# Benchmarking the Performance of Ports on Asset Management

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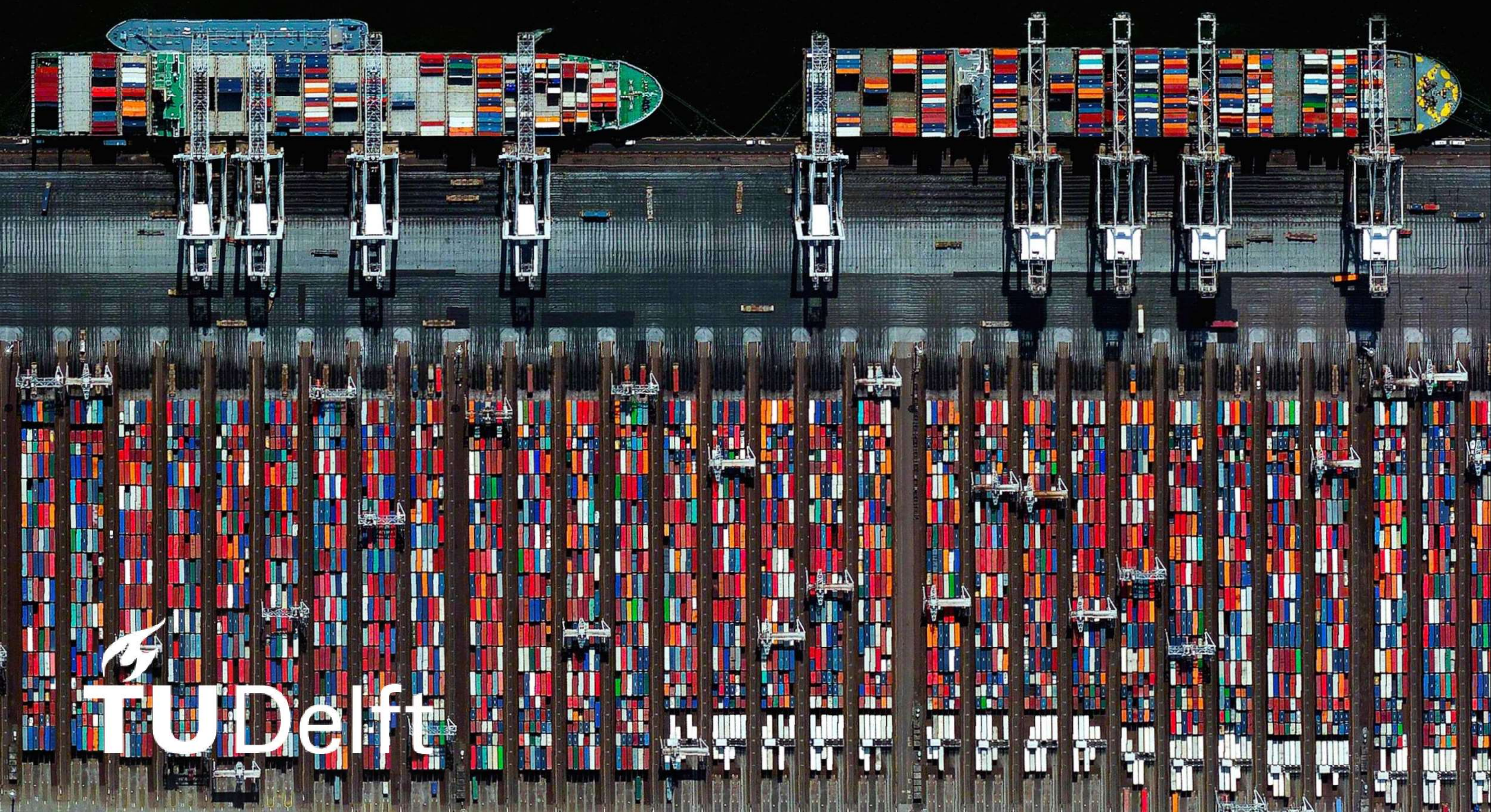

# Benchmarking the Performance of Ports on Asset Management

by

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*This is the public version of the report. Due to confidentiality agreements, this report contains modifications in the contents and part of the information is excluded.*

Image on the cover of this thesis: adapted from (Grant, 2016)

# Preface

This report presents the results of my research, which is part of the Master's degree in Transport, Infrastructure and Logistics at the Delft University of Technology. This research is conducted in cooperation with Delft University of Technology and four European ports, namely Port of Rotterdam, North Sea Port, Port of Hamburg, and Port of Gothenburg. Whilst following courses in Transport and Logistics, the dynamics and robustness of the shipping industry immediately intrigued me. Throughout my study I developed a keen interest in the maritime industry, and I am grateful for the opportunity to conduct a research in cooperation with the aforementioned ports.

