Part I - Ch 2 A constant need for change

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2 A constant need for change

2.1 Triggers of change

Ports and waterways are built for the long term and involve major investments. Moreover, they function in a highly competitive environment, with competitors like nearby ports and other transport modalities. Making the right choices at the right moment is therefore key to the success of a waterborne transport network. This requires, however, looking into the future of a rapidly changing world. The ability to make sensible future projections and take the right decisions based on them is the name of the game in port and waterway development. The possible changes relevant to port and waterway development are many and they are all uncertain:

- technological developments (vessel size, energy transition, communication, autonomous shipping, big data),
- economic and political changes (economic cycles, global economic power shifts, regional changes in Gross Domestic Product (GDP), interest rates, fuel prices),
- changes in society (appreciation of e.g. environmental issues, consumption patterns, availability of labour, demographic changes),
- ongoing environmental changes (erosion/sedimentation, water quality),
- climate change (temperature, river discharge, sediment transport, ecosystem),
- accelerated relative sea level rise (height of quays and other structures, bridge height, flood protection),
- crises and calamities (economic, health, environmental, geopolitical).

In the next subsections we will examine these in more detail, focusing on their relevance to the development of supply chains and port and waterway infrastructure.

2.1.1 Technological developments

Technological developments may have a major impact on port and waterway development, but they are also notoriously difficult to foresee. Suppose 50 years ago we would have had to plan a waterborne transport network with a 50-year planning horizon. It would have been impossible to foresee the increase in vessel size (Figure 2.1), or the growth of container transport, or the spectacular development of communication technology. Robustness (ability to cope with small changes) and adaptability (ability to cope with larger changes) are the only possible responses to this kind of developments.

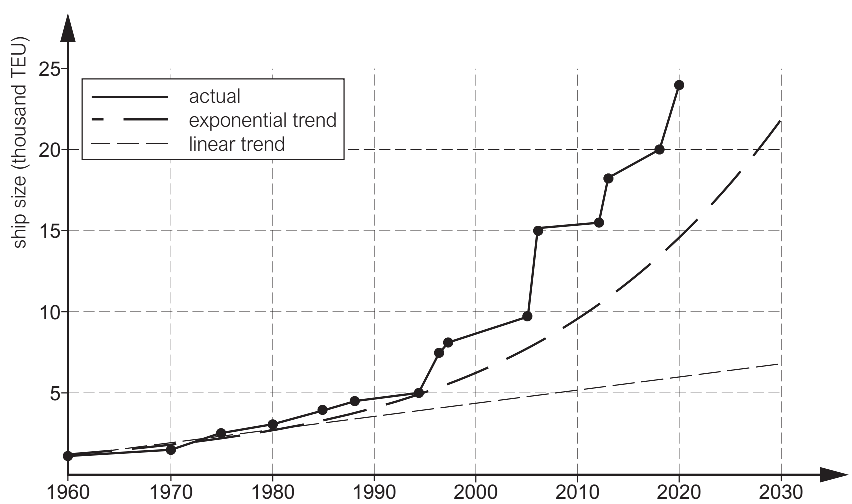

Figure 2.1: Container vessel size increase over time (seagoing vessels) (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Despite the inherent uncertainties, there are ongoing developments that *can* be projected into the future with a certain degree of confidence, such as the upcoming energy transition, developments in port-ship communication, automation and autonomous shipping, artificial intelligence and big data.

Energy transition

Approximately 90% of the world's trade is carried by sea. It's by far the cheapest way to transport large volumes of goods and raw materials around the world. In its third Greenhouse Gas (GHG) Study in 2014, the International Maritime Organization (IMO) estimated all shipping on average emitted 1.015 million tons of CO_2 per year, for the period of 2007 – 2012. This accounts for 3.1% of the estimated global annual CO_2 emissions. Similarly this study estimated all shipping on average emitted 20.9 million tonnes of NO_x (as NO_2) and 11.3 million tonnes of SO_x (as SO_2). These estimates represent 15% of the NO_x and 13% of the SO_x globally emitted by anthropogenic sources, as reported in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5).

The relatively high contribution to global NO_x and SO_x emissions can be attributed to the industry's use of cheaper, lower-quality, high-sulphur fuel oil (Figure 2.2). In 2020 the IMO introduced restrictions to the sulphur and nitrogen content of fuel, which are no longer met by high-sulphur fuel oil. Ships will therefore have to move over to other types of fuel or take special measures, like installing scrubbers, to reduce emissions. Figure 2.7 shows a Goldman Sachs projection of how these restrictions may affect the fuel mix.

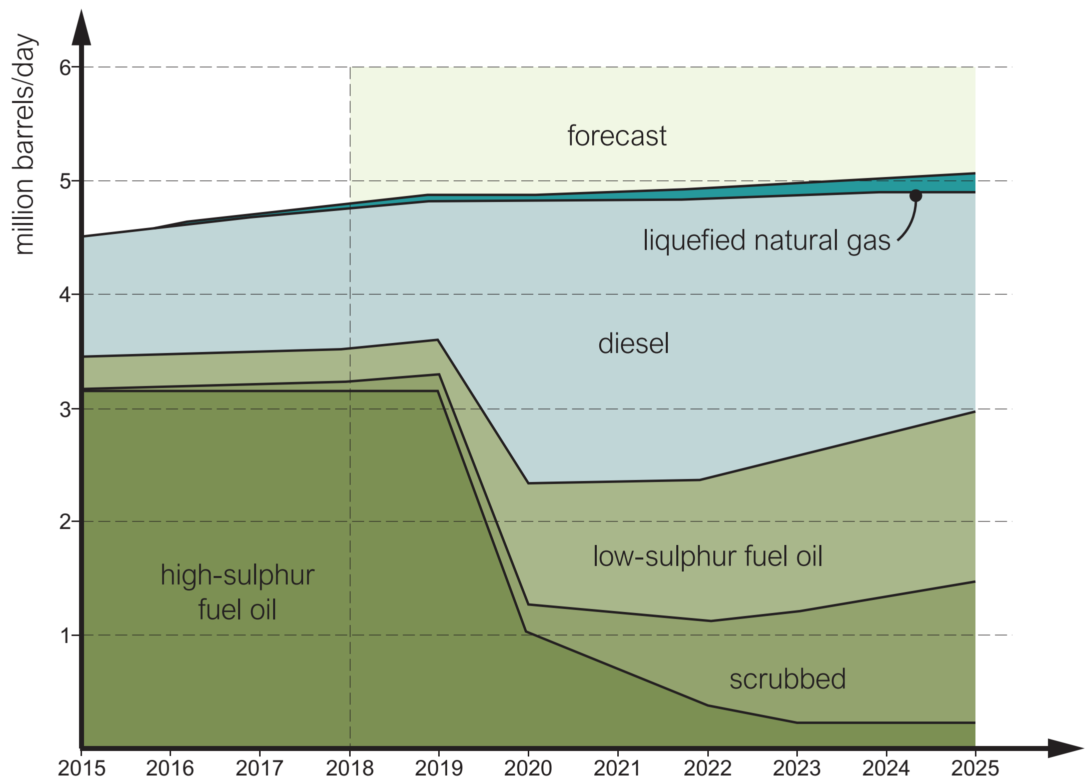

Figure 2.2: Expected evolution of the fuel mix in maritime shipping, in million barrels per day (reworked from www.economist.com by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Changes in the fuel mix may affect the competitiveness of Maritime and Inland Water Transport (IWT) compared to other modalities, or the competitiveness of one corridor over another. Ports will need to adapt their bunkering facilities anticipating future demand. But there is a long list of fuel and other energy carriers that can be used in shipping, and which one will prevail is as yet uncertain. The ones most commonly considered for the short term are LNG, Electricity, Biodiesel and Methanol. Other fuels that could play a role in the future are Liquified Petroleum Gas (LPG), Ethanol, Dimethyl Ether (DME), Biogas, Synthetic Fuels and Hydrogen (particularly for use in fuel cells). All these energy carriers are virtually sulphur-free, and can serve to comply with the new sulphur content regulations. They can be used either in combination with conventional, oil-based marine fuels, thus covering only part of a vessel's energy demand, or to completely replace conventional fuels.

For ports the energy transition presents risks, for instance when the industry moves to a different solution than initially anticipated. It also presents opportunities, however, to undertake new activities, such as creating production and blending areas for renewable fuels, or the production of synthetic fuels from imported hydrogen and captured carbon. If this leads to dismantling offshore oil and gas industry, there is a market for recycling offshore rigs and ships, as well as for supporting other offshore activities, such as the production of renewable energy in offshore wind farms.

It is fairly certain that the shipping industry will go through an energy transition in the coming years. But how this will take place exactly, and which choices will be made by the industry along the way, is still highly uncertain. Ports need strategic planning and adaptability to follow this transition.

Port-ship communication

Whenever ships come into port a whole range of administrative tasks need to be performed: customs declarations are needed for the ship's cargo and stores, immigration clearance is needed for crew, passengers and their baggage, import and export permits need to be arranged, et cetera. All these tasks are time-consuming and considered an administrative burden. Reducing this burden will increase the efficiency of maritime trade and transport.

Like in the case of the energy transition, significant changes are imminent in the way ports and ships exchange information. As of April 2019, national governments are required to introduce electronic information exchange between ports and ships, with the aim to increase the efficiency of the logistics chain. This mandatory requirement comes under the IMO Convention on Facilitation of International Maritime Traffic (FAL). It is a step toward just-in-time operations throughout the supply chain.

While it is fairly certain that information exchange between ports and ships will undergo large changes in the coming years, it is still uncertain which electronic system will eventually become dominant, and how this will affect other processes in the supply chain and the ports.

Autonomous shipping

Another spectacular innovation in the maritime (viz. seagoing and inland) industry is autonomous shipping. A fully autonomous vessel can observe and sense its environment, navigate and manoeuvre without human intervention. It can communicate with other ships, traffic control, waterway infrastructure and terminals. Autonomous shipping is driven by the need to make shipping safer, cheaper and more sustainable and is enabled by developments in sensor technology, telecommunication, artificial intelligence and computing, with improved digital connectivity and intelligence as a result.

Autonomous shipping has the potential to significantly lower transport costs, as it needs less manpower and the space for crew accommodation can be used for cargo. It can improve safety by reducing human error (about 75%

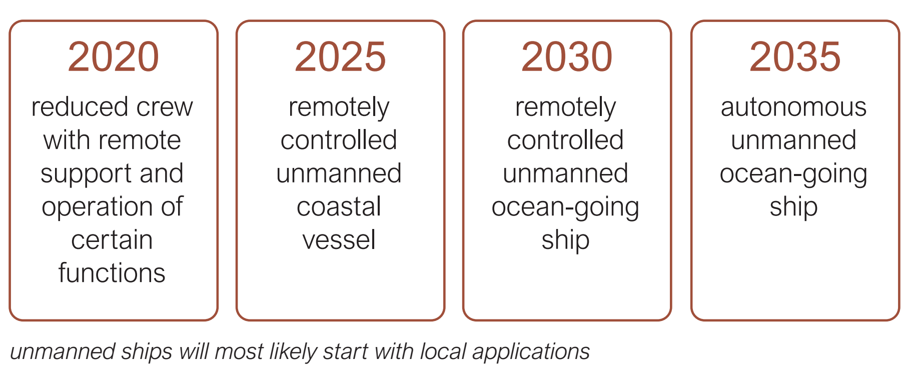

Figure 2.3: Evolution of autonomous shipping (modified from Rolls Royce, Autonomous ships – The next step by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

of maritime accidents are attributed to human errors), improve security by a reduced vulnerability to piracy, is less susceptible to crew shortage and strikes, and able to better integrate shipping in the transport system. Fuel saving through optimal steaming, the potential use of alternative fuels and zero-emission technologies, no ballast and less garbage and sewage are expected to make autonomous shipping more environmentally friendly.

Various parties around the world are working on autonomous shipping concepts. Rolls Royce, for instance, aims at launching its first unmanned ocean going vessel in 2025 (Figure 2.3). In the Netherlands, the first autonomous manoeuvring vessel trials were held in the North Sea in 2019, as part of the Joint Industry Project Autonomous Shipping.

Technologically speaking this development is already maturing, but its uptake in maritime transport lags behind. This is partly because an undisputable business case is still lacking and partly because this requires new international legislation and regulations regarding issues such as safety, insurances and emergencies. Increased digitalisation not only has benefits, but also presents risks (i.e. technical failure, hacking, etc.). Particular challenges are furthermore foreseen for the phase where conventional ships, smart ships and fully autonomous ships all make use of the same facilities.

For port and waterway engineers, the challenge is to figure out the interaction of such smart and autonomous ships with other vessels, the port infrastructure and assets for port operations such as piloting, tug support, berthing and mooring, loading and unloading.

