free Press.

Probst, J. (2006). *Development of 13,400 TEU Post-Panamax container ships*. Available at: http://netforum.sname.org/eweb/. Accessed 1 March 2010.

Project Management Institute (2008). *A guide to project management body of knowledge (PMBOK Guide)*. Available at: http://www.unipi.gr/akad_tmhm/biom_dioik_tech/files/pmbok.pdf. Accessed 1 March 2010.

PSA (2009). *Maritime Port Authority of Singapore - Port Statistics*. Avaialble at: http://www.mpa.gov.sg/sites/global_navigation/publications/port_statistics/port_statistics.page. Accessed 30 January 2012.

Quade, E. S. (1982). *Analysis for public decisions*. NJ, USA: Prentice Hall.

Rahman, S., Malone, K., Van de Kerke, B., and Vader, J. (1999). *Onzekerheidsanalyse van de Ruimtevraag in de Haven van Rotterdam [Risk Analysis of the Demand for Space in the Port of Rotterdam]*, RE-99-014, RAND, Santa Monica, CA. Available at: http://www.rand.org/pubs/rand_europe/RE99-014.html. Accessed 1 April 2012.

Rahman, S., Walker, W., and Marchau, V. (2008). *Coping with Uncertainties About Climate Change Infrastructure Planning: An Adaptive Policy Making Approach*, Ecorys, Rotterdam. Available at: http://www.raadvenw.nl/extdomein/raadvenw/Images/Final%20Report%20V2_tcm107-257701.pdf. Accessed 1 April 2012.

Ramirez, N. (2002). *Valuing flexibility in infrastructure developments: The Bogota water supply expansion plan*. Msc., Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

RAND (1997a). *Adaptive Policies, Policy Analysis and Civil Aviation Policymaking*, DRU-1514-VW/VROM/EZ, Rand, Santa Monica, CA. Available at: http://www.rand.org/pubs/drafts/DRU1514.html. Accesssed 1 April 2012.

RAND (1997b). *Scenarios for examining Civil Aviation infrastructure options in the Nethrlands*, DRU-1513-VW/VROM/EZ, Rand, Santa Monica, CA. Available at: http://www.rand.org/pubs/drafts/DRU1513.html. Accessed 1 April 2012.

RAND Europe (1997). *Maasvlakte 2: Trendbreukanalyse (in Dutch) [Trend break analysis], RE-97.04-MV.* Rand Europe and Projectorganisatie Maasvlakte 2.

Rebel, W. (2009). *Multi-purpose kade Odfjell: Port of Rotterdam.* TSM Business School, The Netherlands.

Reiter, D. (2008). Upgrading of quay walls. In *The proceedings of International navigation seminar PIANC AGA 2008.*

Riley, T. (2010). Scenario-based strategic planning. U.S. Army Corps of Engineers.

RITA (2009). *Effects of Drop in Container Throughput, Research and Innovative Technology Administration, U.S. Department of Transportation*. Available at: http://www.bts.gov/publications/. Accessed 17 July 2012.

Ritchey, T. (1998). Fritz Zwicky, Morphologie and Policy Analysis. In *16th EURO Conference on Operational Analysis, Brussels, 1998.*

Robinson, J. (1982). Energy backcasting - a proposed method of policy analysis. *Energy policy*, 12:337–344.

Robinson, R. (2002). Ports as elements in value-driven chain systems: The new paradigm. *Maritime Policy and Management*, 29(3):241–255.

Rodger, C. and Petch, J. (1999). *Uncertainty & Risk Analysis, A practical guide from Business Dynamics*. PricewaterhouseCoopers, MCS.

Rodrigue, J., Slack, B., and T., N. (2009). *Port Terminals*. Available at: http://people.hofstra.edu/geotrans/. Accessed 1 March 2012.

Roos, D., de Neufville, R., Moavenzadeh, F., and Connors, S. (2004). The Design and Development of Next Generation Infrastructure Systems. In *Systems, Man and Cybernetics, 2004 IEEE International Conference, 10-13 October.*

Ros, R. (2011). *Flexible Infrastructures for Maasvlakte 2*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Ross, A. M. (2006). *Managing Unarticulated Value: Changability in Multi-Attribute Tradespace Exploration.* PhD thesis, Massachusetts Institute of Technology, Engineering Systems Division, Cambridge, MA.

RVW (2009). Witte Zwanen, Zwarte Zwanen (in Dutch) [White Swans, Black Swans]. Technical report, Raad voor Verkeer en Waterstaat.

Rynikiewicz, C. (2011). European port cities as gateways to a green economy? *Network Industries Quarterly*, 13(4):23–25.

Ryuji, K. and Prianka, N. S. (2000). Investment Risk Analysis in Port Infrastructure Appraisal. *Journal of Infrastructure Systems*, 6(4):123–129.

Sachdeva, P. S. (1984). Development planning - An adaptive approach. *Long Range Planning*, 17(5):96–102.

Sakamris, M. and Flyvbjerg, B. (1997). Inaccuracy of traffic forecasts and cost estimates on large transport projects. *Transport policy*, 4:141–146.

Saleh, J. H. (2002). *Weaving Time into System Architecture: New Perspectives on Flexibility, Spacecraft Design Lifetime, and On-orbit Servicing*. PhD thesis, Aeronautics and Astronautics, MIT, June 2002.

Saleh, J. H., Hastings, D. E., and Newman, D. J. (2003). Flexibility in system design and implications for aerospace systems. *Acta Astronautica*, 53:927–944.

Sanne, Y. (2004). *An approach for designing robotized marine container terminals*. PhD thesis, Delft University of Technology.

Saundry, R. and Turnbull, T. (1997). Private Profit, Public Loss: the Financial and Economic Performance of UK Ports. *Maritime Policy and Management*, 24(4):319–334.

Savvides, S. C. (1994). Risk analysis in investment appraisal. *Project Appraisal*, 9:3–18.

Schoemaker, P. J. H. (1995). Scenario planning: A tool for strategic thinking. *Sloan Management Review/ Winter 1995*.

Scholtes, S. (2007). Flexibility: The secret to transforming risk into opportunities. *Business Digest, May 2007*, 174:6–7.

Schuler, M. (2009). *22,000 TEU Container Ship Fact or Fiction?* Available http://gcaptain.com/22000-teu-container-ship-fact-or-fiction/. Accessed 1 April 2012.

Schutte, P. (2008). *Scenario thinking: accelerating strategic learning*. Available at: http://www.schuette.nl/publications/strategicthinking1.pdf. Accessed 1 April 2012.

Schwartz, P. (1991). *The art of long view: Planning for a future in the uncertain world*. New York: Currency and Doubleday.

Selkou, E. and Roe, M. (2004). *Globalization, Policy and Shipping*. Transport Economics, Management and Policy. UK: Edward Elgar publishing.

Shah, N., J., W., Viscito, L., A.M., R., and Hastings, D. (2008). *Quantifying Flexibility for Architecting Changeable Systems*. Available at http://seari.mit.edu/documents/preprints/SHAH_CSER08.pdf. Accessed 1 August 2012.

Sijtsma, F. J. (2006). *Project evaluation, sustainability and accountability: combining cost-benefit analysis (CBA) and multi-criteria analysis (MCA)*. PhD thesis, Rijksuniversiteit Groningen, The Netherlands.

Simon, H. A. (1996). *The Sciences of the Artificial.* (p. 64-65). Cambridge, MA: The MIT Press.

Sletmo, K. G. (1999). Port life cycles: policy and strategy in the global economy. *International Journal of Maritime Economics*, 1:11–37.

Smil, V. T. (2008). *Global catastrophes and trends, The next 50 years.* Cambridge, MA: The MIT Press.

Smit, H. T. J. and Trigeorgis, L. (2007). Strategic options and games in analysing dynamic technology investments. *Long Range Planning*, 40(1):84–114.

Smith, J. E. and Nau, R. F. (1995). Valuing risky projects: Options pricing theory and decision analysis. *Management Science*, 41(5):795–816.