First and foremost, I would like to express my gratitude to my thesis committee who helped to elevate this research to a higher level than I could ever have anticipated. I want to thank the chairman of my committee, Lóri Tavasszy, who provided very helpful feedback from a more aggregated perspective. Further to this, he provided guidance and flexibility throughout the research process, which was much needed in this 'running project' (or 'monster project' as he called it). Second, I would like like to thank Rob Schoenmaker for sharing his extensive knowledge on asset management. Since he was always willing to share his ideas on this field, he provided me valuable insights into the world of asset management which have contributed to the theoretical foundation of my research. I also want to thank Ron van Duin, with whom I share the same passion for the shipping industry, and who has a great understanding of the dynamics within this industry. Although we have met less frequently, he provided me with good and refreshing ideas, and therefore actually played a decisive role in the supervision. At last, but not least, I would like to thank Sander Cornelissen, the fourth member of my thesis committee. His tips and comments have supported my writing capabilities in making my report more readable. I highly appreciate the time which Sander has devoted to provide me with feedback and insights from a business-perspective. It was really great to have such a committee who was enthusiastically involved in the thesis process.

Then I would like to thank the people of the respective ports. First, I want to thank my colleagues at Port of Rotterdam, and more specifically 'AMI'. Everyone was very helpful and always open for questions, and whenever I think about the many jokes I always smile. Partly because of them, I have had a very pleasant internship period. A special thanks to Marlot Schoenmaker who was closely involved in the benchmarking project, and who was always willing to help me. Due to the international nature of my thesis, I had a lot of contact (and fun) with the asset managers working at North Sea Port, Port of Hamburg, and Port of Gothenburg. Without their insights it would not have been possible to deliver a thesis which is so closely aligned to practice. You all have shared interesting thoughts, constructive comments, and personal support.

Last, but certainly not least, many thanks to my family and friends who have stood by me throughout the entire graduation process. Special thanks to my parents who supported me unconditionally. I would like thank all my (study) friends, who provided me with daily motivational talks or simply allowed me to take my mind elsewhere. I promise, and would like, to make more time available for you. To my boyfriend, thank you for all the support, laughter, and carefree moments.

Throughout the entire process of writing this thesis, many people have gone to great lengths to help me complete the project, and together we made something I am proud of.

Thank you all, and I wish you a pleasant read.

*L.A.H. Verbruggen*
*Delft, September 2019*

# Executive Summary

Over the past decade, European cargo transport has grown rapidly. The flows of goods were boosted by globalisation, economic growth, and the rising Chinese economy. These flows are mainly facilitated by maritime shipping, with port infrastructures acting as the main gateway. Regarding the port industry, various developments increased the complexity of operations: increase in throughput, bigger ship sizes, ageing assets, increasing complexity of the harbour area, and major developments in laws and regulations. As global trade increased, vessel sizes and cargo volumes surged, which places additional pressure on assets of ports.

Considering the challenges ports are facing, the need for asset management efficiency within the port industry is imperative. Consequently, asset managers are more willing to improve their performance which contributes to the growing interest in benchmarking. Benchmarking is the systematic process of measuring and comparing an organisation's performance against industry peers. The lessons learned from other organisations can provide insights for performance improvement. This research was conducted at the Port of Rotterdam in collaboration with North Sea Port, Port of Hamburg, and Port of Gothenburg. Asset managers of the respective ports expressed their interest in a collaboration for benchmarking. Existing models in the literature did not comply with the needs of asset managers, as limited research is available on methods for assessing and comparing ports' performance on aspects of asset management. Identifying knowledge in this context sheds light on the aspects of an unexplored research field. In doing so, this research is both of scientific and practical relevance.

The objective of this study is to develop a benchmarking model that allows asset managers in the port industry to measure and compare performance. The main research question is: *'How to compare different ports on aspects of asset management through benchmarking?'*. A design approach is reflected in the five phases of the research: model concept, model design, demonstrate, evaluate and refine, and results. Subsequently, two design challenges are identified for this research:

- Which set of criteria indicates asset management performance?
- How to measure performance of asset management?

The resulting model design provides asset managers a model for practical use. The model connects identified criteria (*what to measure*) and a corresponding method (*how to measure*) for the development of benchmarks. Previously, international comparison of performance was hardly possible because of the lack of uniform definitions and methods. The provided method is a guide for asset managers to create performance measurements that enable benchmarking.