While the end state of this development is highly uncertain and impossible to predict, is seems fairly certain that the coming years will see numerous developments in smart ships and autonomous vessels for specific applications (e.g. survey, inspection, crew change, waste removal). Some of the larger ports are already preparing for increased autonomy.

Big Data and artificial intelligence

Big Data is not just an amount of data too large for traditional data analysis, but rather a set of traditional (i.e. quantitative) data and non-traditional information from texts, images, social media and other such sources, enabling to achieve a certain goal that requires complex multi-parameter decision making. In the waterborne transport sector, this may for instance be route optimisation, fuel saving, emission reduction or waiting time reduction. Optimisation of an entire supply chain may also be such a goal.

One may qualify the data involved as high-volume, high-variety and high-speed, pointing at the large amount, the inhomogeneity and the speed at which the data need to be analysed (Figure 2.4). Note that it is not always possible or efficient to store all these data; sometimes they need to be analysed while streaming, saving only the results of the analysis.

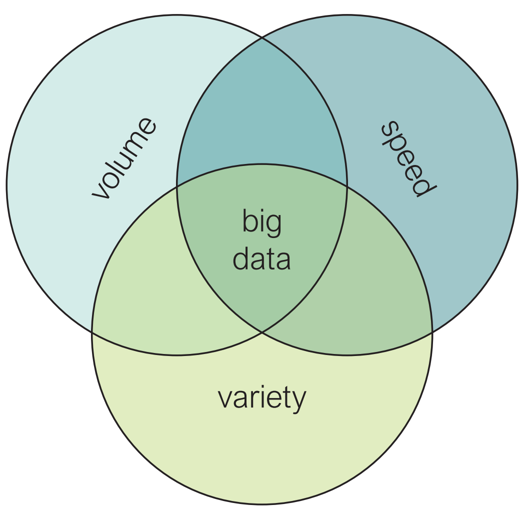

Figure 2.4: Characterisation of Big Data (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

DNV-GL, a worldwide operating registrar and classification organisation, identifies the following areas in which Big Data is expected to be of use in waterborne transport: technical operation and maintenance of vessels, energy efficiency, safety performance, management and monitoring of accidents and environmental risks from shipping traffic, and commercial operation and automation of ship operation (Mirovic et al., 2018).

Big Data offers special perspectives in combination with machine learning, an application of artificial intelligence. It aims at deriving predictive capability from the analysis of data, generally assuming these data to be homogeneous (i.e. free from large-scale trends). Hence, one might consider it as formalised experience, based on a large amount of observations. Machine learning in combination with Big Data can be of use in maritime transport for voyage planning, fuel saving, emission reduction, ship routing, safety, operational efficiency of ports and waterways, optimisation of supply chains, etc.

Producing such large amounts of data requires collaboration of many parties, in this case primarily ships and ports. This is why the Member States of the IMO have agreed that, as of March 2018, all ships larger than 5,000 gross tonnage have to share data on their consumption of all types of fuel oil, as well as some other relevant data, collected according to a uniform protocol. IMO collects these data in its Ship Fuel Oil Consumption Database, which is accessible to all Member States.

In inland waters the expected water depth is a key parameter, because it determines the allowable draught, hence the loading percentage of the vessels (Van Dorsser et al., 2020). Predictive capability of water depths is therefore of great importance for the optimal use of waterways. Especially in rivers, with their variable discharge and their morphologically active bed, this is not a trivial task. A novel development in this field is Covadem (https://www.covadem.org), a scheme in which depth data from on-board sensors of commercial vessels are shared, centrally stored, enriched with model predictions and made available to all participants.

With the advent of big data and machine learning, as well as the rapid developments in communication technology, such as 5G, it is fairly certain that data science techniques will strongly influence port and waterway engineering in the years to come. But where these techniques will be implemented first, and how that will affect all other processes in the supply chain, is still highly uncertain. Nonetheless, port and waterway engineers need to become skilled in data science methods, in order to be able to participate in this highly dynamic future.

2.1.2 Economic and political changes

Economies around the world go through cycles of rapid growth (boom) and stagnation (contraction) or decline (recession), superimposed on a long-term trend (Figure 2.5). These cycles translate directly into variations in trade and transport demand. As these cycles tend to occur at a timescale much shorter than the lifecycle of a port, port authorities and planners have to decide how they deal with them. Designing for the one extreme, the peak demand, is inefficient. Designing for the other extreme, however, implies long waiting times, causing loss of

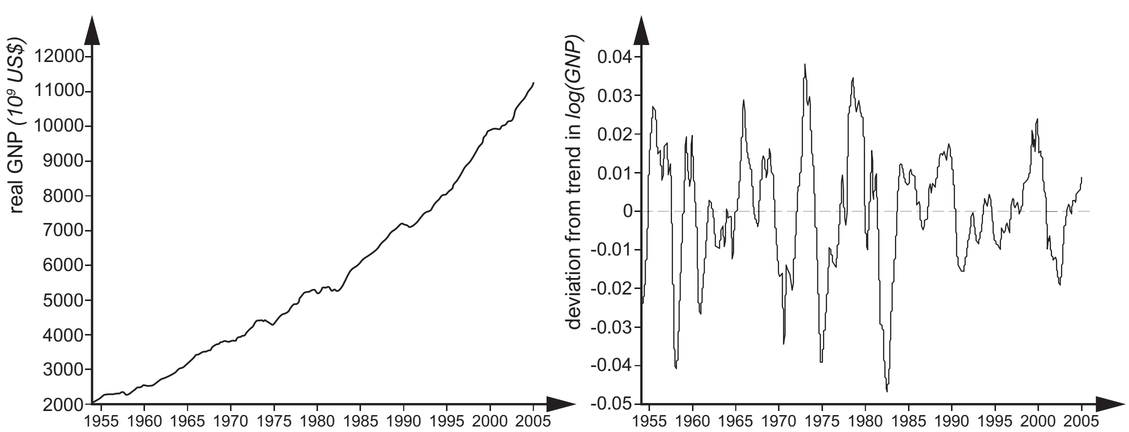

Figure 2.5: GNP-development in the USA between 1955 and 2005 (modified from Businesscycle figure1 and figure3 by Rochecon which are licenced under CC0 1.0, images by TU Delft – Ports and Waterways are licenced under CC BY-NC-SA 4.0).

service levels and reduced attractiveness. Where the optimum lies depends on local factors such as competition and hinterland.

Apart from these cycles, there may be changes in the global economic landscape, with upcoming and declining economies. Striking examples of the former are China and India, which have attracted large industrial complexes and the associated trade. At the moment, China has seven out of ten of the world's largest container ports (https://www.worldshipping.org – 2018). Consequently, at the other ends of the major transport routes large container ports are also needed, such as Rotterdam, Antwerp and Hamburg. It shows that, in order to profit from these worldwide economic developments, port planners need to understand how the global economic system works.

Changing economic relationships also occur at a regional scale. The EU, for instance, actively stimulates its new member states to come economically up to speed. This means that trade with these countries will increase, with obvious effects on international transport. Ports and waterways need to be ready to take on their share of this increasing demand. The opposite development may also occur, with the developments around Brexit as the most recent example.

Political decisions can have large economic consequences. Oil prices, for instance, are to a large extent politically determined, if not by the cartel of oil-producing countries, then by the threat of armed conflict between major states. An example of the impact of politics on the global transport system is related to the Suez Canal (see Section 1.1): its temporary blockades between 1967 and 1975, during the oil crises, led to the development of Very Large Crude Carriers (VLCCs) that are too large for the Canal and have now taken over a significant part of the worldwide transport of crude oil.

Also, customs barriers seem to revive as a political means to influence global trade. In recent years, interest rates are politically determined, due to the interference of the European Central Bank, for instance. The variation of such key parameters greatly influences the business case of a planned development. Their initiators therefore have to estimate how volatile or persistent these changes are, and therefore to what extent they need to be taken into account in their business case.

2.1.3 Changes in society

Society is not a constant factor in long-term decision making. Demographic changes like urbanisation may influence the availability of labour. Changes in consumption patterns, such as meat consumption, may influence the mix of transported goods. Increased drug abuse leads to more contraband, hence more severe cargo scanning and more delays in ports. Changing appreciation of environmental issues may lead to changes in legislation and environmental norms, hence in the possibilities for port expansion.

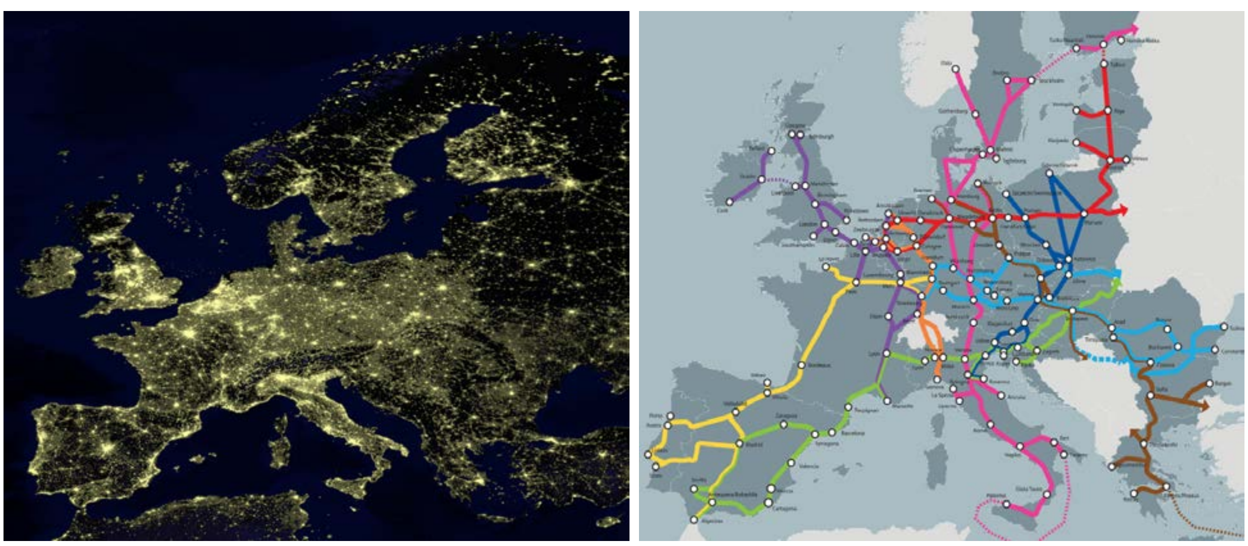

Figure 2.6: Population density and trade corridors. Left: Earthlights 2002 (by NASA is licenced under CC0 1.0); right: The Core Network Corridors (by European Union is licenced under CC BY 4.0).

On the other hand, trade routes and transport networks have influenced society since ancient times. People tend to settle where they can find a source of income and provision of goods. Despite the dramatically increased mobility of people, this is still the case at present. Urbanisation and megacity formation come with enhanced transport systems and they reinforce each other. Large concentrations of population are found around major transport corridors (Figure 2.6) and it is difficult to separate cause and effect.

In the meantime, citizens have become more articulate and know better how to use legal means to object against developments they don't want. The Port of Rotterdam experienced this when the first plans for the Maasvlakte 2 extension were rejected by the Supreme Administrative Court, because the environmental impacts were claimed to be insufficiently investigated. The way for port planners to go about this is not to ignore this kind of opposition, but to take it seriously and seek collaboration and compromises with all stakeholders in an early stage of development (see Part II – Section 1.3).

2.1.4 Climate change

The United Nations IPCC defines climate change as *"... a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer"* (IPCC, 2007, Synthesis Report)). The IPCC has developed multiple models and scenarios that simulate the change of the atmosphere in the future. Emission scenarios, translated into CO_2-equivalents, are important drivers of these models. Nowadays IPCC uses four Representative Concentration Pathways (RCPs) (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) that represent the radiative forcing [W/m^2] of the atmosphere (Figure 2.7).

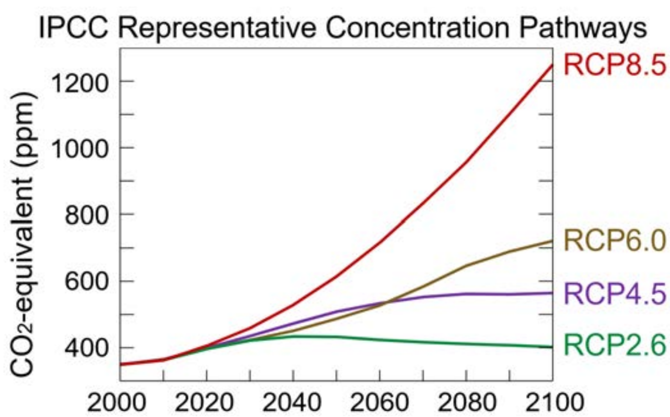

Figure 2.7: RCPs used in the Fifth IPCC Assessment Report (IPCC, 2014) (All forcing agents CO2 equivalent concentration by Efbrazil is licenced under CC BY-SA 4.0).