Smith, K. (2000). Innovation as a systemic phenomenon: Rethinking the role of policy. *Enterprise and Innovation Management Studies*, 1(1):73 –102.

Smith, W. J. (2007). *Mapping the Development of UK Biorefinery Complexes, NNFCC, 2007-06-20*. Available at: http://www.nnfcc.co.uk/tools/mapping-the-development-of-uk-biorefinery-complexes-nnfcc-07-008. Accessed 1 April 2012.

Spijkstra, N. (2006). *Drijvende kadeconstructie (in Dutch) [Floating quay]*. Master's thesis, Hogeschool Rotterdam, The Netherlands.

Stern, C. W. and Stalk, G. (1998). *Perspectives on Strategy from The Boston Consulting Group.* NJ, USA: John Wiley and Sons.

Strangert, P. (1977). Adaptive planning and uncertainty resolution. *Futures*, 9(1):32–44.

Strong, B. (2007). Strategic planning for technological change. *Educause Quarterly*, 3:48–51.

Suh, E. S. (2005). *Flexible product platforms.* PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Suykens, F. (1979). De haven als schakel in het wereldvervoerspatroon. In *Cursus: Havens; Economisch en Bedrijfskundige Aspecten, Stichting PAO, 1979-1980.*

Swanson, D., Barg, S., Tyler, S., Venema, H., Tomar, S., Bhadwal, S., Nair, S., Roy, D., and Drexhage, J. (2010). Seven tools for creating adaptive policies. *Technological Forecasting and Social Change*, 77(6):924–939.

Takamura, O. (1990). Construction of Port of Osaka and civil engineers. *Permanent International association of Navigational Congress (PIANC) - AIPCN - Bulletin*, 69:148–152.

Taleb, N. N. (2007). *The Black Swan: The Impact of the Highly Improbable.* London, UK: Random House.

Taneja, P., Aartsen, M., Annema, J. A., and Ligteringen, H. (2010a). Investment Appraisal for Sustainable Ports. In *Proceedings of 3e international conference on Next Generation Infrastructure Systems for Eco-cities, 11-13 November 2010*, Shenzhen, China.

Taneja, P., Ligteringen, H., and van Schuylenburg, M. (2010b). Dealing with uncertainty in design of port infrastructure systems. *Journal of Design Research*, 8(2):101–118.

Taneja, P., Ligteringen, H., and Walker, W. E. (2012a). Flexibility in port planning and design. *European Journal of Transport and Infrastructure Research*, 12(1):66–87.

Taneja, P., Ros, R., Vellinga, T., and van Schuylenburg, M. (2012b). Flexibility in port infrastructures. *Terra Et Aqua, June 2012*, 127:12–19.

Taneja, P., van Schuylenburg, M., and Ligteringen, H. (2011a). Monitoring for sustainable ports. In *Proceedings of the International Maritime-Port Technology and Development Conference,13 - 15 April 2011, Singapore.*

Taneja, P., van Schuylenburg, M., and Vellinga, T. (2012c). Ports and innovation. In *Key developments in the Port and Maritime Sector, WCTRS - Special Interest Group 2, 21- 22 May 2012.*

Taneja, P., van Turnhout, B. E., and Aartsen, M. E. (2012d). Infrastructure planning under uncertainty. *Internation Journal of Critical Infrastructures*, 8(2/3):134–146.

Taneja, P., Walker, W., Ligteringen, H., Van Schuylenburg, M., and Van Der Plas, R. (2010c). Implications of an uncertain future for port planning. *Maritime Policy and Management*, 37(3):221–245.

Taneja, P., Walker, W. E., Ligteringen, H., and van Schuylenburg, M. (2011b). Adaptive Port Planning using Real Options. *International Journal of Engineering Management and Economics*, 2(4):313–334.

Tavasszy, L., Minderhoud, M., Perrin, J. F., and Notteboom, T. (2011). A strategic network choice model for global container flows: specification, estimation and application. *Journal of Transport Geography*, 19:1163–1172.

te Lindert, M. (2009). *Dertig bereikbaarheidsmaatregelen voor Rotterdam (in Dutch) [Thirty accessibility measures for Rotterdam].* Available at: http://www.logistiek.nl/distributie/multimodaal-transport/nid8397-dertig-bereikbaarheidsmaatregelen-voor-rotterdam.html. Accessed 1 April 2012.

Thomas, C. and Maurice, S. (2005). *Managerial Economics, Concepts and Applications.* Tata Mcgraw-Hill, New York.

Thoresen, C. A. (2004). *Port Designer's Handbook.* UK: Telford.

Tidd, J., Bessant, J., and Pavitt, K. (2005). *Integrating Technological, Market and Organizational Change.* John Wiley & Sons Ltd, Chichester, England.

Tobin, A. J. (1975). Ports of America and Canada 1971/1972. *Rotterdam Europoort Delta, Tijdschrift, Gemeentelijk Havenbedrijf Rotterdam*, pages 24–35.

Toffler, A. (1970). *Future Shock*. Random house publishing group.

Tol, R. (2008). *Economic Crisis*. Springer Berlin Heidelberg.

Toor, S. and Ogunlana, S. (2009). Beyond the iron triangle: Stakeholder perception of key performance indicators (KPIs) for large-scale public sector development projects. *International Journal of Project Management*, 28:228–236.

Transumo (2009). *Transumo: Themes*. Available at: http://www.transumo.nl/En/Organisation.aspx. Accessed March 21 2012.

Trigeorgis, L. (1996). *Real Options*. Cambridge, MA: The MIT Press, Cambridge, MA.

Tsinker, G. P. (2004). *Port Engineering: Planning, Construction, Maintenance, and Security*. NJ, USA: John Wiley and Sons.

UNCTAD (1985). *Port Financing*. Available at: http://r0.unctad.org/ttl/docs-un/td-b-c4-291/en/TD_B_C4_291e.pdf. Accessed 1 December 2012.

UNCTAD (1992). *Port Marketing and the Challenge of the Third Generation Port*. Available at: http://r0.unctad.org/ttl/docs-un/td-b-c4-ac7-14/en/TD%20B%20C4%20AC7%2014e.pdf. Accessed 1 April 2012.

UNCTAD (1993). *Strategic planning for Port Authorities*. Available at: http://r0.unctad.org/ttl/docs-un/unctad-ship-646/en/g9352871.pdf. Accessed 1 April 2012.

UNCTAD (2005). Regional shipping and port development strategies, container traffic forecasts. Technical report, United Nations Conference on Trade and Development, Geneva.

UNESCAP (2012). *Maritime Policy Planning Model (MPPM)*. Available at: http://www.unescap.org/ttdw/common/TIS/MPPM/Maritimepolicyplanningmodel.asp. Accessed 1 April 2012.

van Binsbergen, A. (2004). *The changing world of container logistics*, chapter Container science and fiction, pages 83–104. Delft University Press.

van Breugel, M. P. (2003). *Kademuur van de Toekomst, Met Lego kun je alles maken (in Dutch) [Quay wall of the future, With Lefo uou can make everything]*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

van de Riet, O. (2008). Scenario analysis and the adaptive approach: superfluous or underused in transport infrastructure planning? In *Conference on Building Networks for a Brighter Future, 1012 November 2008, Rotterdam, The Netherlands, 2008.*

Van de Voorde, E. and Winkelmans, W. (2002). *Port competitiveness: an economic and legal analysis of the factors determining the competitiveness of seaports*, chapter A general introduction to port competition and management. De Boeck Ltd, Antwerp.

van den Dobbelsteen, A. and Alberts, K. (2001). Milieueffecten van bouwmaterialen - duurzaam omgaan met grondstoffen. Technical report, Delft University of Technology.

van der Heijden, K. (1996). *Scenarios: the Art of Strategic Conversation*. Chichester: Wiley & Sons.

van der Steen, M. (1997). *Rotterdam sluit de ogen voor nadelen tweede Maasvlakte*, 31 januari 1997. Available at: http://www.trouw.nl/tr/nl/15/archief/integration/nmc/frameset/archive/archiveDay.dhtml?archiveDay=19970131. Accessed 1 April 2012.