By combining both findings from literature and expert knowledge, a benchmarking model is designed which forms a strong basis for international benchmarking. A review of relating literature contributed to an appropriate benchmark method for this study. The acquisition of a conceptual framework for performance measurement is the first step in the design process. This framework covers the criteria which the benchmarks have to comply with, which entails that proper benchmarks should fit within three theoretical concepts:

1. *Processes of asset managers:* position of the benchmark in the input-output performance measurement framework. The input-output diagram represents the processes involved when managing assets.
2. *Control of asset managers:* position of the benchmark within the port control model. This concerns the control relations between an organisation and its environment. The benchmark should be related to the controllable part of the model.
3. *Focus of asset managers:* position of the benchmark in relation to asset management objectives. The main objective can be stated as the realisation of value while balancing performance, costs, and risk attributes.

The benchmark should attribute to value creation and should match the involved processes when managing assets. Moreover, measurements should be controllable, providing asset managers insights into performance improvement. Following the defined criteria, both benchmarks on port and asset level (*what to measure*) are listed in this research. The benchmarks on port level express the differences between ports in terms of size,

operations, and activity in and around the port area. These figures provide both information on identified benchmark partners and context for the benchmarks on asset level. Each port handles their own structure and format in collecting and storing asset information (IAM, 2015). International comparison on asset level is hardly possible because of the lack of uniform definitions and performance measurement methods. Therefore, asset managers agreed upon international asset information standards, such as the asset description. These standards are compiled per asset type in the so-called asset terminology. For this research three generic benchmarks are identified to benchmark on asset level, subsequently specific benchmarks per asset type are defined in the case study:

- Maintenance Costs
- Condition
- Availability

This research created a user's manual (*how to measure*) to guide asset managers in the process of benchmark development. This instruction manual comprises of the following elements: organisational structure, planning, working method, and supporting tools. The organisational structure suggests a clear division of roles within the benchmarking group, which consists of both a working group and a steering committee. The working group prepares information for the benchmark analysis, and sub-groups of the working group should focus on a specific asset type. Throughout the process, the working group should be supported by the steering committee by providing feedback. The specification of the generic benchmarks is performed by the working method as presented in this research. This step-wise method (in Figure 1) follows a sequence of steps, tolerating multiple iterations: brainstorm, define, check, collect, measure, compare, and analyse. Asset managers are required to be closely involved in the process. The benchmarks are defined in a performance measurement template. This tool enables asset managers to assemble the required information in a structured way. The benchmark analysis, which is the final step of the process, is performed by means of a web application. A dashboard enables asset managers to measure, monitor, and manage the developed benchmarks. The dashboard is a tool that processes the input elements to produce the outputs, which are the benchmark results as presented in the dashboard. The processing function of the dashboard is presented in an IDEF0 diagram, which leads to a structured graphical presentation of an activity (Akasah, Amirudin, & Alias, 2017).

Throughout the process of benchmark development, attention is paid to the requirements of the dashboard. The approach of software development advocates adaptive project planning and iterative benchmark development. The so-called agile software development is an approach under which requirements and solutions evolve through the collaborative effort of self-organising and cross-functional teams (Collier, 2012). These characteristics are reflected in the benchmark development process, which enables continuous improvement of the benchmarks.

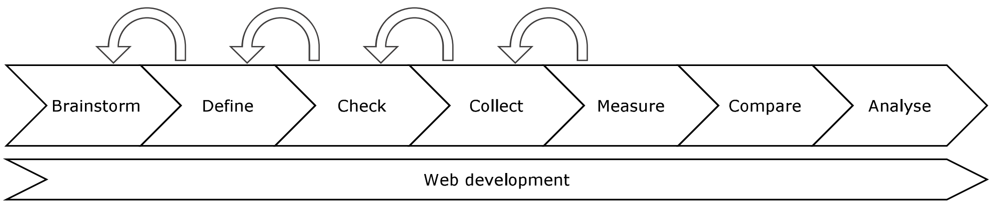


Figure 1: Step-wise method in development of asset benchmarks

A case study for the respective ports is conducted to validate the general model for a specific case. This results in a more profound understanding of the model's practical use. The empirical research, in the form of a case study, encompasses two sub-cases as set out in Table 1. The demonstration concerns a Proof of Concept, which is a small exercise to test the model design. Asset managers are consulted to develop the benchmarks by following the steps as presented in the model design. Both maintenance costs and condition benchmarks provide insights into the performance of managing assets. As the data used for the Proof of Concept is not validated, results need to be interpreted with caution. Nonetheless, the presented theoretical relations seem to be promising as asset managers are able to link the results to their asset management strategy. During the case study there is decided to eliminate the availability benchmark from the analysis. Among other things, this is due to the fact that time and resources imposed constraints. This report outlines both the specification of the benchmarking model and the benchmarking process. The specification shows how the required information is collected, subsequently it elaborates on the results of the case study. The description of the benchmarking process pays attention to the collaborative approach of the method, and points out the challenges that came across. The process is at least as important as the results, since benefits arose from the collaborative process as value lies in the dialogue before, during, and after the benchmark. Following a successful Proof of Concept, it can be stated that a strong foundation is created as the benchmarking model provides asset managers a clear working method and valuable insights.