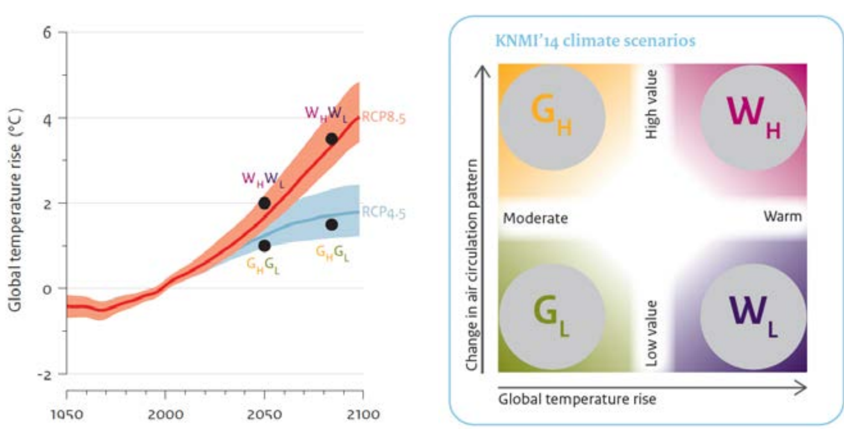

Figure 2.8: Climate scenarios (KNMI, 2014) (left: Global temperature rise according to IPCC (2013) is licenced under CC0 1.0; right: KNMI '14 scenarios is licenced under CC0 1.0).

For the Netherlands the IPCC-scenarios are translated for the Northwest-European region by the Royal Dutch Meteorological Institute (KNMI). It has defined four climate scenarios (G_L, G_H, W_L, W_H, see Figure 2.8) for the Netherlands that can be applied for the time horizons between 2050 and 2085 (flyer KNMI '14 climate scenarios, 2015 KNMI, 2015).

Impact on oceans, rivers and weather

The increase of the concentration of greenhouse gasses leads to global warming, of both the atmosphere and the oceans, and to changes in precipitation patterns. As a result of higher ocean temperature and melting of land-based ice sheets, the sea level will rise.

The melting of sea ice, especially around the North Pole, may have a quite different effect: the opening up of northerly navigation routes during a significant part of the year. This may lead to major changes in transport routes, for instance between Europe and Asia (see also Wikipedia: Arctic_shipping_routes).

There are no clear indications that there will be more storm activity on the Northwest-European coasts. As global water temperatures rise, there is an increased probability of Atlantic hurricanes bending northward (Haarsma et al., 2013), much like hurricane Sandy that hit New York in 2012. Such hurricanes can cause major damage to infrastructure on the coast, including port facilities. This may lead to not only significant repair costs, but also downtimes much longer than the storm's duration.

Climate change will also affect rivers, because they become more dependent on rainfall and groundwater seepage as mountain glaciers shrink. Hence the water inflow becomes more variable, which is aggravated by changes in precipitation patterns (longer droughts and more intense rainfall events). Hence discharge and water level variations are bound to become more extreme (Figure 2.9). Higher water levels during high flows give more downtime by lack of air draught under bridges, or more delays because bridges need to be opened. During extremes shipping

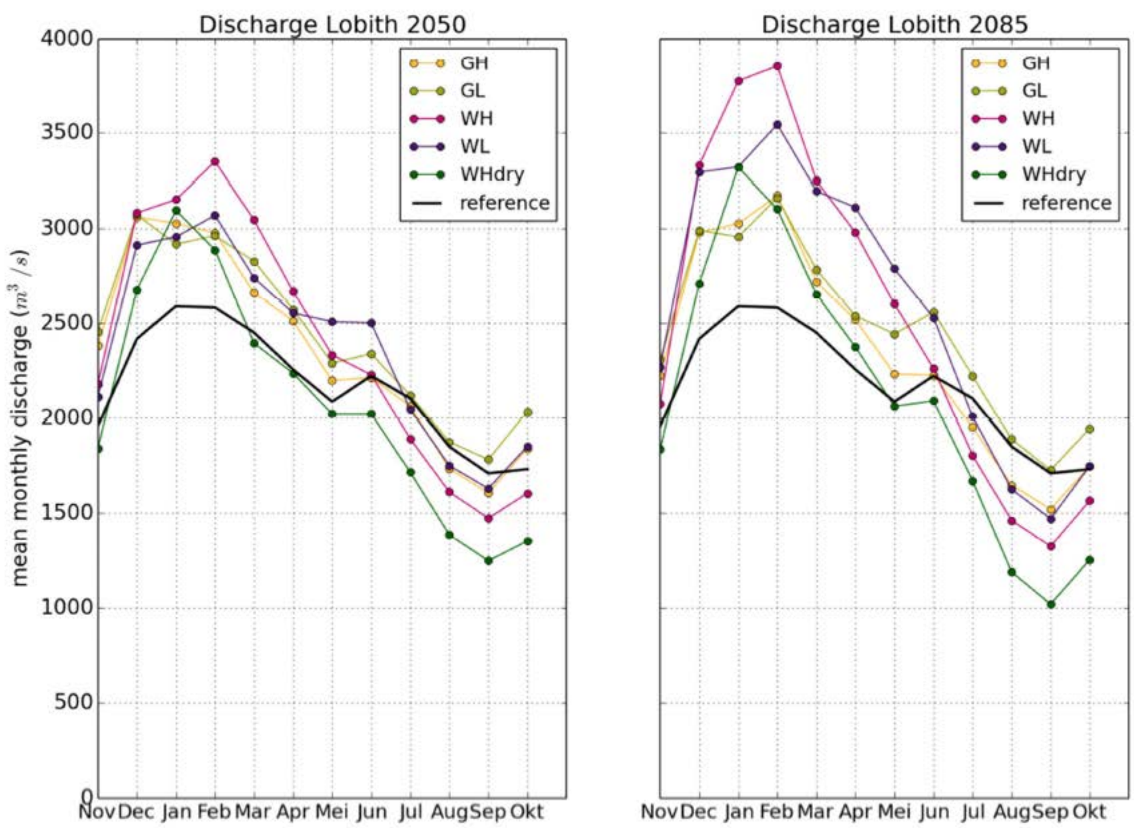

Figure 2.9: Monthly average Rhine discharges at Lobith for the different KNMI '14 climate scenarios (Sperna Weiland et al., 2015).

may be temporarily suspended to reduce pressure on dikes and levees at risk of overtopping/breaching. Low water levels during draughts reduce the load capacity of the vessels, hence to capacity of the waterway (Jonkeren, 2009; Van Dorsser, 2015; Van Dorsser et al., 2020). Here too restrictions may be imposed on shipping during extremes.

Without compensating measures, such effects clearly have implications for port operations and waterway capacity. PIANC-Envicom TG3 lists potential impacts and responses in its report Climate Change and Navigation (PIANC, 2008b). Many of them, however, are location-specific. Therefore, performance analyses of current supply chains have to reveal their vulnerability to climate change, as well as effective measures to prevent or mitigate them.

2.1.5 Accelerated relative sea level rise

Sea level has been rising throughout the Holocene, currently in the North-East Atlantic at a rate of about 0.20 m per century. In deltaic areas with a soft subsoil, this so-called eustatic sea level rise has to be combined with subsidence in order to calculate the change of sea level with respect to ground level. Subsidence can be due to tectonic effects (glacial rebound), the compaction of recently deposited sediments or peat oxidation. In the western part of the Netherlands, these subsidence effects add up to a multiple of the eustatic sea level rise.

Climate change is bound to accelerate eustatic sea level rise, at least on average, due to large-scale melting of land ice (Figure 2.10), though locally there can be deviations that are associated, for instance, with a changing mass distribution over the globe.

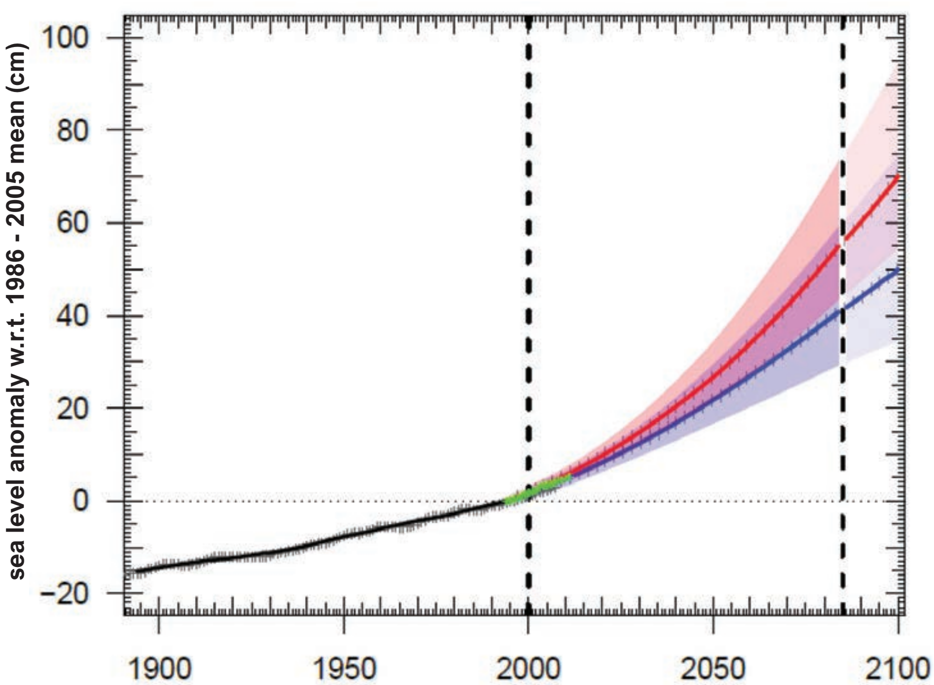

Figure 2.10: Eustatic sea level rise projections based on the KNMI '14 scenarios (modified from KNMI, 2014).

Relative sea level rise will have its impacts on coasts, ports and inland waterways. Coasts will exhibit a morphological response, generally erosive. This may also influence sediment transport patterns, possibly leading to increased port sedimentation. Inside the ports, structures need to be adapted to the higher water levels. It may also be necessary to take flood prevention measures for terminals and other port terrains.

The higher water levels, hence also the tide, will penetrate further into the rivers. Initially this will mean that fixed bridges need to be raised in order to maintain the fairway capacity. The increased tide also leads to erosion, but after some time this will be undone by sedimentation from upstream. The gain in navigable depth is therefore likely to be temporary. In the very long run, the effect of sea level rise is not restricted to the lower parts of the rivers, but will gradually extend upstream.

Adaptive and mitigating measures

To minimise the impact of climate change and relative sea level rise, a variety of adaptative or mitigating measures can be taken. Here we define the following main categories:

- port engineering measures (breakwater adaptation, flood protection measures, robust equipment, etc.);
- river engineering measures (detention areas, longitudinal groynes, floodplain measures, etc.);
- infrastructure adaptation (port water bodies, weirs and locks, bridge height, quay platform height, etc.);
- information management (water level forecasts, storm forecasts, Least Sounded Depth online, Covadem, route selection support, etc.);
- vessel technology (lighter materials, vessel design/dimensions, vessel trains, autonomous sailing, draught reduction devices, etc.); and
- logistic measures (hubs, synchro modality, stockpiling, 24/7 operations, etc.).

2.1.6 Ongoing human-induced changes

Apart from climate change and sea level rise, ongoing changes can occur in ambient conditions, for instance in response to events or interventions in the past. One example is the ongoing large-scale erosion of the Rhine branches, due to interventions such as the normalisations in the 19th and 20th century, sand mining and bend cut-offs. In large parts of the river this process is expected to continue in the next decades. As the water level follows the bed, structures of fixed height, such as lock thresholds or fixed bed layers, have to be adapted or built deeper than presently necessary. The former is the case, for instance, with the fixed outer bend layer near Nijmegen (Figure 2.11), the latter, for instance, with the new lock in the Twente Canal near Eefde, on the river IJssel.