van der Waarde, R. and Jaquet, E. (2009). *Risicomanagement (in Dutch)] [Risk Management]*. Port of Rotterdam.

van der Wel, M. (2010). *The use of a floating quay for container terminals*, Internship Report at Public Works Department, Rotterdam.

van Diepen, A. (2012). *Effects of global long term scenarios on container throughput in the Port of Rotterdam*. Master's thesis, Delft University of Technology, Faculty of Civil Engineering and Geosciences, The Netherlands.

van Diepen, A., Carlier, K., and Tavasszy, L. (2012). Predicting the effect of global spatial economic scenarios on long term container port throughput. In *5th ALRT Asian Logistics Roundtable & Conference, University of British Columbia, Canada, June 14-15th*.

van Essen, H., Rijkee, X., Verbraak, G., Quak, H., and Wilmink, I. (2009). *Modal split and decoupling options*, Paper 5 draft. Available at: www.eutransportghg2050.eu. Accessed 1 April 2011.

van Groningen, G. and van de Graaf, F. (2006). *Een onderzoek naar ondergrondseopslag van vlooibare goederen (in Dutch) [Underground liquid storage: A study into underground storage of liquid bulk goods]*. Master's thesis, Hogeschool Rotterdam, The Netherlands.

van Meijeren, J., Noordegraaf, D. V., and van Rooijen, T. (2009). *Van Maasvlakte naar Achterland: duurzaamvervoer als uitdaging (in Dutch) [From Maasvlakte to Hinterland: Sustainable Transport as a challenge]*, Projectnummer PT 06-62A Rotterdam, Transumo A15. Available at: http://www.tno.nl/content.cfm?context=thema&content=prop_publicatie&laag1=894&laag2=913&laag3=101&item_id=542. Accessed 1 April 2012.

van Notten, P., Sleegers, A. M., and van Asselt, M. B. A. (2005). The future schocks: On discontinuity and scenario development. *Technological Forecasting & Social Change*, 72:175–194.

van Putten, A. B. and MacMillan, I. (2009). *Unlocking opportunities for growth: How to profit from uncertainty while limiting your risk.* NJ, USA: Pearson Education Inc.

van Schaardenburg, A. A. (2009). *Tastbaar risicomanagement (in Dutch) [Tangible Risk Management]*. Master's thesis, Hogeschool Rotterdam, The Netherlands.

van Schuylenburg, M. (2002). Timing of the Second Maasvlakte. Technical report, Port of Rotterdam.

van Schuylenburg, M. (2004). *Container logistics in the extended Port of Rotterdam In The changing world of container logistics. pp. 35-55. A. van Binsberg and M. Duinkerken (eds.). Delft: Delft University Press.*

Vastert, J. G. (2003). *Effectiviteit van het risicomanagement bij Design & Construct projecten van HBG Civiel (in Dutch) [Effectiveness of Risk Management for Design & Construct Projects of HBG Civil]*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Veldman, S. and Buckmann, E. (2003). A model on container port competition: an application for the west european container hub-ports. *Maritime Economics and Logistics*, 5(1):3–22.

Vellinga, T. (2010). Environmental monitoring construction Rotterdam port expansion Maasvlakte 2. In *PIANC MMX Congress, Liverpool 2010*, Liverpool.

Vellinga, T. (2012). *Sustainability in ports and coastal zones.* Lecure material, International Port Seminar 2012, UNESCO-IHE.

Vellinga, T. and de Jong, M. (2012). Approach to climate change adaptation in the port of rotterdam in *Maritime transport and the climate change challenge*, pp. 305-319. r. asariotis and h. benamara (ed.). london and newyork: Routledge:.

Verbraeck, A. (2009). *Technologically Complex Projects: Success and Failure of Projects, Project Management (Lecture notes)*. Faculty of Technology, Policy, and Management, Delft university of technology, The Netherlands.

Verhaege, R. J. (2007). *Data, modeling and decision making (Lecture Notes)*. Delft University of Technology, The Netherlands.

Verhoeven, P. (2009). *A review of the port authority functions: Towards a renaissance?* Available http://www.bpoports.com/assets/files/2-34%20paper.pdf. Accessed 1 April 2012.

Verschuren, D., Verschuren, P., and Doorewaard, H. (1999). *Designing a Research Project.* IN, USA: Purdue University Press.

Vesselfinder (2012). *World's Largest Container Ship*. Available at http://www.vesselfinder.com/news/753-Worlds-Largest-Container-Ship?goback=%2Egde_62542_member_196142013. Accessed 14 December 2012.

Volberda, H. (1998). *Building the flexible firm: How to remain competitive.* Oxford, UK: Oxford University Press.

Vrijling, H. (2005). The economic aspects of life cycle approach. In Ligteringen, H., editor, *Proceedings PIANC Seminar Life Cycle Approach in Port Infrastructure, Reducing Financial Risks, and Achieving Cost Savings, February 2, 2005. Brussels*, pages 27–33.

Waardekker, A. (2011). *Climate change impact assessment and adaptation under uncertainty.* PhD thesis, Utrecht University, Utrecht, The Netherlands.

Walker, J. (1985). Factors affecting international trade through Scottish Ports. *Maritime Policy and Management*, 12(3):227–239.

Walker, W., Harremos, P., Rotmans, J., van der Sluijs, J., van Asselt, M., Janssen, P., and von Krauss, M. (2003). Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment*, 4(1):5–17.

Walker, W. E. (1994). The policy analysis approach to public decisionmaking, *National Public Administration Day Congress (Landelijke Bestuurskunde Dag), University of Groningen, 17 March 1994*.

Walker, W. E. (2000). Policy analysis: A systematic approach to supporting policymaking in the public sector. *Journal of Multi-Criteria Decision analysis*, 9:11–27.

Walker, W. E. (2009). *Introduction to EPA 2132 and Review of Policy Analysis*, Lecture presentation. Faculty of Technology, Policy and Management, Delft University of Technology.

Walker, W. E., Marchau, V., and Kwakkel, J. H. (2012). Chapter 9. Uncertainty in the framework of policy analysis In *Public Policy Analysis: New Developments*. w. e. walker and w. thissen (eds.). new york: Springer.

Walker, W. E., Marchau, V., and Swanson, D. (2010). Addressing deep uncertainty using adaptive policies: Introduction to section 2. *Technological Forecasting and Social Change*, 77(6):917–923.

Walker, W. E., Rahman, S. J., and Cave, J. (2001). Adaptive policies, policy analysis, and policymaking. *European Journal of Operational Research*, 128(2):282–289.

Wang, T. (2005). *Real Options In Projects and Systems Design Identification of Options and Solutions for Path Dependency.* PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Wang, T. and de Neufville, R. (2005). Real options in projects. In *9th Real Options International Conference, Pais, France, June 2005.*

Werkgroep Strategische Reserve Maasvlakte 2 (1997). *Onderzoek strategische reserve Maasvlakte 2(in Dutch) [Research strategic reserve Maasvlakte 2]*. Technical report, Port of Rotterdam.

Wiegmans, B., Van der Hoest, A., and Notteboom, T. (2008). Port and terminal selection by deep-sea container operators. *Maritime Policy Management*, 35(6):517–534.

Wijnants, G., van der Toorn, A., Schuylenburg, M., Heijnen, M., de Gijt, J., Molenaar, W., Ligteringen, H., and Krom, A. (2000). Meeting Quay 2k30s requirements. In *International conference on port and maritime development and innovation, 5-7 september 2005*.

Wildavsky, A. B. (1991). *Searching for safety*. NJ, USA: Transaction publishers, New Brunswick.

Wilds, J. (2008). *A Methodology for Identifying Flexible Design Opportunities*. PhD thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA.

Willcocks, L. (1994). *Information management: the evaluation of information systems investments*. London, UK: Chapman & Hall.

Winkelmans, W. (2007). *New EU Port policy: View points regarding Seaport development*. Available at: http://www.port-net.net/activities/pdf/riga_winkelmans_handout_29112007.pdf. Accessed 1 April 2011.