Table 1: Structure of the case study

| | **Case 1** | **Case 2** |
|---|---|---|
| *Asset type* | Road | Quay wall |
| *Ports* | Port of Hamburg,<br>North Sea Port,<br>Port of Rotterdam | Port of Hamburg,<br>Port of Gothenburg,<br>North Sea Port,<br>Port of Rotterdam |
| *Benchmark* | Maintenance Costs, Condition, Availability | Maintenance Costs, Condition, Availability |
| *Year* | 2018, and fictitiously: 2015-2017 | 2018, and fictitiously: 2015-2017 |

The model's validity is explored through both validation and verification: assessment on predefined requirements and design, expert interviews, and evaluation of the process. This is done by evaluating the results obtained from empirical research in the form of a case study. In conclusion, the model is perceived as added value to the (prospective) users.

As a result, asset managers share knowledge before, during, and after the benchmark analysis. The *benchmarking model* structures the definition of benchmarks by providing templates and other tools. In doing so, a replicable and standardised method is provided. The *benchmarking model* has the following unique characteristics:

- *Operational perspective:* the perspective of the system's user (i.e. the asset managers) left a significant mark on the model design. The model framework ensures that benchmarks reflect the performance of 'managing assets' in ports.
- *In-depth benchmarking analysis:* previous studies on benchmarking models generally focus on single measurements, where this research provides a benchmarking model for conducting an in-depth analysis. Close attention is paid to explanatory factors and contextual variables.
- *Collaborative design:* as limited research is available, the benchmarking model is obtained through consulting asset managers. Consequently, the model is retrieved in collaboration with experts by adapting existing theories. Due to the international nature of this study, asset managers agreed on international standards for benchmarking.

This research has several limitations which suggests some avenues for future research. The first limitation is the lack of data and the reliability of the available data. In addition, there was limited time and therefore only a small exercise is conducted in testing the model. As a result, opportunities for further research lie within the inclusions of more context variables in the analysis of the current benchmarks. These variables may explain the benchmark results and provide a more profound analysis. Next to this, this model considers a small selection of asset types, benchmarks, and ports. Further development of the benchmarking model can be realised by introducing other asset types, developing other benchmarks, and attracting different benchmark partners. In the long run, it may be of interest to link the benchmark results of various departments, both within the overarching asset management department as within the entire organisation of the ports. In this manner the relations between organisation's strategic, tactical, and operational level can be outlined.

This research focuses only on a small part of the port control model. The port control model is a class of abstracts systems, each consisting of a controlled part, an environment and a controller. This control model especially directs attention to the dual control-relationships between an organisation and its environment (De Leeuw, 1982). However, when considering additional subsystems and relations, more (asset management) departments should be involved in the benchmarking process. Besides the fact that in this case other theories should be selected, the benchmarking process will become more challenging and complex.

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# 1 Introduction

## 1.1. Background

During the last decade European cargo transport has grown rapidly. The flows of goods were boosted by globalisation, economic growth, and the rising Chinese economy. These flows are mainly facilitated by maritime shipping, with port infrastructures acting as the main gateway. The container terminals of ports particularly play an important role in a country's or even region's economic, supply chain and logistical development (Wang & Cullinane, 2015). Due to the advanced nature of the inland transportation systems and the relative proximity of competitors, container terminals in Europe face fiercer competition than in the rest of the world (Notteboom, 1997). As a result, ports increasingly compete for the same inland areas, necessitating efficiency improvement. The hinterland is no longer exclusive, and ports lost their monopolies (Zhang, 2009).

Ports in general are facing lots of challenges which require more efficient management of their assets. Operations have become complex due to various developments: increase in throughput, bigger size of ships, ageing assets, increasing complexity of the harbour area, rapidly changing world (e.g. energy transition, globalisation, and digitisation), and increasing complexity of legislation and regulation. As global trade increased, vessel sizes and cargo volumes surged, which places additional pressure on assets of ports. Due to the complexity of the competitive port industry, companies are becoming increasingly interested in solutions that can significantly contribute to optimising the current operations, promoting efficiency and cost reduction, all without requiring major investments in new infrastructure and equipment. Asset managers are willing to operate more efficient as asset management represents a major source of the organisations' costs. One of the issues that managers face is the lack of knowledge on specific cases of asset management.