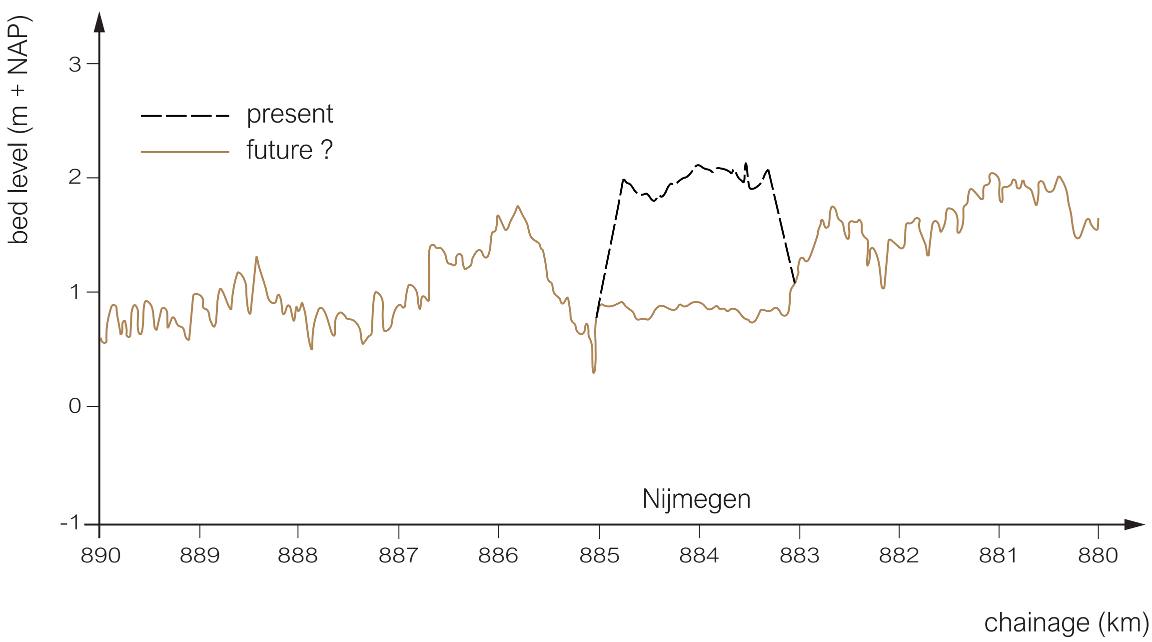

Figure 2.11: Fixed outer bend layer in the River Waal (built in 1988) sticks out of the eroding river bed and forms an obstacle to navigation (reworked from MIRT Onderzoek Duurzame Bodemligging Rijntakken, Rijksoverheid, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Another example of ongoing change is the Lower Ems (Tide Ems) upstream of Emden, Germany. Normalisation and deepening of the main channel to allow large cruise vessels to sail from the shipyard in Papenburg to the sea has led to an ever-increasing mud content in the river, up to environmentally unacceptable levels. Remediation requires expensive measures, leaving alone the question whether further deepening and widening for still larger vessels is an option.

Water and soil pollution can also exhibit long memory effects. If an area for port development is polluted, it should be remediated, otherwise the problem keeps coming back. Polluted water bottoms may keep leaching for a long time. Moreover, water quality problems outside the port, such as algal blooms, may penetrate into the port water bodies. Therefore, the recirculation times of these water bodies should be given due attention.

2.1.7 Crises and calamities

By definition, crises and calamities are unforeseen events with a large impact. Global economic crises may come to mind, but these are often stock-market crises which may be a forerunner of a recession. The response of trade and transport activities is generally not immediate or acute, so there is some time for adaptation. On the other hand, an economic low can last for several years, so it may certainly harm the transport system in the longer run.

Environmental crises can be more acute. Especially large events such as a calamitous release of poisonous matter or an accidental oil spill may lead to temporary closure of (parts of) a port to allow for remedial action.

In some cases calamities may be so detrimental that port operations are disrupted for a very long time. An example is the explosion, around 6:00 PM on August 2020, of 2.750 tons of ammonium nitrate which devastated the port of Beirut and a large part of the city. With port infrastructure and major storage facilities destroyed or severely damaged from the blast, all main supply chains into Lebanon were instantly disrupted. Since Lebanon relies nearly entirely on imports for all of its needs, this calamity impacted the country as a whole. Leading container lines immediately diverted ships to Lebanon's smaller port of Tripoli. Where Beirut's container terminal had an annual average capacity of just over 1 million TEU, Tripoli's has a capacity of 400,000 TEU. This could be enlarged to 600,000 TEU and a maximum of 750,000 TEU if more cranes are installed. Still, it would take a long time for all supply chains to be fully restored.

Futhermore, devastating earthquakes and tsunamis may bring down port activities for a longer time. Such events cannot be predicted accurately, but they can be prepared for, in areas where they are to be expected. This may save much trouble, costs and delays whenever they actually happen.

A special type of crisis is a large-scale health crisis. More or less regular examples are flu epidemics, which may temporarily reduce labour capacity. The 2020 Covid pandemic is a more extreme example for the transport sector, which has lasted longer and disrupted economic activities worldwide. This has financial consequences requiring robust financial buffers, but it also causes disorder in cargo throughput and supply chains, and may even bring long-lasting or permanent changes.

2.2 Planning port and waterway networks under conditions of uncertainty

When modifying existing waterborne transport networks, or developing new ones, the capacity to adapt to changes like the ones described in Section 2.1 should be taken into account. This requires knowledge of the waterborne transport system's functioning, as well as planning and design skills (technical, economic, legal). It also requires insight into the relevant trends, the uncertainties involved and ways to deal with these. In this chapter we lay a basic methodological groundwork for this. Part II – 'Ports and terminals' and Part III – 'Waterways' further elaborate the specific elements of the system and how to dimension these. Part IV – 'System performance' discusses how to analyse system performance.

2.2.1 The planning and design process

A transport network is a large-scale infrastructure that interferes at many points with spatial planning and environmental management. A port often covers a vast area which it excludes from other functions, and may have a significant environmental impact. A waterway cuts through an existing landscape and interferes with existing properties. It also crosses other infrastructural elements such as roads, railways, pipelines, cables or other waterways. Therefore, the development or adaptation of a transport network requires careful and time-consuming planning and design.

Suppose this has led to an overarching strategic goal at the political level, e.g. to stimulate the economy of an area, and that a first analysis reveals that this requires a better functioning transport network. Also suppose that the government has decided to enter the realisation process, what are the steps to be taken then?

Strategic Master Plan

The first step is a Strategic Master Plan (or pre-feasibility study), which includes explorative studies like:

- a global trade and transport analysis and the role the area may aspire to play;
- a problem analysis, focusing on what is lacking in the present transport infrastructure (e.g. a larger sea port, the ability to accommodate more types of cargo or better-functioning hinterland corridors);
- a solution outline (a new port, extension of an existing port with new terminals, satellite inland ports, capacity increase of certain fairways, etc.);
- economic considerations (may the benefits be expected to exceed the costs? What are the economic risks involved?);
- initial project definition (e.g. to extend an existing port with new terminals, to build a new sea lock for vessels of a certain size and with a certain capacity or to increase the navigable depth of a fairway);
- general functional requirements per project;
- planning implications (what to create where? How does this affect spatial planning? What are the environmental implications?);
- embedding in existing overall spatial plans.

This must lead to a Go/NoGo decision on a certain line of development, consisting of one or more projects to be further explored and elaborated.

Note that this process already has the character of a design process, in that iteration between steps may be necessary in order to achieve a solution that meets all requirements. It is also the phase where stakeholder involvement should begin, because this concerns the 'why' of the project(s).

Project Master Plan

Once the overall strategic Go-decision has been taken, a Project Master Plan is made for each of the projects to be realised. Part II - Chapter 2 describes such a plan for a port development. In general it includes:

- the strategic goal: what exactly one aims to achieve with the project;
- the relevant data (site conditions, cargo or traffic forecasts, vessel mix, etc.);
- specific functional requirements (service level, embedding in the network, etc.);
- a basic design, making it possible to investigate the project's feasibility;
- financial and economic feasibility studies, including a risk analysis;
- environmental aspects, not only in the form of an Environmental Impact Assessment (EIA), but also considering the possibilities of 'Building with Nature';
- social aspects, often in the form of a Social Impact Analysis (SIA), or a Societal Cost Benefit Analysis (SCBA);
- safety and security;
- management structure;
- type of contracting (construct-only, design and construct, design-finance-construct, design-construct-maintain, etc.).

This plan must provide sufficient information for a further Go/NoGo decision that sets the stage for permit procedures, financing arrangements, property acquisition, etc. A Go is also the start of the design process, which consists of the phases described below.

Functional design

The functional design translates the project requirements into one or more concrete objects that meet these requirements. Further below in this chapter we will give an example of how this works. Depending on the type of contracting, this design is made in-house by the project owner, by a hired consultant or by a contractor (often a contracting consortium). As port and waterway development usually involves large projects, the latter two options require a tender procedure.

Structural design

In this design phase the object is elaborated structurally, such that it is strong, rigid and stable enough under the design load conditions and can serve all its desired purposes. A quay structure, for instance, must be strong enough to carry the weight of the equipment and cargo on top of it, but also to resist the forces exerted on it by a moored vessel. Moreover, its foundation has to be stable enough to prevent subsidence and its earth-retaining structure has to be rigid enough not to give way to the soil-mechanical forces exerted on it.

Execution design

Designing an infrastructural object is one thing, constructing it is another. The realisation of a complex object like a port, terminal, lock or waterway is a complicated operation that requires careful planning in space and time. It encompasses timely ordering, delivery and storage of material and components, organisation of construction activities, management of subcontractors, safety and security, reduction of interference with other activities and infrastructures, etc. In this phase the last permits may have to be arranged. In case of large projects with a high exposure, a special point of attention is public communication (publicity, visitors, logging, etc.).

Operation and maintenance

Once the object has been realised, it is handed over to the user. Clearly, enabling optimal operation is a design requirement. Sooner or later, however, maintenance will be needed. Facilitating this (in order to reduce costs and downtime) increasingly receives attention in the design phase.

2.2.2 The 'Frame of Reference' approach to design

The basic template

Planning and design, as described in the previous subsection, is an iterative process that people use to achieve certain objectives. A systematic approach to this is the Frame of Reference (FoR) approach developed by Van Koningsveld and Mulder (2004) (see also Laboyrie et al., 2018). It works with a set of closely interconnected elements that need to be specified in any planning and design process (see Figure 2.12).

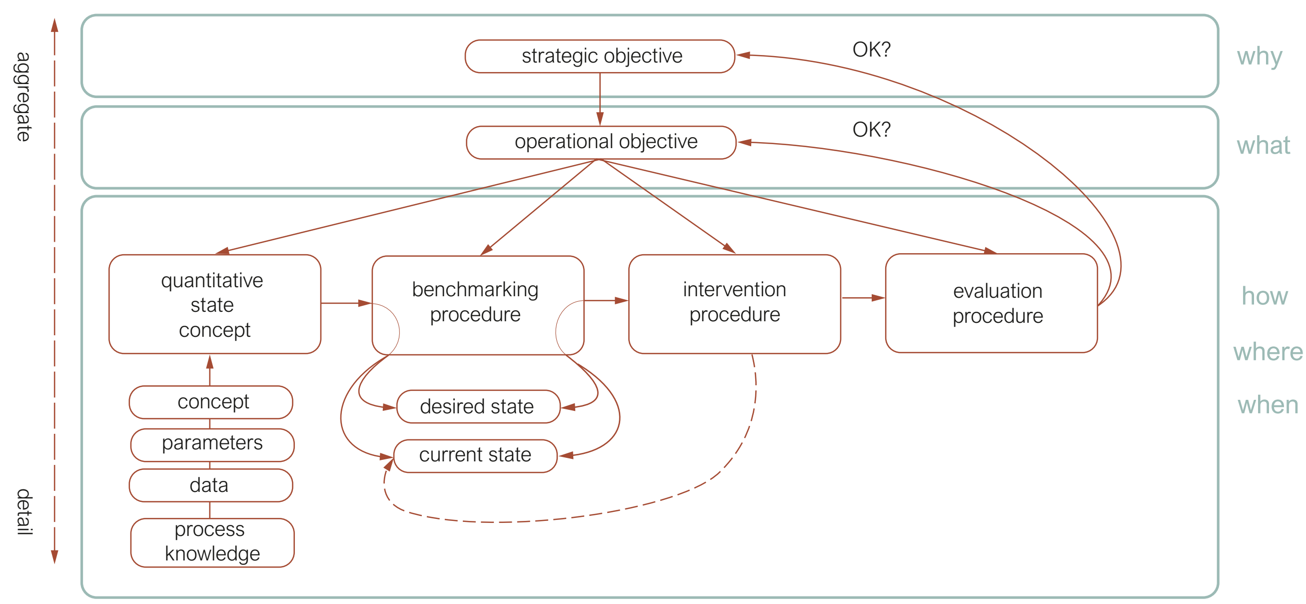

Figure 2.12: Basic 'Frame of Reference' template (reworked from Marchand, 2010, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

It starts with the definition of clear objectives at strategic (why?) and operational (what?) levels. When the objectives are clear a practical decision recipe should be designed, specifying how, where and when the objectives will be met. The decision recipe involves specification of the following elements:

- a Quantitative State Concept (QSC),
- a benchmarking procedure,
- an intervention procedure, and
- an evaluation procedure.

The **strategic objective** indicates 'why' the planning and design process is needed in the first place. It often specifies an overarching larger-scale longer-term goal, such as the ambition to develop an efficient and sustainable transport network.