Winkelmans, W. and Notteboom, T. (2007). *The reality and dilemmas of globalization*, chapter Port master planning: balancing stakeholders interests. Gdansk: The Foundation of the Development of Gdansk University.

Woo, S., Pettit, S., and Kwak, D. (2010). Trends and themes in port research since 1980 - a decadal approach. In *Annual Conference of the International Association of Maritime Economists, 7-9 July 2010, Lisbon, Portugal*.

Woolthuis, R., Lankhuizenb, M., and Gilsingc, V. (2005). A system failure framework for innovation policy design. *Technovation*, 25:606–619.

World Bank (2007). *Port Reform Toolkit : Effective Support for Policymakers and Practitioners (2nd edition)*. Available at: http://ppp.worldbank.org/public-private-partnership/sector/transportation/toolkits. Accessesd 1 April 2012.

World Bank (2012). *Global teminal operators*. Available at: http://siteresources.worldbank.org/INTRANETTRADE/Resources/Internal-Training/Global_terminal_operators.pdf. Accessed 1 April 2012.

WorldCargoNews (2010). *APMT unveils FastNet concept*. Available at: http://www.worldcargonews.com/htm/w20101013.640450.htm. Accessed 1 Novemember 2012.

Yang, Y. (2009). *A Screening Model to Explore Planning Decisions in Automotive Manufacturing Systems under Demand Uncertainty*. PhD thesis, Engineering Systems Division, Massachussets Institute of Technology, Cambridge, MA.

Yeo, K. T. and Qiu, F. (2003). The value of management flexibility - a real option approach to investment evaluation. *International Journal of Project Management*, 21:243–250.

Yin, R. (2009). *Case study research: Design and methods. 3rd ed.* CA: Thousand Oaks, Sage.

Yu, A. T. (1989). Trends and advances in bulk terminal systems. *Permanent International association of Navigational Congress (PIANC)- AIPCN - Bulletin*, 67:88–97.

Zauner, A. (2008). Strategic Port Planning: A Case Study of the Rotterdam Seaport Cluster applying the SWOT Framework. *der Markt*, 3:130–141.

Zeisler, S. and Harris, D. (2000). Order from Chaos: part two. *Scenario and Strategy planning*, 2(2):14–17.

Zhao, T. and Tseng, C. (2003). Valuing flexibility in infrastructure expansion. *Journal of Infrastructure systems*, 9(3):89–98.

Zijian, Y. (2007). *Very large Floating container terminal and optimal layout of gill cells*. Master's thesis, Department of Civil Engineering, National University of Singapore, Singapore.

Zohil, J. and Prijon, M. (1999). The MED rule: the interdependence of container throughput and transhipment volumes in the Mediterranean ports. *Maritime Policy and Management*, 26(2):175–193.

Zuckerman, E. (2007). *Marc Levinson's 'The Box'*. Available at: http://www.worldchanging.com/archives/006557.html. Accessed 25 December 2012.

Zuidgeest, R. (2009). *Binnenvaart Service Centrum op Maasvlakte 2: Een haalbaarheidsstudie (in Dutch) [Inland Service Centre at Maasvlate 2]*. Master's thesis, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands.

Zurek, M. and Henrichs, T. (2007). *Linking scenarios across geographical scales in international environmental assessments, Technological forecasting and social change*. Available at: http://www.gecafs.org/documents/PP11Zurek.pdf. Accessed 25 June 2012.

Zwicky, F. (1969). *Discovery, Invention, Research - Through the Morphological Approach*. Toronto: The Macmillian Company.

Appendix A

Agenda for Brainstorm Sessions in 2008 & 2010

This appendix gives an overview of the two brainstorm sessions organized in the framework of this research in 2008 and 2010 respectively. The results of the first session were used as an input for the case study presented in Chapter 6. The outcome of the second session over flexibility in infrastructures was used to mark out the subsequent steps of this research. The most important results have been presented in Chapter 5.

Brainstorm Session 2008 on Trend and Trend-break developments

Objectives	:	To obtain strategic insights in the future developments relevant for ports, and discuss the implications of these developments for Maasvlakte 2
Location	:	Port of Rotterdam (PoR)
Participants	:	8
Organizations represented:		CITG, TU Delft; TPM, TU Delft; various divisions of PoR; Projectbureau Maasvlakte Rotterdam (PMR); Department of Public Works Rotterdam (IGWR)

Agenda:

1. Part 1
   (a) A short presentation over the objective of the brainstorm session
   (b) An inventory of the relevant trend and trend-break developments for PoR among the participants
   (c) Clustering and ranking of developments identified in (b)

2. Part 2
    (a) Recapitulation session 1
    (b) Discussion of impacts of the developments identified in session step (1c)
    (c) Further ranking of significant developments using expert opinion
    (d) Conclusions and further actions

Brainstorm Session 2010 on Flexible Port Infrastructure

Objectives	:	To carry out an inventory of cost-effective strategies for flexibility in infrastructures and generate new ideas for research
Location	:	Eemshaven, Rotterdam
Organizations represented	:	PoR, TU Delft, BAM, Royal Haskoning, ECT, APMT, Department of Public Works Rotterdam

Agenda:

1. Introduction:
   - Research project Flexible Port
   - Steps in the Brainstorm session
2. Presentation over Research project 'The Flexible Port'
3. Generation of flexible concepts to be carried out in groups
4. Presentation of the most promising idea by each group, followed by a discussion
5. Conclusions and further actions

Appendix B

Survey Questionnaire

A survey was conducted to gather various perceptions of flexibility from a mixed group of participants. The survey consisted of three categories. The questions were general in the first category and specific in the second category. The third category was aimed at barriers or bottlenecks to implementing flexibility.

Questionnaire

Instructions: How far do you agree with the following propositions? Select one of the following four alternatives by ticking in the appropriate column:
- agree
- agree a bit
- disagree a bit
- disagree

Category 1: Uncertainty and Flexibility

	agree	agree a bit	disagree a bit	disagree
We can't do much about uncertainty				
Ports need strategies to deal with uncertainties				
It is possible to react to situations in a flexible manner only if flexible options are available				
Flexibility creates extra complexity in projects				
Flexibility reduces efficiency in projects				
Flexibility in infrastructures is only a means; the objective is to extend the economic life of infrastructures				
In the future, flexibility will dominate the evaluation criteria for large engineering projects				
Flexibility in one node of the supply chain will not solve anything				
It is better to focus upon flexibility in processes and procedures				
Flexibility for one can represent a risk for another				

Comments if any, can be given here:

Instructions: How far do you agree with the following propositions? Select one of the following four alternatives by ticking in the appropriate column:
- agree
- agree a bit
- disagree a bit
- disagree

Category 2: Infrastructure

	agree	agree a bit	disagree a bit	disagree
Flexibility in infrastructures is myth				
Relocatable infrastructure is not economical				
Building in margins in infrastructure (over-dimensioning and provision of overcapacity),is the only manner to prepare for unforeseen events				
Phasing the construction of a port is an effective strategy to consciously deal with uncertainty				

Comments if any, can be given here:

____

____

____

____

Instructions: How far do you agree with the following propositions? Select one of the following four alternatives by ticking in the appropriate column:
- agree
- agree a bit
- disagree a bit
- disagree

Category 3: Implementation

	agree	agree a bit	disagree a bit	disagree
Implementation of flexible solutions is more difficult than devising them				
Institutional problems (rules and regulations) will not allow for effective employment of flexible solutions				
The costs and value of flexibility should be included in a project business case				
De engineering, commercial, and financial divisions in a firm must think along the same lines, otherwise the flexible solutions will end up in a waste paper basket				
Only if the land prices in Rotterdam rise, innovative flexible solution such as underground infra. or floating structures become more interesting				
The government (and the society) must contribute financially towards sustainable flexible solutions				

Comments if any, can be given here: ____

Appendix C

Decision Tree Analysis

The three decision trees created with @Risk software are shown in Figure 1. From top to down, these trees depict the traditional valuation of a project, the valuation of a project with flexibility, and valuation of a project with flexibility whereby uncertainty has been reduced through additional research.