Currently, the dominant approach of ports to manage assets is based on their own historical performance. High costs are involved when managing assets, including maintenance, inspection and investment projects. Ports prefer to minimise the disclosure of confidential information of competitive value, as they are afraid information will go in hands of competitors (Stana, 2010). Ports nowadays are more interested in solutions for optimisation, and business could become easier through data-sharing platforms, for example.

The challenges ports are facing, as well as the willingness to ensure continuous improvement contribute to the growing interest in benchmarking. Benchmarking creates the possibility for ports to identify and learn from best practices elsewhere in the world (Elmuti & Kathawala, 2002). It is a tool for the assessment of the performance, and set up partnerships to share knowledge on specific cases. Since the information on asset management is not directly related to their competitive position, ports are willing to share data. Research on possible contribution of exchanging knowledge of asset management in the port industry has not yet been conducted.

The process of benchmarking consists of defining valid performance measures for the comparison of companies' operations, and in the end establishing a standard of excellence. This study concerns the complexity of making international comparisons of asset management performance[1]. Complexity rises since there are a number of inter-related aspects and activities involved which cannot be captured by one single measure.

Four European ports entered into cooperation in order to create a platform for benchmarking, namely the Port of Rotterdam, North Sea Port, Port of Hamburg, and Port of Gothenburg. The asset managers, which are industry experts, are willing to provide input and required data for the benchmarking model. To scope the research only two infrastructure assets will be benchmarked: quay walls and roads. The aim of this study is to investigate how benchmarking can provide insights into performance improvements on asset management. The focus is on more efficient management by learning from best practices. For the sake of the respective ports there will be a practical application: creating a framework for an asset management benchmarking model in the form of a dashboard. The exchange of knowledge and best practices in asset management of ports and harbours would benefit the entire sector. Since ports cope with the same problems and challenges, they could learn from each other by sharing knowledge.

In the following, Chapter 1 provides a description of the knowledge gaps, both scientific and practical. Moreover, in Section 1.3 the research objective will be presented, followed by the research questions. Section 1.4 briefly introduces the research methods of the research phases. Section 1.5 concludes this chapter by elaborating on the structure of the report.

## 1.2. Research Field

### 1.2.1. Problem Description

The foreseen increase in global seaborne trade and the increasing vessel size results in larger cargo volumes that need to be handled via the ports' current assets. The flows of goods, were boosted by recent macroeconomic developments, are mainly supported by maritime shipping with port infrastructures acting as the main gateway. The assets serve as an interface between sea and land in maritime transport, a link in international trade. Ports are increasingly seen as critical nodes of global supply chain (Loh & Van Thai, 2014). This emphasises the importance of the availability of assets and the efficiency of asset management.

Figure 1.1 shows the growth of international trade for the European Union. The operations in the ports have become more complex due to congestion and high costs for maintenance. Ageing networks ask for replacement or maintenance in order to meet the needs of growing demand. Many seaports worldwide are now facing the problem of a shortage in capacity. The option to expand the harbour area is not always the preferred option due to space constraints, a lack of space in port areas for new assets (Abdul Rahman, Ismail, & Lun, 2016). Therefore, it is even more important to efficiently use the resources to manage the ports' current assets.

Asset managers are facing challenges resulting from significant growth in freight cargo worldwide. Dramatic increases of transport and mobility accelerate ageing of the ports' infrastructure. The life of many assets is shortened by wear and tear, and the constructions cannot function at an acceptable level of performance anymore (Verlaan & Schoenmaker, 2013). The pressure on the road infrastructure network and the quay wall constructions increased. More and larger ships will call the ports, and without intervention this leads to growing asset management challenges that are time consuming and costly. Managing the port's assets requires complex cost and social benefit trade-offs of managing public infrastructure through consideration of multiple constraints that challenge ageing infrastructure assets. Proper functioning of assets is essential for growing ports. Ports are confronted with a fall in earnings because of fierce competition. As a result, asset managers face increasing budget constraints. It is therefore important to be more efficient, and make optimal use of resources. Since many ports face the same challenges it could be beneficial to share knowledge and experiences.