The **operational objective** specifies 'what' will be undertaken specifically to achieve this overarching goal; more or less like the program requirements of a construction project. In the case of a lock design, for instance, it indicates what the capacity of the lock should be, under what conditions it has to function, what environmental constraints have to be respected, what the cost limit is, etc.

The **Quantitative State Concept (QSC)** specifies how important aspects of the operational objective will be quantified, i.e. related to transport capacity, environmental impact, operating cost et cetera. As such the QSC forms the explicit link between the operational objective and the benchmarking procedure that indicates whether or not intervention is required to achieve that objective.

In the **benchmarking procedure** the current (or predicted) state of the system is compared with its desired state; both expressed in terms of the QSC. Any discrepancy is an indicator of a problem, and as such a trigger for intervention.

We should point out that we define 'indicators' as assemblages of QSCs that indicate whether or not there is a problem. This implies the need for comparison with a reference or benchmark. Often the word, indicator, is used for things that should actually be considered parameters, values or system properties. Here we reserve the word, indicator, specifically for usage in a problem-solving context: the indicator must indicate if there is a problem.

The **intervention procedure** should (iteratively) produce an intervention of such dimensions that the problematic current (or predicted) state is converted to an acceptable state. This may sound trivial, but in practice is often not explicitly demonstrated.

In the **evaluation procedure** the performance of the decision recipe is evaluated against the operational *and* the strategic objectives. This two-level evaluation procedure may give rise to reformulations of the objectives, a different QSC, a different reference state or a different intervention procedure.

It is furthermore important to specify which authority is assumed to be responsible for the implementation of the resulting FoR, as this may affect the specification of solution elements.

Ideally, all elements of the basic FoR template are made explicit in the end user-specialist interaction. Remaining 'white spots' represent information gaps for decision making and may become part of a knowledge agenda.

The FoR approach has been applied to a variety of projects, in which specialists from different disciplines, nationalities and backgrounds engaged with policy- and decision-makers. It has been used (implicitly) since the 1990s in the Netherlands for the successful development and implementation of a scale-resolving coastal sediment management policy (Van Koningsveld and Mulder, 2004; Mulder et al., 2011). It was also used in various European research programmes, for example in the CoastView project, where the Argus video observation system, among others, was employed in the management of dynamic navigation channels (Medina et al., 2007). Laboyrie et al. (2018) recently proposed to use the FoR approach as tool for project assessment.

In this book we apply the FoR approach to port and waterway problems. Examples of where the FoR approach could be of use are:

- *Functional design of a lock* – To maintain the transport capacity of a waterborne transport network in an efficient manner (strategic objective), it may be decided that waiting times should not exceed 30 minutes (operational objective). A QSC that describes the total passing time of a vessel (including time spent waiting) could be used in an iterative design process where lock dimensions are varied until the 'modelled' waiting time, for the design traffic intensity, is smaller than the maximum allowable waiting time of 30 minutes (benchmarking/intervention procedure). The evaluation would show that the operational objective is achieved (waiting times < 30 min), but a closer look might reveal that high costs are incurred for a rarely occurring situation, or that mooring line forces exceed safe limits. This could trigger a round of sharpening the objectives, modifying the QSC, changing the intervention procedure, et cetera.

- *Functional design of a container terminal* – To competitively handle a certain throughput of TEU (strategic objective), it may be decided that average waiting times should not exceed 10% of the average service times (operational objective). A QSC that derives berth occupancy from a predicted vessel mix and call size and a selected crane capacity and number of cranes, could be used in an iterative design process where quays and cranes are added until the 'modelled' waiting time as a factor of service time is smaller than the maximum allowable 10% (benchmarking/intervention procedure). The evaluation would show that the operational objective is achieved ($\overline{WT}/\overline{ST} < 10\%$), but a closer look might reveal that the calculated quay and crane configuration is not very robust for future changes, or that other elements of the terminal now become bottlenecks. This could trigger a round of sharpening the objectives, modifying the QSC, changing the intervention procedure, et cetera.

Obviously many other examples can be conceived. In Part II – Part IV information is provided that should enable you to develop complete FoRs for a wide range of port and waterway related design challenges and perform first-order quantification.

2.2.3 The 'supply chain' concept

The previous subsection described the FoR approach as a systematic procedure to develop designs. A pivotal element in the basic FoR template is the QSC, as it creates an explicit link between the operational objective and the benchmarking procedure. A useful concept in the analysis of waterborne supply chains is the supply chain concept, which we briefly introduced in Chapter 1 as the multi-stage connection between the supplier of a good and the receiving customer (Figure 2.13). Supply chain analysis helps to give insight into how a transport system functions and interconnects, whether it performs as desired and what are potential measures for improvement.

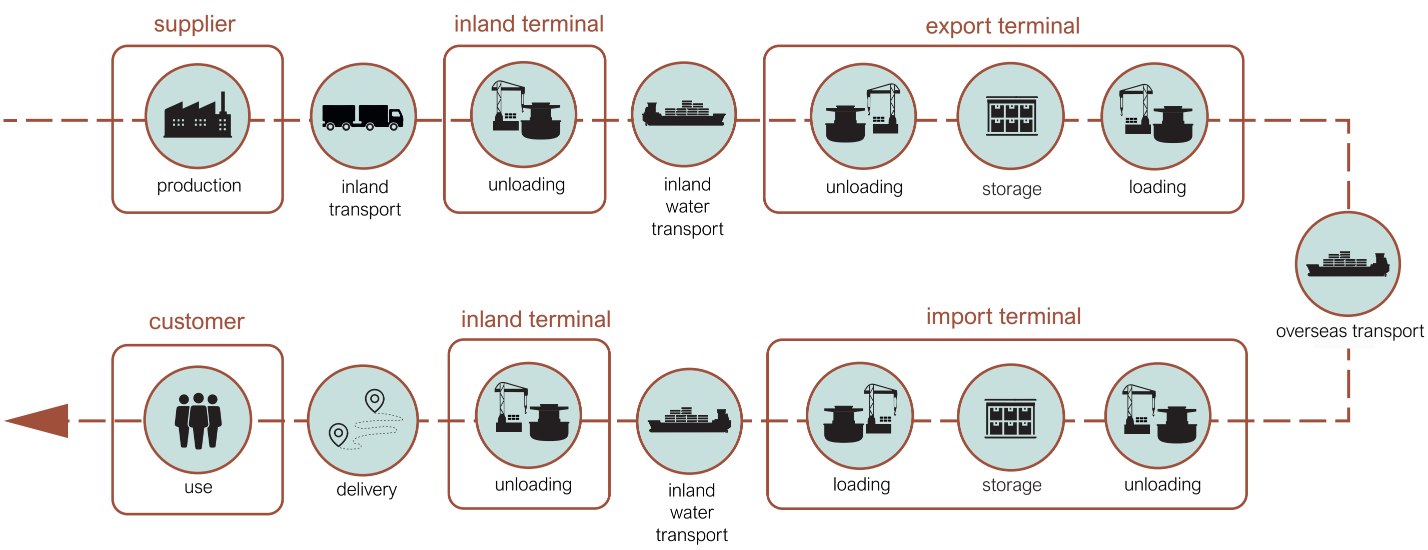

Figure 2.13: Supply chain as the link between supplier and customer (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The chain concept also applies at a more detailed level to many of the elements of this overall supply chain. The functioning of an import terminal, for instance, can be mapped onto such a chain model (Figure 2.14). Clearly, this chain can also be reversed in the case of export.

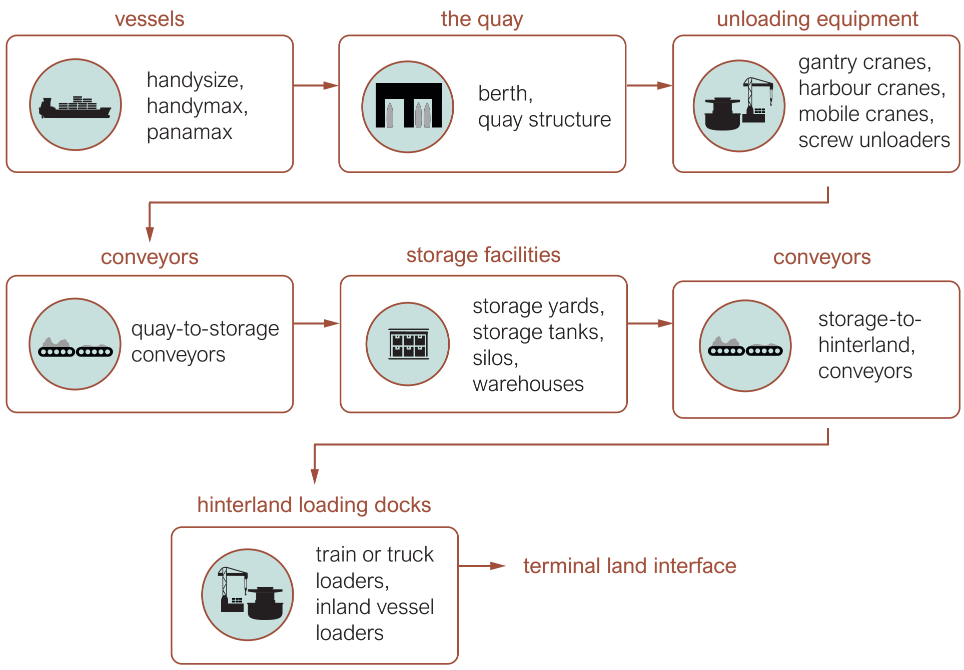

Figure 2.14: Chain model of a dry bulk terminal structure (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Other parts of the overall supply chain can also be represented by a chain model, as shown in Figure 2.15 for inland transport.

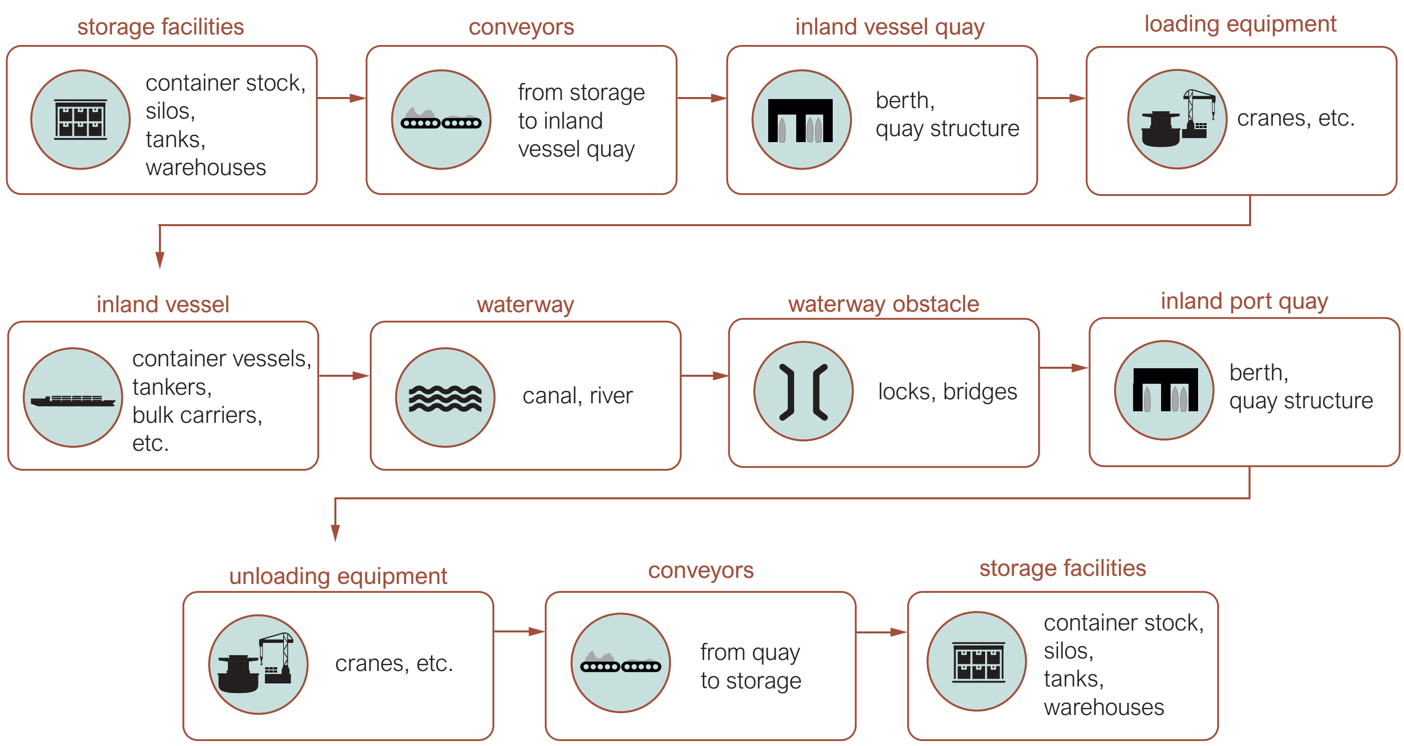

Figure 2.15: Chain model of inland waterway transport facilities (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Note that Figure 2.13, Figure 2.14 and Figure 2.15 suggest a linear process. The interactions, however, are mutual, with multiple feedback effects. If congestion occurs at a certain point in the chain, for instance, 'upstream' actors may decide to temporarily change their operations, or to move over to another transport modality. Furthermore, other chains may link in or split off, for instance in case of multiple suppliers in different parts of the world, or multiple customers at different locations.