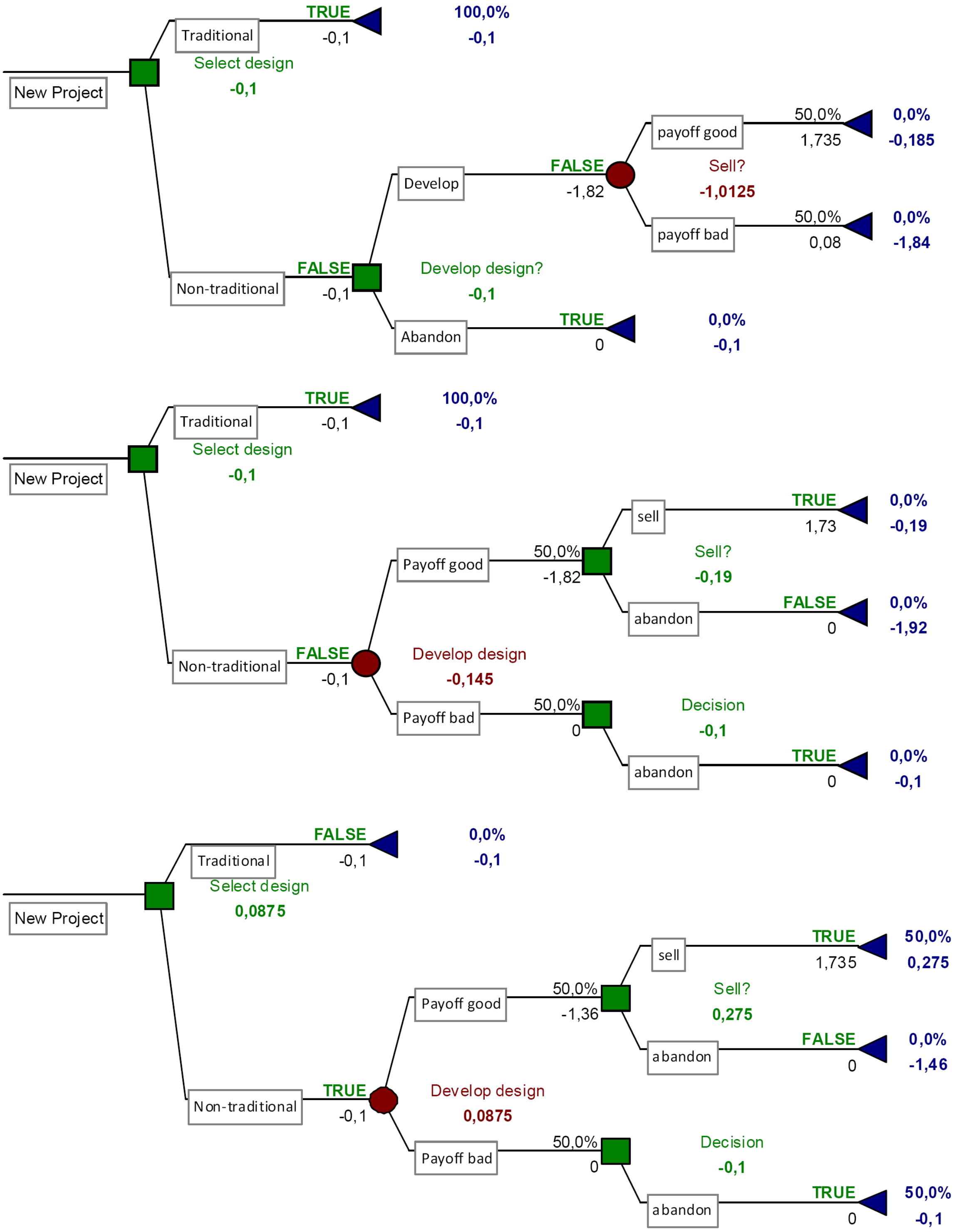


Figure 1: Traditional valuation, Flexibility valuation (1), Flexibility valuation (2) (top to down)

Appendix D

Binomial Lattices

Appendix D, based on Kodukula and Papudesu (2006), discusses binomial lattices, and is referred to in Chapter 7.

Lattices look like decision trees and lay out, in the form of a branching tree, the evolution of possible values of the underlying asset during the life of the option. An optimal solution to the entire problem is obtained by optimizing the future decisions at various decision points and folding them back in a backward recursive fashion into the current decision. The most commonly used lattices are binomial trees.

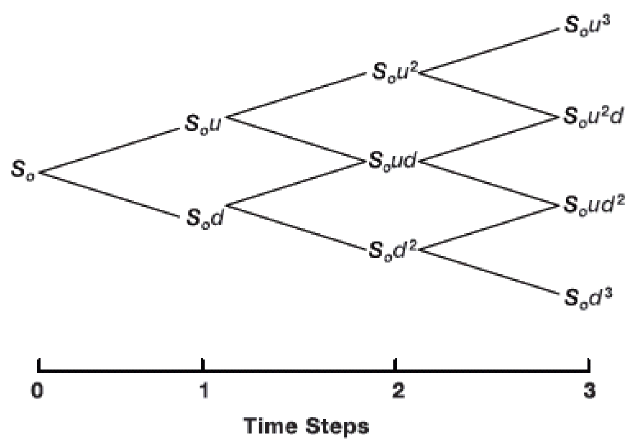


Figure 1: A Generic Recombining Binomial Tree

The binomial model can be represented by the binomial tree shown in Figure 1. S_o is the initial value of the asset. In the first time increment, this value either goes up or down and from there continues to go either up or down in the following time increments. The up and down movements are represented by u and d factors, where u is >1 and d is <1 and we assume u = 1/d. The magnitude of these factors depends on the volatility of the underlying asset.

The first time step of the binomial tree has two nodes, showing the possible asset values (S_ou, S_od) at the end of that time period. The second time step results in three nodes and asset values (S_ou2, S_oud, S_od2), the third time step in four

($S_o u3, S_o u2d, S_o ud2, S_o d3$), and so on. The last nodes at the end of the binomial tree represent the range of possible asset values at the end of the option life. These asset values can be represented in the form of a frequency histogram. Each histogram signifies a single asset value outcome, and the height of the histogram is a function of the number of times that outcome will result through all possible paths on the binomial tree (Figure 2).

by as many time steps as desired. While the range (minimum and maximum) of outcomes at the end of the lattice may not change significantly with an increase in the number of time steps, the number of possible outcomes increases exponentially and their frequency distribution curve will become smoother. The higher the number of time steps, the higher the level of granularity and therefore the higher the level of accuracy of option valuation.

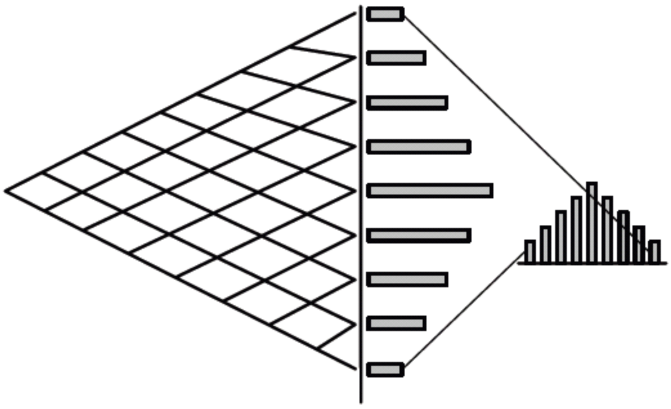


Figure 2: Distribution of Outcomes

Binomial lattices can be solved to calculate option values using two different approaches:
(1) Risk-neutral probabilities
(2) Market-replicating portfolios

The theoretical framework for both approaches is the same, yielding identical answers, while the mathematics involved are slightly different. The basic methodology of the risk-neutral probabilities approach involves risk adjusting the cash flows throughout the lattice with risk-neutral probabilities and discounting them at the risk-free rate. Irrespective of the option to be valued, the binomial lattice representing the underlying asset value has the same properties and can be described by the equations presented below. The up and down factors, u and d, are a function of the volatility of the underlying asset and can be described as follows:

$$u = e^{\sigma\sqrt{\delta t}} \tag{1}$$

$$d = e^{-\sigma\sqrt{\delta t}} \tag{2}$$

where σ is the volatility (%) represented by the standard deviation of the natural logarithm of the underlying free cash flow returns, and δt is the time associated with each time step of the binomial tree. (σ and δt units should be consistent.)