[1]Asset management performance: for the purposes of asset management, performance can relate to assets in their ability to fulfil requirements or objectives (IAM, 2015). In this research benchmarks are formulated in such way that asset managers are able to measure and compare the performance of managing (physical) assets. As a result, these measures enable asset managers to monitor the performance of their assets under management. The term asset management performance is used, as this terminology is used by asset managers

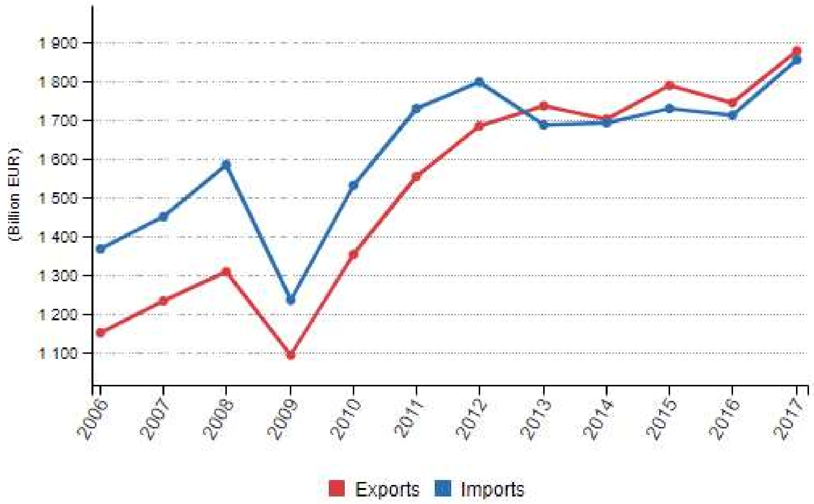


Figure 1.1: Development of international trade in goods for the EU, EUR2-28, 2006-2017 (Eurostat, 2018)

The use of benchmarking is suitable as it contributes to continuous improvement, performance measurement, and controlling costs effectively (Elmuti & Kathawala, 2002). The theory proved to be successful in various industries, since the operationalisation of a benchmarking model for asset management considers predominantly back-office data. Sharing this information does not necessarily affect the competitive position. Developing a benchmarking model creates the opportunity to get more efficient insight into asset management performance, and assists asset managers in finding improvement options.

In summary, the need for benchmarking rises as there are developments in trade, putting pressure on the port's physical assets. Moreover, efficiency management is necessary to maintain budgetary control. As there is currently no platform for ports to share their knowledge with regard to asset management, they are constantly 'reinventing the wheel'. This underlines the lack of knowledge on specific cases of asset management. Benchmarking enables the exchange of knowledge for continuous improvement.

Earlier attempts did not succeed, and show that defining benchmarks for the specific context is complex. The reasons for not succeeding are valuable lessons learned and will be taken into account in the approach as described in Section 2.1.1. The set-up of the benchmarking working group offers new opportunities to gain valuable insights into both the process towards a benchmarking model and the benchmarking model itself.

**Research Scope**

The research scope is delineated to the following areas:

- Focus is on the port industry
- Focus is on asset management
- Focus is on two (physical) asset types: quay walls and roads
- Perspective: both from a theoretic and asset manager's perspective
- Demographic: asset managers, working in ports worldwide, lacking experience in benchmarking

The asset managers all work in the same industry, having similar processes, same assets types, and comparable goals. The comparison of performances enables them to map the relative performance. Understanding how the ports manage their assets in terms of risks, costs, and performance is therefore vital.

### 1.2.2. Research Relevance

Four different streams of literature are considered: benchmarking, performance measurement, ports, and asset management. Literature is reviewed by combining these streams in different ways. A literature review in the field of port benchmarking indicates that the studies on benchmarking mostly consider the performance of ports, where the performance is looked upon from a more holistic point of view. Macro performance indicators quantify aggregate port impacts on economic activity. A number of studies on the subject of port performance and efficiency are already conducted (Bichou & Gray, 2004; De Langen, Nijdam, & Van Der Horst, 2007; Talley, 1994; Tongzon, 1995a). These studies identified the various factors underlying a ports' performance and efficiency. The performance of ports can be measured in terms of the number of containers moved through a port on the assumption that ports have the objective to maximise throughput (Tongzon, 1995a). Several ways to measure port efficiency, depending on which aspects of the port operation are evaluated, are identified. The studies remain on a high level of abstraction. Benchmarking on detailed or operational level in previous research is limited.

A justified approach for ports benchmarking on international scale is identified (Tongzon, 1995b). Findings from this research can be used for the area of asset management, since differences between ports on port level can be taken into account when comparing ports on asset level. By using measures for performance on port level, like-for-like comparisons can be objectively made. Conceptual and organisational differences between ports explain the large variety of measures available, emphasising the difficulty and complexity of port benchmarking. As there is no unanimously accepted approach to the roles and functions of ports, the subject of what and how to measure will remain debatable. Moreover, most of the literature on international benchmarking of port performance focuses on competitive benchmarking rather than comparing the performance of operations and processes (Bichou, 2007).