By considering a terminal as a chain of interlinked elements, and terminal operations as a coherent set of activities that move cargo through this chain, it is possible to calculate handling times, queue formation and throughput estimates, and to identify bottlenecks that limit these throughputs. Hence the 'supply chain'-concept forms a basis for balancing and optimising the terminal design (at master plan level as well as at functional design level). Implemented in simulation software it can help establishing how best to respond to changing conditions, such as a throughput increase that exceeds the existing capacity, or a change in vessel mix that no longer fits the existing quay structure. It also enables risk analysis at system level and the establishment of redundancy requirements in case one or more elements underperform or fail. Finally, it provides the basis for economic analysis.

Considering the inland transport network as a chain of interlinked elements and inland shipping as a coherent set of activities that move cargo through this chain provides similar opportunities for analysis, optimisation and adaptation. Applying this concept to both terminals and waterways allows us to connect them to form waterborne transport systems.

2.2.4 Financial aspects and investment decisions

The previous subsections discussed the process of planning and design, the use of the 'Frame of Reference' to approach this systematically, and the supply chain concept as a means to analyse system performance and to develop and assess the effectiveness of alternative measures. A next step is to investigate the feasibility of the alternatives. A key aspect to decide on feasibility is how costs and benefits are balanced. It is good to realise that there is a big difference in the way private organisations and public entities come to a decision.

Private financing or ownership

The role of private parties in the financing of infrastructure can be twofold. One possibility is that a private financier makes capital available against a certain annual rate of return without being involved in the operation. A Cost-Benefit Analysis (CBA) of the project can be performed to estimate the risk, hence to establish the rate of return that is required. In such an analysis incoming (+) and outgoing (-) cash flows are compared, to check if the net result is positive. The second possibility is private ownership, where the private party finances the infrastructure and has it built, operated and maintained. Such parties also decide to invest on the basis of a CBA.

Outgoing cash flows to be taken into account are:

- the costs of invested capital (opportunity costs of own as well as borrowed capital),
- the CAPital EXpenditures (CAPEX), to produce non-consumables such as built structures, but also to acquire land, for instance;
- the OPerational EXpenditures (OPEX), associated with running the infrastructure, such as labour cost, energy cost, insurance, etc.
- the costs of maintenance (yearly maintenance costs are usually included in OPEX),
- renovation and/or replacement costs requiring new capital, and
- the costs of decommissioning.

Furthermore, there may be exhaust emission costs in each development step.

Revenues are mainly operational, e.g. from port dues and tolls if the investing actor is a port authority, or from product sales if the investing actor is a terminal operator. The overall business case should account for the residual value that is represented by the assets at the end of the projected lifecycle.

The aforementioned costs and revenues materialise at different points in time, as Figure 2.16 shows. It is important to note that these timing aspects can be very important for the overall business case.

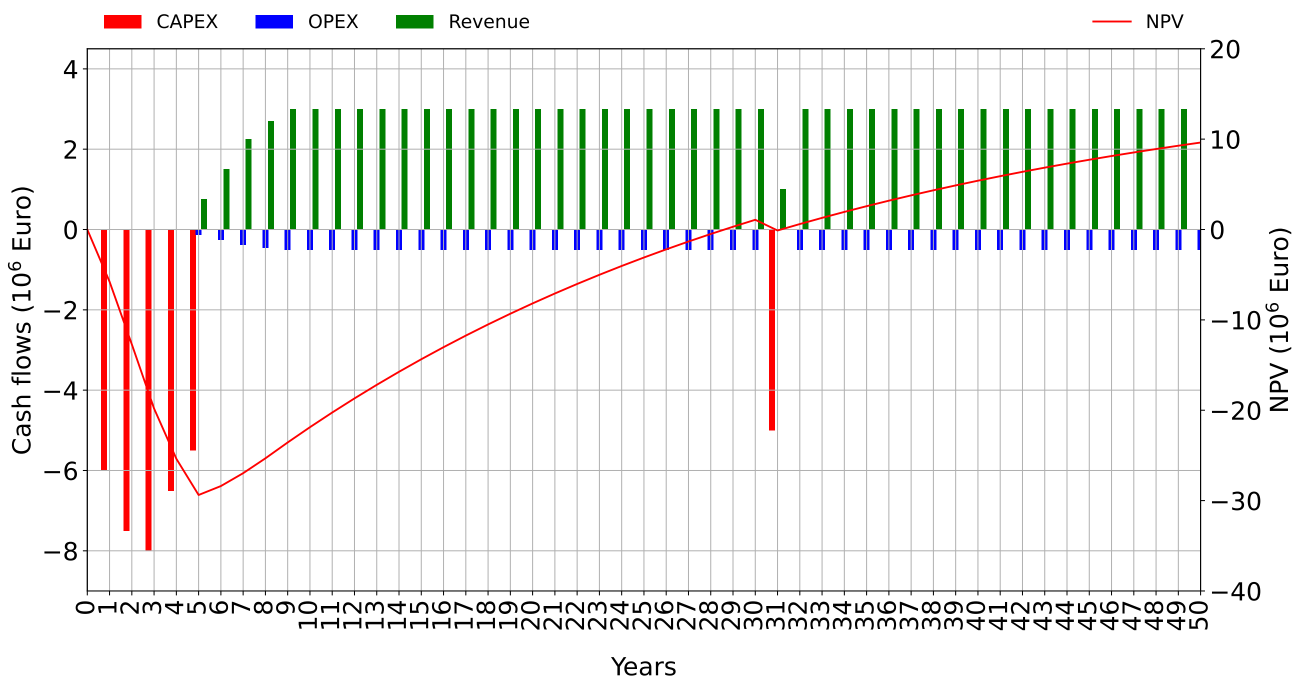

Figure 2.16: Hypothetical example of the time-distribution of expenditures and revenues, with a capital-demanding renovation after 30 years (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

The Time Value of Money (TVM) concept implies that an amount of money spent or earned now is worth more than that same amount in the future. This is based on the assumption that money can earn interest. To take the TVM concept into account, all cash flows are translated to one point in time, to arrive at the Present Value (PV). This can be done by a process named discounting. Assume that if an investor can have an annual rate of return on capital of r percent on average, then he will expect a similar revenue from an investment in an infrastructural project infrastructure. The same goes for own capital: if it would be invested elsewhere, it would produce an annual rate of return r percent on average, so if it is invested in the project it may be expected to produce the same return. From the point of view of the project, these are cost items, named opportunity costs of the invested capital.

In order to cover the opportunity costs, the invested capital C_0 has to grow every year by a factor $(1+r)$. So after n years it has become:

$$C_n = C_0(1+r)^n \tag{2.1}$$

assuming the rate of return r to be constant over time. The other way around, the present value of C_n follows from:

$$C_0 = C_n(1+r)^{-n} \tag{2.2}$$

So, the further into the future, the smaller the present value of capital.

If we apply Equation 2.2 to the yearly Net Cash Flow (NCF), the total Net Present Value (NPV) for years 0 to n becomes

$$NPV_n = \sum_{k=0}^{n} \frac{NCF_k}{(1+r)^k} \tag{2.3}$$

in which r is called the discount rate. If a project has a positive NPV over its life cycle, it is financially feasible.

Yet, this is not the whole story. If one considers the nominal value of capital, a monetary unit (Euro, Dollar, etc.) in the future is the same as that unit now. But the real value, i.e. amount of goods one can buy for that unit, changes over time due to inflation. So if an investor requires a real rate of return of r' percent, the discount rate has to be corrected for inflation. Assuming a constant inflation rate i and following the same rationale as above, the real value of the invested capital grows in one year by a factor $(1+r)/(1+i)$, in which r is the nominal discount rate. This means that after n years it has become:

$$C_{nr} = C_0 \left(\frac{1+r}{1+i}\right)^n \tag{2.4}$$

and the present value of an amount C_{nr} now follows from:

$$C_0 = C_{nr} \left(\frac{1+r}{1+i}\right)^{-n} \tag{2.5}$$

This means that the discount rate corrected for inflation follows from:

$$r' = \frac{1+r}{1+i} - 1 \tag{2.6}$$

In summary, inflation implies that the nominal capital should accrue more in order to compensate for the loss of real value, and that the discount rate should therefore be smaller.

Apart from the NPV, other useful financial metrics are:

- the Internal Rate of Return (IRR), which is the discount rate that yields an NPV of exactly zero,
- the Benefit Cost Ratio (BCR), i.e. the ratio of the revenues over the expenditures (CAPEX + OPEX), all expressed in present values, and
- the discounted payback period, i.e. the time needed for the cumulative PV of the revenues to exceeded the cumulative PV of the expenditures (the break-even point).

In the Netherlands, a fixed discount rate for public projects is set by the government. In other cases, it depends on the market for capital, which is often rather volatile. The sensitivity of the investment decision to the ensuing uncertainty can be estimated by evaluating the NPV for various discount rates. In general it can be stated that business cases will improve if outgoing cash flows (costs) are reduced and postponed, and incoming cash flows (revenues) are increased and brought forward.

The NPV analysis described above implicitly assumes that capital investments, once committed, stay as they are. Since the future is uncertain, it may be necessary at some point in time for the project management to adapt to changing conditions, with additional financing needs and implications for the project's further prospects. Techniques such as Real Options Value (ROV) allow us to take flexibility into account in the initial financial assessment.

Publicly owned infrastructure

Government decisions are less driven by financial return on investment than by the consequences for the welfare and well-being of society as a whole. Nevertheless, the government is expected to underpin its decisions with facts and figures. Therefore, such decisions are supported by another evaluation tool, the SCBA. In principle, this tool can be used to evaluate alternatives in the funnelling process of a master plan (see Part II – Section 2.1). The complexity of large infrastructure projects, however, with many stakeholders and affected interests, a long life cycle with many uncertainties, and costs and benefits falling to different parties, makes the application of SCBA rather complex and laborious. Therefore, its application is often limited to comparing the preferred alternative with the null-alternative, so as to underpin a Go/NoGo for the project.

An SCBA systematically maps out all relevant societal and environmental effects of a project, if necessary based on preceding impact analyses specifically made for this project. As far as possible, these effects are quantified and expressed in mutually comparable monetary terms (PVs), leading to a balance of costs and benefits for these effects. By doing the same for the null scenario, avoided costs and missed benefits can also be taken into account.

Not all effects can be monetised on the basis of market prices. Techniques such as risk assessment and ecosystem service assessment can help to valuate these aspects so that they still can be taken into consideration (see also Laboyrie et al., 2018). Yet, some relevant effects will remain that cannot be expressed in monetary terms and still have to be made visible in the SCBA. In view of the often complex and laborious nature of a full SCBA, simpler forms have been developed. In order of increasing complexity:

- *Quick Scan* – gives a first indication of the most important effects and related costs and benefits on the basis of substantiated assumptions and experience from similar projects.
- *Index-based CBA* – similar to a full SCBA, but effects, costs and benefits are estimated on the basis of generally applicable index values derived from other studies.

Public-private partnership

There are many forms of Public-Private Partnerships (PPPs), from joint financing, via joint realisation through to joint operation and maintenance of projects. Correspondingly, there are many contract forms, in which the distribution of costs, benefits and risks among the partners is an important issue. In project realisation arrangements the government generally focuses on the final goal of the project and does not interfere with the realisation process. This is different than the traditional way of working, where the government and its consultants produce a complete design, which is executed as such by the contractor. In PPP arrangements, the government focuses on achieving the ultimate goal, which gives the private parties room to optimise the realisation process.

Examples of such integrated contract arrangements are:

- *Design and Construct (D&C)* – where the contractor, often assisted by consultants, develops and builds the design and subsequently hands it over to the client. This enables optimal tuning of design and execution. Many of the projects of the Room for the River program in the Netherlands have been realised under this type of contract. Maasvlakte 2, the recent extension of the port of Rotterdam, was also realised under a D&C-contract.
- *Design, Construct, Maintain (DCM)* – where the contractor guarantees the proper functioning of the object during a set period of time. This stimulates maintenance-friendly designs. An example is the new City Bridge across the river Waal at Nijmegen.
- *Design, Build, Finance, Maintain (DBFM)* – where the contractor also arranges the project's financing. Examples of DBFM-projects in the Netherlands are the second lock in the Twente Canal near Eefde and the new sea lock in the North Sea Canal at IJmuiden.
- *Design, Build, Maintain, Operate (DBMO)* – where during a specified period of time the contractor is also responsible for the operation and maintenance of the project. This enables further optimisation.
- *Design, Build, Finance, Maintain and Operate (DBFMO)* – this is at present the most extensive form of integrated contracting.