Equation 2 can be rewritten as follows, which is mathematically the same:

$$d = \frac{1}{u} \tag{3}$$

The risk-neutral probability, p, is defined as follows:

$$p = \frac{e^{r\delta t} - d}{u - d} \tag{4}$$

where r is the risk-free interest rate or rate of return on a riskless asset during the life of the option. The risk-neutral probabilities are not the same as objective probabilities. (The latter is used, for example, to describe the probability that a certain event will occur, as in decision tree analysis.) The risk-neutral probability is just a mathematical intermediate that will enables one to discount the cash flows using a risk-free interest rate. The inputs required to build the binomial trees and calculate the option value are: σ, r, S_0, X, T, and δt, where σ is the volatility factor, r the risk-free rate, S_0 the present value of the underlying asset value, X the cost of exercising the option, T the life of the option, and δt the time step chosen for the calculations

Appendix E

Input for the Business Case

Table 1: Input for the Business Case

Financial parameters
Inflation
(required) Return on investment
Discount land rent first year
Discount land rent second year
Discount harbour dues first year
Discount harbour dues second year
Discount harbour dues from third year
LNG location 2 (Variant 1, 3)
Start construction
Investment jetty
Construction connecting road (part 1)
Construction connecting road (part 2)
Maintenance costs (% van investment)
Area allocation (m2)
Ground price (m2/year)
Throughput in ton
Harbour dues Tariff per ton
Empty Depot location 2 (all variants)
Start construction terminal
Construction connecting road (part 1)
Construction connecting road (part 2)
Maintenance costs (% van investment)
Area allocation (m2) part 1
Area allocation (m2) part 2
Ground price (m2/year)
Liquid Bulk location 2 (all variants)
Start construction terminal
Construction connecting road (part 1)
Construction connecting road (part 2)
Maintenance costs (% van investment)
Area allocation (m2)
Ground price (m2/year)
Throughput in ton
Harbour dues Tariff (per ton)

Table 2: Input for the Business Case *cont.*

Barge-feeder terminal Euromax location 5 (variant 1)
Start construction terminal
Investment quay wall
Maintenance costs (% van investment)
Area allocation (m2)
Ground price (m2/year)
Lengte quay (m)
Tariff quay dues per metre
Throughput in ton
Harbour dues Tariff (per ton)

LNG location 5 (variant 2)
Start construction
Investment quay wall
Maintenance costs
Area allocation (m2)
Ground price (m2/year)
Throughput in tonnen 100%
Harbour dues tariff (per ton)

Barge- feeder terminal Euromax + 1 LNG tank (variant 3)
Start construction container terminal
Start construction LNG tank
Investment quay
Maintenance costs (% van investment)
Area allocation container terminal (m2)
Ground price container terminal (m2/year)
Length quay container terminal (m)
Tariff quay dues per metre
Throughput in ton containers
Harbour dues Tariff containers (per ton)
Area allocation LNG tank (m2)
Ground price LNG (m2/year)
Length quay LNG (m)
Tariff quay dues (per m)
Throughput in ton LNG
Harbour dues tariff (per ton)

Appendix F

Alternatives for the Inner Lake at Maasvlakte 2

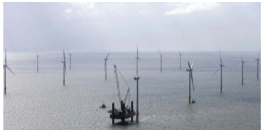
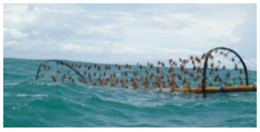
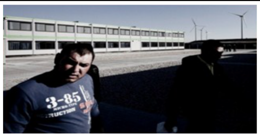
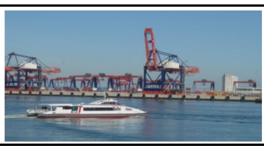
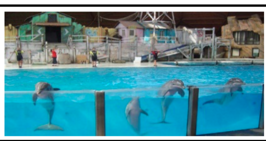
Activity		Requirements	Structure	Allocation
Wind energy		- Power cable - Center to center distance of about 500m - Boat or road access - Obstacle to water sports	- Wind mills (by operator)	- Closed & open part inner lake
Mussel farming		- Tidal range + flow - Fisher boat access - No oil spillage	- Sleeves (by operator)	- Closed & open part inner lake
Algae farming		- No oil spillage - Boat access	- Sleeves (by operator)	- Closed & open part inner lake
Hotel at work		- Floatel: 200x30x7 m - Road connection - Parking area - Not next to activities that cause noise	- Jetty with retaining height of 14m, width 1/10: 140m width 1/40: 50m	- Open part inner lake next to sea defense or temporary dike
Fast ferry		- Ferry: 20x4x2 m - Minimum amount of passengers	- Jetty with retaining height of 6m, width 1/10: 60m width 1/4: 24m	- Open part inner lake next to sea defense or temporary dike
Nature reserve		- Not next to other activities - No oil spillage		- Closed part inner lake
Water sports		- Parking area - Safety distance to vessels	- Parking area	- Closed part inner lake
Dolphinarium		- Basin & accommodation - Sheds, grandstand, facilities basic needs - road access, parking area	- Quaytype structure LxWxRH: 50x50x8m - Fence to separate basin from inner lake	- Closed part inner lake next to beach or temporary dike

Figure 1: Alternatives for the Inner Lake (1)

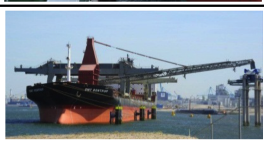
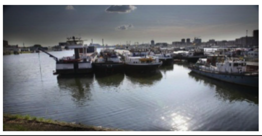
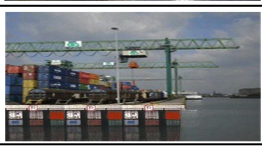
Activity		Requirements	Structure	Allocation
Liquid bulk transshipment		- 150,000 DWT, 400x45x16 - Mooring facilities - Oil spillage measures - Safety distances - Tug assistence	- One dolphin or buoy per 50,000 DWT	- Until Suezmax, draft less than 16m in the open part inner lake next to Yantzehaven
Dry bulk transshipment		- 44,000 DWT, 201x28x6 - Several hectares for storage	- Contractor quay wall	- Open part inner lake at contractor quay wall
Wind mill assembling		- 6-25 ha, 30-60kN/m2 - Quay=200m, draft=6m - 365/24 access for oversize trucks & vessels - warehouse of 1,000m2	- Contractor quay wall - Or, dedicated quay with length of 200m & retaining height 13m	- Open part inner lake next to sea defense or temporary dike
Mooring spaces		- Inland vessels: 3,000 DWT, 135x10x5 - Feeders: 16,000 DWT, 170x30x10	- Dolphin or buoy for one or several vessels	- Open part inner lake next to Yantzehaven
Common barge terminal		- 3,000 DWT, 135x10x5 - Terminal equipment - Quay=300m, draft=5m - Road & vessel access	- Dedicated quay with length of 300 m and retaining height 12m	- Open part inner lake next to sea defense or temporary dike

Figure 2: Alternatives for the Inner Lake (2)

Samenvatting

Een haven moet een meesterwerk van engineering en een kunstwerk zijn, en vooral moet het de tand des tijds kunnen doorstaan. Het moet flexibel zijn, zodat latere generaties het kan aanpassen naar hun eigen behoeften!