The identified research on ports benchmarking using macro performance indicators is oriented at the level of the whole organisation, and not only of its individual operational units. In addition, most of existing research on micro performance indicators evaluating input/output ratio measurements of port operations focus on the context of terminal operations, or logistics and supply chains. Moreover, predominately the perspective is strategic and the identification of performance indicators from the operational perspective is limited. From the perspective of asset managers, operational indicators which cover all aspects of their daily activities are desirable. Research on benchmarking the performance of physical or infrastructure assets is often restricted to maintenance performance, which covers only a small part of the asset manager's job (Hyman, 2004).

The scientific contribution of this research is the integrated approach of different literature fields. By combining both findings from literature and expert knowledge, a benchmarking model is designed which forms a solid basis for international benchmarking with regard to asset management in ports. The model serves a practical purpose as it provides asset managers clear guidelines for performance benchmarking. Both scientific and practical relevance are further discussed in the following sections.

#### Scientific Relevance

Asset management plays an important role in the organisation of ports and is unique due to specific characteristics of the industry. For the set-up of a generic benchmarking model, the unique characteristics of the port's asset management need to be taken into account. Management of a port, and its assets is rather complex. The variety of asset types (quay walls, port roads, radar stations, waterways, real estate, cranes, vessels, etc.) makes it difficult to adopt a consistent overall policy. Activities being part of the businesses in this industry lead to added-value on goods and services in ports, industries, transport, and commercial activities, which are essential for the growth of the national economy (Ankobiah, 2001). Ports are operating in an asset-intensive industry, and are increasingly capital constrained. They own a large and diverse portfolio of highly visible and mature assets which pose unique maintenance, repair and replacement challenges. The circumstances to which assets in port areas are exposed are unique. For example, for port roads the percentage of heavy goods vehicles is higher than other types of roads. This has a significant impact on the physical condition of the assets as they degrade and deteriorate faster. Investments in physical assets is an expensive and risky venture due to the dynamic and competitive nature of maritime transport.

Both conceptual and organisational differences between ports can be denoted. For example, there is a difference between assets owned by the state and privately owned assets as they have different purposes and functions with varying reasons for investment. Because assets are in general costly and have a long life span, the focus is often more on investments and design decisions. Relatively less attention is paid to optimising operations. Given the complexity of the port's performances it is difficult to get a concise view on benchmark opportunities and resources.

A comprehensive performance measurement system should capture all appropriate activities in the process and incorporate the interests of all relevant members and stakeholders. Capturing all these aspects is not straightforward due to the complex interactions between port objectives, institutions and functions (Bichou, 2007). In the context of port performance, when undertaking performance measurement and benchmarking the perspective (customer, operator, regulator, etc.) one is considering is debatable. The perspective of this research is predefined as the research is approached from the asset managers' perspective. Conventional frameworks tend to favour the interests of the regulator. Other members and stakeholders may have different, and sometimes conflicting, objectives. For this reason the asset management performance measurement framework is placed into the context of port performance.

Existing research showed different approaches to benchmarking for ports. Studies on micro performance indicators consider measurements of port operations, and is therefore restricted to a subsystem of the port's total system. No research is yet conducted on asset management operations, which can be seen as one of the subsystems. In order to identify relative criteria for measuring asset management performance, the characteristics of this research area requires integration of both asset manager's and theoretical perspective in forming a conceptual framework. Currently, no appropriate method exists for assessing and comparing the ports' asset management performance. Identifying knowledge in this context sheds light on the aspects of a formerly unexplored research field. The research is novel for two reasons: the unexplored nature of asset management performance in literature, and the lack of appropriate benchmarking frameworks for asset management in the maritime industry.

Several reviews of benchmarking methodologies are published over time. Together they present a comprehensive overview of benchmarking methodologies (Sekhar, 2010). It is a case-by-case decision which method to select. Two design challenges can be introduced for this research:

- *Which set of criteria indicates asset management performance?*
- *How to measure performance of asset management?*

Performance benchmarking is basically merging the two methodologies: performance measurement and benchmarking against a comparable group. This research is an integrated approach of the four components: benchmarking, performance measurements, ports, and asset management. The characteristics of the system under study require the integration of several disciplines to form a theoretical framework. A benchmarking model is obtained with input from experts using grounded theory. Consequently, a generic model for practical use in a specific context is constructed. The consistency of the performance system is ensured by a standardised method for benchmark development. In addition, the benchmarking model should provide clear guidance to the model's users. The designed model is demonstrated with a case study to verify whether the model has practical potential.