2.2.5 Natural and social environmental aspects

Apart from financial feasibility, which is typically driven by supply chain optimisation and investments in capacity and efficiency (cost and benefits), an intervention's overall feasibility also depends on environmental aspects. Natural as well as social environmental aspects (negative or positive) need to be considered carefully whenever designing port and waterway solutions. Some aspects can be monetized and may be incorporated into the investment analysis. Other aspects, however, may be hard to monetize but can be influential nonetheless.

Ports, waterways and the activities they support are bound to have environmental effects. Not only by the space they occupy, but also by producing emissions, noise, light, dust, odour, waste, water, air and ground pollution, dredging, (contaminated) dredged material management and the like. The transport of hazardous goods may lead to risks for public and natural environment.

The increasing public awareness of environmental issues drives interest groups and administrations to demand reduction of adverse environmental footprints. It has led to national and international legislation and conventions concerning various types of environmental impacts. Examples of the former are the European Union (EU) Framework Directives. Examples of the latter are the International Convention for the Prevention of Pollution from Ships (MARPOL), a global convention initiated by the IMO, and the regional Convention for the Protection of the Marine Environment in the North-East Atlantic (OSPAR).

Meeting these demands and the range of environmental legislation requires a change in attitude of authorities and decision makers, towards a proactive approach of the environment, public access to relevant information, participative decision making and fair cost allocation (see also Laboyrie et al., 2018).

When developing and operating ports and/or waterways, due attention must be paid to important environmental policy issues, such as:

- decision making based on balanced environmental, social and economic considerations,
- protection, conservation, restoration of nature values,
- mitigation and compensation of (residual) environmental effects, and
- seizing opportunities to cleverly combine infrastructure development and operation with nature enhancement (e.g. Building with Nature (BwN), Engineering with Nature (EwN) and Working with Nature (WwN)).

In most countries, port development requires Environmental and Social Impact Analysis (ESIA), embedding in existing spatial plans and compensation or mitigation of negative impacts. In Part II of this book we describe how these fit into the port planning process. Here we briefly discuss some environmental aspects, associated with ports and waterways, that deserve special attention:

Accidents Waterway operations and IWT involve risks. Shipping accidents may lead to blockage of the fairway and vessels having to make long detours in order to reach their destination (Figure 2.17), resulting in time loss, extra energy consumption and extra emissions. The accidental blockage of the Suez Canal of March 2021 is a prime example of an accident with implications at global scale. Accidents may also lead to spills and hazardous situations with dangerous cargo (explosions, chemical gas releases) involving fatality risks or public health risks. Port and waterways planners should take the probability of accidents into account, and consider alternative options they need to make available should an accident actually occur.

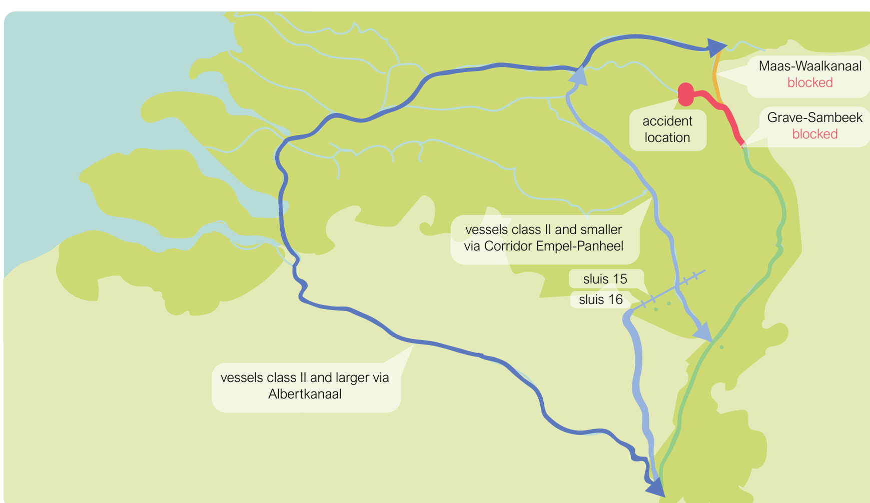

Figure 2.17: Detours required after a shipping accident at the weir of Grave (red circle) (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Dangerous cargo A determining factor for the risk involved in handling dangerous cargo in ports is the location. A risk analysis can produce risk contours (Figure 2.18), such that in the design of the port layout one can make sure that sensitive areas stay outside contours with unacceptable risk levels.

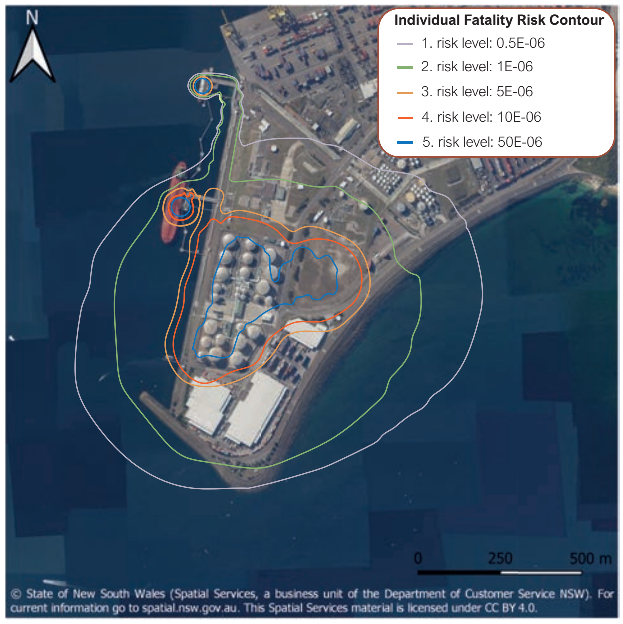

Figure 2.18: Individual fatality risk contours for an oil terminal, Port Botany, Australia (background: Spatial Service State of New South Wales, contours: Sherpa consulting, image by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

Important risk-reducing measures are

- structural measures (buffer areas, containment systems, firefighting facilities, safe storage),
- information (when will how much of this type of cargo be in the port?),
- operational measures (regulations, communication, safety measures), and
- contingency and emergency plans and corresponding facilities.

RVW (2020) (see Part III – Chapter 5) also refers to risk contours along waterways. Within a certain contour (e.g. individual fatality risk 10^{-6}) no buildings are allowed. Information provision, operational measures and contingency and emergency planning also apply to waterways.

Dredging and dredged material management Dredging is common in most ports and waterways, to create channels or port water bodies (capital dredging), to remove deposited sediment (maintenance dredging), or to remove contaminated sediment (environmental dredging). Apart from consuming energy and emitting greenhouse gases, dredging disrupts the benthic system, causes turbidity, and produces dredged material (see also Becker et al., 2015; Laboyrie et al., 2018). Turbidity plumes can be carried with the current to environmentally sensitive

Figure 2.19: Dredging activity in the Fehmarnbelt, Germany ("Fehmarnbelt Fixed Link Dredging and Reclamation, 2021" by Royal Van Oord is licenced under CC BY-NC-SA 4.0).

places, where they may do harm by extinguishing light and depositing sediment. Within ports the currents are generally weak, but nevertheless plumes may spread (Figure 2.19), for instance due to wind-driven currents, tidal filling and emptying and density effects. In rivers and coastal zones currents, and hence turbidity spreading, are obviously stronger. In rivers groyne fields and other sheltered zones cause additional dispersion, because turbidity lingers there. Research efforts have long been focused on reducing the source (hopper overflow) or containing the turbidity where it does less harm, using screens or bubble screens, for instance (Figure 2.20). Recent research also focuses on reducing the impact on the ecosystem, for instance by careful timing of dredging operations and the re-use of dredged materials (Laboyrie et al., 2018).

Figure 2.20: Dredging-induced turbidity containment with a bubble screen (Turbidity & Dredging by Royal Van Oord is licenced under CC BY-NC-SA 4.0).

What to do with the dredged material depends on its properties. Clean sand can be used in the building industry, or for coastal nourishments, landfills or land reclamation. Within a few years dewatering of unpolluted mud yields clay (Van Eekelen and Bouw, 2020), which can be used for dike building, for instance. Unpolluted clayey material with a sufficient organic content can also be used for wetland restoration. Slightly polluted material can be placed at designated locations, away from the dredging location at sea, for instance. The biggest problem is the heavily polluted material, which needs to be decontaminated prior to re-use or disposal, or stored isolated from the environment. An example of such a storage area is the Slufter near Rotterdam (Figure 2.21).

Figure 2.21: The Slufter storage basin for polluted sediment (yellow box) (Sentinel-2 cloudless 2020 by EOX IT Services GmbH is licenced under CC BY-NC-SA 4.0).

Dust, noise and light Especially the handling of dry bulk cargo, such as grain, coal, china clay and metallic ores, produces dust. Strong winds may also entrain fine particles from stockpiles. Furthermore, soot and ash are produced by ship engines burning fuel oil. These ship engines, however, also emit sulphur and nitrogen oxides, which can react in the air to dust. Prevailing winds may spread this dust over adjacent residential areas. Especially fine dust (particle size less than 10 μm) is a threat to public health. The present EU-limit of 20 $\mu g/m^3$ for air pollutant concentrates is rather demanding for many a port.

Dust production by cargo handling can be reduced by spraying, covering during transport, using vapour return systems when stocking, and careful profiling of stockpiles. Careful port layout planning, taking into account residential areas and the prevailing wind direction, is a prerequisite. Fine dust production by sulphur and nitrate emissions can be reduced by changing to other fuels for seagoing vessels. The IMO is trying to achieve this by compulsory information provision on the use of heavy fuel oil and by imposing sulphur oxide limits per ship (see Section 2.1.1). Another emission product that causes environmental problems is nitrate, which acts as a fertiliser in nature areas and thus threatens biodiversity. Although port operations and inland water transport are not the main sources, this requires attention. Especially in the vicinity of intensively used waterways, such as the river Waal, the contribution can be significant (Bloemen et al., 2006).

Noise and light produced by port activities and port-related traffic can be significant nuisances for people living nearby, sometimes even a health risk. The port layout, with elements like green areas and cleverly positioned service buildings, can help sheltering residential areas from such noise and light. An EIA generally requires noise level contours, including scheduling of noise activities to occur at times of the day that cause least effect for receptors.

Waste Waterborne transport systems inevitably produce waste. This can be waste from ships (sewage, household waste, bilge water, oily water from engine operations, ballast water), from industry, offices, warehouses, dwellings and other facilities. Ports are supposed to have reception facilities and usually organise waste reception in such a way that it does not cause unduly delays to the vessels. Hazardous waste (as explicitly defined in EU-directive 2008/98/EC on waste) has to be stored in a well-isolated and well-controlled landfill. Storage and treatment of waste are generally significant cost items, so they should be taken into account in the port's economic analysis, as well as in its design.

A kind of waste that deserves special attention from an environmental perspective is ballast water. If natural water is taken in and discharged elsewhere in the world, it may introduce invasive species that may disturb the local ecosystem. A possible temporary measure is to exchange ballast water mid-ocean, but it is better to either take in treated water, or treat it while the ship is on the way to its destination. In 2017 the IMO Ballast Water Management Convention came into force. It requires 'all ships in international traffic to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan'.

Water and soil pollution Important causes of water and soil contamination around ports and waterways are (illegal) disposal, leakage, spills and accidents. Industrial and tank storage areas in ports, for instance, can be sources of serious contamination if they are not properly isolated from the surrounding water and subsoil. Even if isolation measures are currently in place, there is often a legacy from the past.

Prevention is the best strategy, as remediation is usually quite expensive, if possible at all. Depending on the environmental risk it constitutes, contaminated soil can be isolated, or the contamination can be immobilised otherwise. If contaminated water is released into the groundwater, one may attempt to contain the plume. Oil spills on confined water, such as a port basin, can be removed will oil beams, since oil floats on water and mixes poorly with it. The port must have protocols and facilities ready to combat this kind of events. If an oil spill occurs at open sea, removal is much more difficult, because wind and currents spread the oil slick quickly. This can lead to environmental disasters, like the 1989 Exxon Valdez disaster in Prince William Sound, Alaska (Figure 2.22).

Soluble contaminants entering surface water will soon disperse and become difficult to remove or contain. There can also be diffuse sources, such as leaching from old soil contaminations. One example is eutrophication by fertilisers leaching from former agricultural land. This may lead to harmful algal blooms, also within port water bodies. The remedy is regular recirculation of the port water, for instance by flushing.