In de huidige turbulente, door technologie gedreven, concurrerende, mondiale economie, worden havens geconfronteerd met veel onzekerheden. Ze hebben te maken met nieuwe eisen voor wat betreft functies en schaal, nieuwe externe beperkingen, en veranderde verwachtingen. Het onvermogen om adequaat te voldoen aan deze eisen kan voor een haven dure aanpassingen of het verlies van lading en concurrentiepositie betekenen. Echter, de traditionele praktijken van havenplanning blijven statisch in deze dynamische wereld. We passen nog steeds lineaire methoden op complexe niet-lineaire systemen om de toekomst te kunnen voorspellen, en baseren onze plannen dan op deze voorspelde toekomst. Dit plan is gedoemd te mislukken als de toekomst niet aan de verwachtingen voldoet. Hoewel er een brede consensus bestaat over de noodzaak om met onzekerheid om te gaan, zijn er maar weinigen die een kader of een set van gereedschappen hebben voorgesteld om dit daadwerkelijk te doen. Daarom wordt in dit proefschrift aandacht besteed aan de vraag: hoe kunnen we onze haveninfrastructuur plannen onder onzekere omstandigheden?

Onzekerheid kan worden gezien als elke afwijking van het onbereikbare ideaal van volledige voorspelbaarheid. Een haven kan worden beschouwd als een dynamisch, open en complex technisch systeem, blootgesteld aan onzekere externe invloeden. Een verkenning van de vele facetten van zogenaamde 'diepe' onzekerheid, dat wil zeggen de aard, het niveau en de locatie, geeft aan dat dit het meest bepalend is bij havenplanning. Gezien als de situatie waarin meerdere beslissers het niet eens kunnen worden over het systeemmodel, de a-priori waarschijnlijkheden voor de onzekere parameters van het systeemmodel en/of de waardefunctie, karakteriseert diepe onzekerheid vele situaties. Daarom moeten we een manier vinden om onzekerheid het hoofd te bieden. Bovendien moet havenplanning de implicaties van de heersende en opkomende trends begrijpen, die directe of indirecte gevolgen hebben voor onze doelen, onze plannen en ontwerpen, of onze wijze van planning en ontwerp. Deze omvatten de voortschrijdende globalisering en containerisatie, veranderende functies van havens en vergroting van de schaal van havenprojecten, het veranderen van deelnemers in de havenarena, veranderende technologie, en de grotere aandacht voor het milieu.

Traditionele havenplanning, bestaande uit elementen zoals masterplanning, ontwerp van de infrastructuur en de beoordeling van projecten, richt zich op korte termijn onzekerheden. Er is een grote afstand tussen de econoom die de prognoses voorbereidt (waarop de plannen zijn gebaseerd), de ingenieur die de planning doet, de financiele manager, die de business case opstelt en de uiteindelijke besluitvormer. De planners denken doorgaans niet in termen van onzekerheid, en stellen daarom inflexibele alternatieven voor. De lineaire planning aanpak voor de meeste projecten betekent dat de besluitvorming niet kan profiteren van nieuwe informatie, die onzekerheid vermindert. Beoordeling van de investering houdt een financile evaluatie in een business case in, en de keuze van het juiste alternatief is gebaseerd op de meest waarschijnlijke uitkomst van een situatie. Het is echter niet mogelijk noch wenselijk dat de besluitvorming voor een project met meervoudige onzekerheden op een enkele monetaire waarde is gebaseerd. Flexibiliteit kan de waarde van een project verbeteren, maar kan met traditionele methoden niet op waarde worden geschat. Onverstandige besluitvorming leidt tot inflexibele keuzes, zodat we havenlayouts en infrastructuren krijgen, die ontoereikend zijn als de eisen veranderen. Het is duidelijk dat een nieuwe aanpak nodig is.

Flexibiliteit helpt aanpassing van een haven aan een breed scala van exogene ontwikkelingen. Een flexibele haven kan relatief eenvoudig aangepast worden om ook kosteneffectief te kunnen functioneren onder andere, nieuwe of veranderende eisen. Dit komt er op neer dat met minimale extra investeringen de dienstverlening gehandhaafd of zelfs verbeterd kan worden. Flexibiliteit wordt soms in een systeem ingebed, maar in andere gevallen moet het worden gecreerd door strategisch te denken. Dit is op alle niveaus van een haveninfrastructuursysteem mogelijk, d.w.z., in de fysieke infrastructuur, de procedures en activiteiten, en de diensten die het levert. Hiervoor is wel begrip nodig van flexibiliteit (en de systeemattributen relevant voor de flexibiliteit in een systeem) en van het havensysteem. Wij stellen een raamwerk voor, dat gebruikt kan worden door havenplanners om flexibiliteit te identificeren. Hiervoor is een systematisch onderzoek naar de veelzijdige concepten van onzekerheid en flexibiliteit nodig, alsook begrip van het havensysteem en alle exogene krachten daaromheen.

Wij stellen *Adaptieve Port Planning (APP)* voor, een aanpak die de beperkingen in de traditionele praktijken van havenplanning overbrugt door overwegingen van onzekerheid en flexibiliteit mee te nemen. Het biedt de planner een kader om plausibele alternatieven in het kader van zijn planningdoelstellingen en zijn definitie van succes te genereren, kritische onzekerheden te identificeren (kwetsbaarheden en kansen); flexibiliteit te introduceren, en om te gaan met onzekerheden door het nemen van acties in de planningsfase, of door acties voor te bereiden, die genomen kunnen worden als bepaalde gebeurtenissen zich voordoen. Vervolgens beoordeelt de planner de alternatieven en maakt een selectie – de waarde van flexibiliteit wordt in zijn evaluatie meegenomen. Tijdens de uitvoeringsfase, worden acties ondernomen naar aanleiding van signalen van een monitoringsysteem dat is opgezet voor het geselecteerde alternatief. In dit systeem wordt de externe omgeving bewaakt en bekeken op nieuwe ontwikkelingen zodat planners kunnen worden gewaarschuwd als er behoefte bestaat de plannen aan te passen.

Case studies uit de praktijk hebben aangetoond dat APP aan diverse planningswensen tegemoet kan komen en flexibele en robuuste oplossingen kan leveren, die beter bestand zijn tegen een wispelturige toekomst. Deze case studies behandelen kritische kwesties zoals ruimtelijke ordening onder onzekerheid en energietransitie, of dienen om de kenmerken van flexibiliteit te illustreren. Dit behelst onder meer ontwerpen van flexibele infrastructuur, flexibele logistieke concepten en flexibiliteit in de besluitvorming. De illustratieve case studies zullen een planner op weg helpen om de voorgestelde methode toe te passen.

Flexibiliteit in (fysieke) infrastructuur is onderzocht door middel van een brainstormsessie met diverse belanghebbenden in de haven (gerelateerde) industrie. Onder de favoriete strategieën voor flexibiliteit in de fysieke infrastructuur kwamen ontwerp modulariteit, standaardisatie, en generieke en robuuste ontwerpen naar voren. De aanpak voor planning, ontwerp en de beoordeling van projecten moeten overwegingen met betrekking tot flexibiliteit omvatten. Vier alternatieve benaderingen voor infrastructuurontwerp werden vastgesteld – ontwerp volgens vaste specificaties en het aanpassen naar behoefte; ontwerp voor veroudering en slopen; ontwerp voor robuustheid door ruimere ontwerpcriteria. Het is essentieel dat deze voor elk project afzonderlijk worden beschouwd in plaats van te kiezen voor een klantspecifiek ontwerp. Flexibiliteit in infrastructuur maakt hergebruik van infrastructuur, constructies of onderdelen daarvan, en van materialen mogelijk, optimaliseert het gebruik van natuurlijke hulpbronnen, vermindert afval en verontreiniging van het milieu, leidt tot energiebesparing, en kan leiden tot aanzienlijk lagere lifecycle kosten. Hiermee draagt het dus bij aan duurzaamheid. In de Rotterdamse haven zijn echter geen voorbeelden van flexibele infrastructuur te vinden. De praktijk met betrekking tot hergebruik is beperkt tot down-cycling van materialen in minderwaardige toepassingen. Overwegingen over flexibiliteit (en duurzaamheid), waaronder ontwerpen voor afbreken en hergebruik, moeten worden meegenomen in alle ontwerpen. Daarom is hiervoor een leidraad voor aanpassing en hergebruik gepresenteerd.

In de afgelopen tijd zijn veel innovatieve logistieke en infrastructurele concepten voorgedragen. Echter, deze werden ondanks uitgebreid onderzoek en investering in proefprojecten of haalbaarheidsstudies nooit uitgevoerd. Een onderzoek naar de factoren die ten grondslag liggen aan zowel mislukte als succesvolle innovatieve inspanningen in de Rotterdamse haven, bevestigt dat innovatie gevormd wordt door een samenspel van behoefte, en economische en institutionele factoren. De belangrijkste bevindingen waren dat de strategieën voor flexibiliteit niet los gezien kunnen worden van de ingrepen die vaak nodig zijn op institutioneel niveau om flexibiliteit te kunnen implementeren. Het is essentieel dat de toegevoegde waarde van flexibiliteit voor het management zichtbaar gemaakt wordt.

In het kader van APP is een *waarderingsmethode* nodig, die in staat is om rekening te houden met de verschillende onzekerheden en flexibiliteiten in havensystemen, die zich leent is voor de karakteristieke eigenschappen van havenprojecten en toepasbaar is voor de havenmarkt. Voorts moet deze transparant zijn en management kunnen overtuigen van de voordelen van flexibele oplossingen. De methoden van de traditionele economische analyse – zoals Simulatie (in feite een stochastische Discounted Cash Flow methode) of Decision Tree Analysis (DTA) – zijn geschikt om een bruikbare en consistente vergelijking van alternatieven te maken. Terwijl simulatie geschikt is voor voortdurende risico's, wordt DTA aanbevolen als er duidelijke investeringsopties en onzekere beslissingen zijn. Simulatie, zelfs uitgevoerd met een eenvoudig spreadsheet model, leidt al tot een bandbreedte van mogelijke uitkomsten, met daarbij de kans van voorkomen. Het is een eerste vereiste dat men de onzekerheid, die inherent is in alle ramingen, expliciet maakt, wat een groot voordeel is. Het maakt gebruik van de uitgebreide kennis van het havensysteem (en de bijbehorende processen) tijdens planning en ontwerp, zodat weinig inspanning nodig is om een evaluatiemodel op te zetten.

Een reële opties analyse (ROA) gebaseerd op de financiële optie theorie werd niet geschikt bevonden vanwege de impliciete aannames, die niet geldig zijn voor havenprojecten en markten. Echter, verder onderzoek in dit snel groeiende veld kan tot extra inzicht leiden om deze aannames te omzeilen. De inherente complexiteit en ondoorzichtigheid beperken het gebruik van ROA nog meer. Echter, het reële optie denken dat de waarde van flexibiliteit in een project aan het management kan laten zien, moet worden ingebed in de standaard procedures van een organisatie.

APP is gebaseerd op het *monitoren van de externe omgeving*. Het monitoren is gericht op de evaluatie van gebeurtenissen of ontwikkelingen die zich nu voordoen of in de nabije toekomst. Het gaat om activiteiten zoals meten, analyse, evaluatie en prognose, zodat tijdige acties kunnen worden gestart. Echter, het definiren van passende signalen om te bepalen wanneer externe ontwikkelingen kunnen leiden tot veranderingen in een systeem is verre van eenvoudig. We laten zien dat eenvoudige voorspellingstechnieken, die zijn gebaseerd op statistische methoden, het mogelijk maken de ontwikkelingen te bewaken, die grote kwetsbaarheden voor havenprojecten inhouden. Veranderingen in de containermarkt kunnen worden bewaakt met economische indicatoren, zoals het Bruto Nationaal Product (BNP). Met milieuverkenning, mediaonderzoek en deskundig advies kunnen beleidsveranderingen gevolgd worden, of zelfs aanstaande veranderingen vroegtijdig bepaald worden. Voorspelling van technologische ontwikkelingen is meer een kunst dan een wetenschap. Door het identificeren van fysieke beperkingen in een bestaande technologie (of in een opkomende technologie), en het volgen van de ontwikkelingen die deze beperkingen ofwel kunnen verwijderen of kunnen vermijden, kunnen wij tijdig op de hoogte komen van een mogelijke doorbraak.

Het succesvol *implementeren van APP* door organisaties, die betrokken zijn in havenplanning en havenontwerp wordt beperkt door vele barrières. Voorbeelden van deze barrières zijn: de conservatieve havenindustrie, de aard van havenprojecten, die worden beperkt door juridische procedures die flexibiliteit limiteren, de traditionele rol van een ingenieur die de planning doet, de organisatiecultuur die weinig ruimte biedt voor nieuwe technieken, de extra investeringen die flexibele ontwerpen met zich mee brengen, en het feit dat innovatie een lage prioriteit heeft in onzekere tijden. Door de recente gebeurtenissen in de wereld is een nieuwe manier van denken ontstaan, en men realiseert zich het belang van het zichtbaar maken van de toegevoegde waarde van flexibiliteit. APP moet worden toegepast in een multi-actor en multi-disciplinaire omgeving die sociale, economische, milieu, juridische en politieke grenzen overschrijdt. Er is behoefte aan een "strategische planner", een generalist met een holistische benadering, die verstand heeft van de functie en taken van een ingenieur, econoom, manager en beleidsmaker, en die kan communiceren met de vele disciplines in zijn planning team. Deze moet in staat zijn om hun kennis te integreren, onzekerheidsoverwegingen mee te nemen in projecten en ontwerprichtlijnen, innovatie na te streven en de keuze voor een flexibele boven een traditionele oplossing bij het management te rechtvaardigen

In een onzekere wereld, waar verantwoorde beslissingen voor een zeer verre toekomst nu gemaakt moeten worden, worden taken voor velen beschreven. Havenplanners moeten adaptieve planning toepassen. Beleidsmakers moeten normen en richtlijnen stimuleren, die onzekerheidsoverwegingen omarmen, en leiden tot ontwerpen van en oplossingen voor een flexibele infrastructuur. Een havenautoriteit moet breed gedragen inspanningen initiëren, om innovatieve oplossingen voor de problemen van morgen te vinden. Zowel de terminal operators (van wie velen nu multinationale ondernemingen zijn) als de havenautoriteiten moeten pioniers (risiconemers) zijn in de uitvoering van nieuwe oplossingen. Het ligt binnen de verwachting dat de overheid een leidende rol in innovatie op zich neemt, vooral door de zeer grote omvang van de projecten en de benodigde bevoegdheid om de institutionele verandering bij (technologische) innovatie te realiseren.

Tot slot, dit proefschrift “De Flexibele Haven” gaat over planning onder onzekerheid. Onzekerheid zal niet verdwijnen. We moeten het herkennen, ons daarop voorbereiden, aanpassen, het beheersen, en ervan profiteren. We moeten gebruik maken van een adaptieve benadering om voor havens Masterplannen te maken en infrastructuur te ontwerpen die de tand des tijds kunnen doorstaan. We moeten flexibiliteit inbouwen zodat latere generaties deze infrastructuur kunnen aanpassen aan hun eigen behoeften.

Curriculum Vitae

Poonam Taneja was born on 26 June 1964, in New Delhi, India. After obtaining a degree in civil engineering in 1986, she started working for Howe India Pvt. Ltd., a consulting engineering firm specializing in ports, as a design engineer. A part-time study led to a Masters degree in Applied Mechanics with a specialization in Computer aided designs, from IIT, Delhi. The association with port projects at Howe inspired her to pursue a Master's study in Port Engineering in the Netherlands at UNESCO-IHE. Following this study, she worked briefly at Delft University of Technology (DUT) as a researcher, and in Indonesia as a marine engineer.

In 1995 she began working at the Public Works department in Rotterdam (IGWR). Initially involved in transport infrastructure projects designing metro tunnels and stations etc., she soon shifted to the Ports and Waterways department. Up until 2011 she gained experience with many aspects of port projects in the Netherlands, and more specifically in the Port of Rotterdam. Between 2007 and 2012, she worked part time as a researcher at the Department of Civil Engineering at DUT. Her research deals with an investigation into flexibility and adaptability aspects in ports. After leaving IGWR in 2011, she began working as a lecturer at DUT and UNESCO-IHE, in the field of ports and waterways. She is actively trying to promote her research through teaching, and seeking practical applications in port projects all over the world.