Figure 2.22: The Exxon Valdez oil spill disaster, Alaska, 1989 (left: OilCleanupAfterValdezSpill by NOAA is licenced under CC0 1.0; right: EVOSWEB 013 oiled bird3 by Wikimedia commons is licenced under CC0 1.0).

A special kind of pollutant originates from some types of antifouling on ship hulls. Fouling is the formation of a layer of micro-organisms and larger species (e.g. mussels, barnacles, seaweed) on the submerged part of the hull. It causes extra resistance and influences the manoeuvring properties of the ship. Moreover, ships with fouled hulls spread the organisms all over the world, thus causing problems with invasive species. In the seventies and eighties of the last century an environmentally very harmful type of anti-fouling paint was used. Since then, more environmentally-friendly alternatives have been developed.

Habitat Ports cover large areas from which a variety of species may have been driven off. Canals intersect habitats, thus blocking the exchange of terrestrial species and cutting predator territories. Fluvial waterways have often required river regulation, at the expense of habitat variation in the river bed. Estuaries, being links between ocean and inland waters, are favourite places for port development, but also places where one can find the biologically most productive wetlands (worldwide loss of these wetlands stands at 35-40% since 1970; see Ramsar Convention on Wetlands, 2018).

Such environmental impacts generally require compensation. International conventions, such as the Ramsar Convention for Wetlands, see to this. Regional regulations like the EU Framework Directives and Natura 2000 formulate environmental protection objectives and force countries to develop and enforce compliant legislation.

The impact of port and waterway activities on sensitive habitats can be minimised by taking proper mitigation measures, determined by the local conditions (environmental, social, legislative). In general, it is most environmentally friendly and cost-effective to prevent loss of habitats by minimizing the footprint of activities, rather than to lose and restore them. If impact cannot be avoided, restoration is often required by an EIA or societal pressure. Before carrying out habitat restoration, an in-depth analysis is needed of the physical, ecological and societal boundary conditions to select the most suitable and cost-effective method. Following the restoration activities, monitoring is critical to document the status and development of the restored habitats over time.

Although scientists have been discussing ecosystem services and ecosystem valuation for decades, this concept has found broader acceptance only recently (see also Laboyrie et al., 2018). It provides a method to quantify the effects of an envisaged development on the ecosystem in monetary terms and include them in an SCBA.

Ecosystem services are generally grouped into four broad categories (MA, 2005):

- *supporting services* – such as nutrient cycling, primary production, soil formation, habitat provision and pollination,
- *provisioning services* – such as the production of food, raw materials, energy and medicinal resources,
- *regulating services* – such as carbon sequestration, climate regulation, waste decomposition, water purification and flood protection,
- *cultural services* – such as spiritual, recreational, scientific, educational and therapeutic.

Valuing these in monetary terms requires subcategories. One of the methods to do so is contingent valuation, based on public inquiries into the 'willingness to pay' for certain ecosystem services.

2.3 Adaptive planning

The previous section outlined basic steps that need to be considered when planning port and waterway networks under conditions of uncertainty. We should realise that these steps can be completed under different paradigms, all of which acknowledge the prevalent uncertainty and try to manage it.

2.3.1 Uncertainty and increasing complexity

Planning of infrastructure involves various timescales, such as the:

- *planning horizon* – the time period for which the plan is made;
- *technical lifetime* – the time during which a structure or equipment is expected to keep on functioning technically;
- *economic lifetime* – the time during which structures and equipment fulfil the system's functional requirements;
- *depreciation time* – the time during which the carrying amount of the infrastructure is reduced to zero; and
- *trigger timescales* – the timescales at which the various triggers of change take place.

These timescales are not mutually independent and tend to become shorter now that market, technology and circumstances change more rapidly. As this shortening is not uniform over the various timescales, their mutual relationships may change, which increases complexity.

In the past, transport infrastructure was built to provide the same service for a long time. The technical lifetime of civil engineering infrastructure, for instance, is typically 50 years or more. This used to be of the same order of magnitude as the planning horizon and the economic lifetime. At present, 50 years is way beyond the latter timescales. This means that the concept of a single functionality throughout the technical lifetime has to be abandoned, or that one should opt for a shorter technical lifetime. But this is not the only complicating factor in present-day infrastructure planning for waterborne transport. Uncertain future developments (see Section 2.1) further complicate the challenges of port and waterway planning.

2.3.2 Towards a new paradigm

The traditional way of dealing with uncertainty and complexity is to reduce uncertainties to a level at which they can be ignored or captured in safety margins. Now that changes become faster, more unpredictable and more extreme, this paradigm is no longer good enough: we have to accept risk and uncertainties and deal with them explicitly and systematically. In management literature, this is referred to as decision making under Volatile, Uncertain, Complex and Ambiguous (VUCA) circumstances (see Barber, 1992); the US Army War College is attributed for introducing the term VUCA. This new paradigm is referred to as 'Adaptive Planning' (see Taneja, 2013).

Risk and uncertainties not only create vulnerabilities, they also provide opportunities. The challenge is to seize the opportunities and hedge or reduce the vulnerabilities. This can be achieved by incorporating flexibility (the ability to be modified if and when needed) and robustness (the ability to withstand or overcome adverse conditions) in the system, whether it is a port, a port network or a supply chain. As far as uncertain events or developments can be specified, one may devise measures to deal with them and implement them when needed. Clearly, uncertain events or developments which we are not even aware of at present can only be faced with robustness and hedging.

Measures providing flexibility to real systems and projects are known as Real Options. They can be incorporated in physical infrastructure, in operations or in services. These Options can be exercised in case of changed functional requirements. We will illustrate this by a number of examples.

In the 1990s, when major investments in container terminals were being made at the Maasvlakte (Port of Rotterdam), fourth-generation ships with a draught of 12.5 m were current. Yet, the container terminals at the Europahaven and Amazonehaven were provided (at extra cost) with deeper draughts and higher quays which could accommodate heavier cranes, so as to accommodate the larger ships that might call at the port in the future. As ship size continued to grow, this flexible Option has enabled berthing much larger vessels (starting with an 11,000 TEU container ship in 2008) (Taneja, 2013). In Part IV – Section 3.2 we describe how such an extra investment can be justified by estimating the added value of a flexible Option in a business case.

Another Rotterdam-based example is the phased construction of Maasvlakte 2, which gave the port authority the option to abandon or defer the following phase of the project and avoid part of the capital expenditure in case the market deteriorated (Taneja, 2013).

The unprecedented growth of container transport forced some ports to adapt their bulk terminal to handle containers (cf. Part II – Figure 1.5). Ports that did not adequately respond (adapt, expand, resettle) were forced out of business. Presently, as hydrogen is being touted as the fuel of the future, investigations into adapting existing LNG terminals are in progress worldwide.

As these examples illustrate: flexibility offers advantages during uncertain times, as ports can be adapted for new or changed use, thereby also promoting sustainability by way of efficient use of resources. This does not mean, however, that investments in flexibility are always taken into consideration. The focus on short-term profits, the lack of a long-term perspective in planning, and the lack of tools to value flexibility are deterrents to such investments.

2.3.3 Adaptive Port Planning

The planning of capital-intensive systems with a long lifetime needs to account for uncertainty and incorporation of flexibility and robustness during the planning process. Adaptive Port Planning (APP) is an integrated planning method that guides planners to systematically deal with uncertainties that appear over the lifetime of a port. It allows for change, learning and adaptation over time, based on new knowledge and changing circumstances.

APP recognizes that the value of a project (or a design alternative) is driven by the flexibility and robustness it needs, in order to survive in the uncertain and rapidly-changing world. Therefore, identifying, evaluating, incorporating and managing Real Options is an important step in APP. APP results in a robust, flexible and adaptive plan that stands a good chance to perform well no matter what the future brings (Taneja, 2013).

The next steps are the implementation of this plan, implementation or preparation of the measures and the development and implementation of a monitoring plan that must identify early signals of relevant change, thus triggering activation of the contingency plan. Table 2.1 compares the traditional and adaptive planning approaches.

Aspect	Traditional planning approach	Adaptive planning approach
Attitude towards the future	Assumes it is useful and possible to predict the future	Assumes the future cannot be predicted, or it is risky to do so
Treatment of uncertainties	Uncertainty is included in the scenarios, but planning is eventually based on single-point forecasts	Imagines trend-breaks and events and prepares for them
Planning process	Static and instantaneous, or at most periodic	Dynamic and continuous
Focus	Demand forecasts	Vulnerabilities and opportunities
Approach	Target-oriented	Performance-oriented (hence flexible, robust and integrated)
Reactivity	Ad hoc to strong signals (certain knowledge of the future)	Monitoring and responding to predefined triggers (mostly performance indicators)
Decision making	Based on available information	Based on regular acquisition of new information and evaluating potential developments as a way to deal with uncertainty

Table 2.1: Comparison of planning approaches (Taneja, 2013).

Figure 2.23 presents a schematic of the adaptive planning process (after Taneja, 2013). The result of this process is the preferred basic plan plus a set of pro-active measures to deal with uncertainties and a contingency plan.

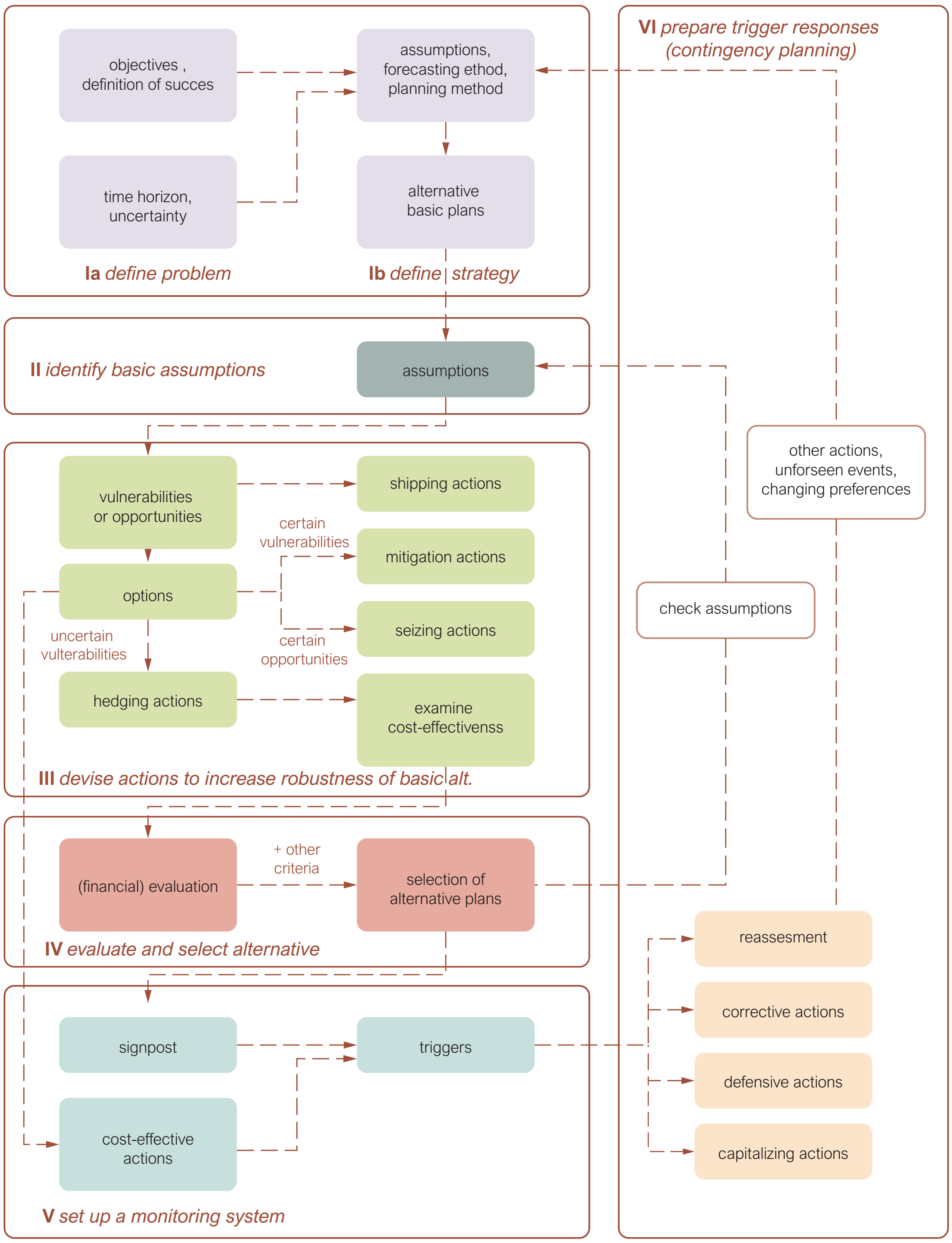

Figure 2.23: Framework for Adaptive Port Planning (reworked from Taneja, 2013, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).