**Practical Relevance**

For ports it may be valuable to map their asset management performance as they aim for more efficiency. As mentioned earlier, asset managers are facing challenges resulting from significant growth in freight cargo worldwide. Since asset managers of ports face similar challenges it may be beneficial to share knowledge. The performance measurement framework provides increased insight as an asset management tool, as a standalone assessment method, and as a benchmarking tool. Performance measurement brings transparency, and results in many forms of rationalisation. It triggers the port's internal discussion on how various activities contribute to the performance of the organisation. In this manner the organisation will likely benefit as soon as they start measuring own performance. The next step, comparing performance, allows ports to learn from other organisations in the same industry with similar activities. Because the users of the model (i.e. asset managers) are involved throughout the process, the usability and added value is continuously monitored. Communication of the research results to other organisations could benefit the entire industry. The demonstrated model is a Proof of Concept, which shows that the presented model may be useful for asset managers of ports all around the world.

## 1.3. Research Objective and Research Questions

The research objective follows the identified gaps, the design challenges, and the problem statement. The development of the benchmarking model is a design-oriented research project. This study's theoretical and practical objective are highly interrelated, as the practical goal cannot be reached without addressing the scientific gap. The information following this research will act as input for a practical benchmarking tool, an online dashboard for asset managers. The tool needs to reveal specific areas of improvement and provide more insights into best practice subjects. Hence, it will serve as a tool for decision-making. The method should present visual solutions as this is an effective way of communicating the benchmark results. The practical objective for ports can be explained through the following objectives:

- Investigate relevant benchmarking subjects and develop related performance measurements
- Generate useful data for the bottom-up and/or top-down process
- Facilitate the exchange of knowledge in the field of asset management between ports
- Develop an online platform to share this knowledge among peers (i.e. ports) worldwide

The benchmarking tool assists asset managers in confirming their competitive position, gauge the opportunity for improvement, and identify practices employed. All performance measurements are developed in such way that they can be monitored in a dashboard which visualises all measurements. The web development of the dashboard is partly parallel to the process of developing performance measurements. Transparency, uniformity, verifiability, and reproducibility of the working method is therefore of key importance. This working method describes the different steps that need to be taken, and is supported by different tools that are standardised. Tools are a manual, supported by both a template for defining performance measures and data collection. To briefly summarise, the main objective of this research is: *the design of a benchmarking model for asset managers in the port industry in order to measure and compare performance, and assist ports with the identification of improvement potential of the ports' own performance. The aim is to develop a generic design process to develop measurements in benchmarking ports on the aspects of asset management. The resulting model should provide insights into asset management performance and contribute towards greater efficiency.*

The following main research question is formulated from the knowledge gaps and research objectives:

***How to compare different ports on aspects of asset management through benchmarking?***

Several sub-questions are formulated to structure the research and obtain an answer for the main research question:

*Model Conceptualisation*

1. What are theories and applications of generic benchmarking, and what does literature provide in order to specify benchmarking for the purpose of this research?
2. Which framework for benchmarks can be developed for the purpose of this study?

*Model Design*

3. Which performance measurements can be obtained to measure asset management regarding port roads and quay walls?
4. How can input of the benchmarking model be used to determine the value of performance measurements?
5. Which data needs to be collected to conduct the analysis with the benchmarking model?
6. Which benchmarking model can be acquired to benchmark asset management performance?

*Demonstration*

7. What are the performances of ports in terms of relative efficiency following the case study analysis?

*Evaluation*

8. To what extent do the performance measurements and the proposed benchmarking model provide insight into performance of asset management?

## 1.4. Research Approach

The aim of this research will be achieved through the development of a framework using grounded theory and input from experts in the research field. The benchmarking model for practical use is based on this conceptual model and provides asset managers a clear working method. The model design will be specified according to a case study, a method suitable to assess the suitability of the benchmarking model when working on a specific case. Case study as a research strategy is useful in testing whether theories and models actually work in the real world. Furthermore, a working method will be validated by independent experts. At last, both the benchmarking model design and the process of development, which is done in a collaborative way, will be evaluated.

Throughout the research several steps are executed to structure the design study. The design steps are based on the process for systems development research by Nunamaker, Chen, and Purdin (1990), and the design science research methodology by Peffers, Tuunanen, Rothenberger, and Chatterjee (2008). The study will be conducted and reported according to the diagram presented in Figure 1.2. The phases of this design approach will first be discussed in Section 1.4.1. The figure captures both the research phases, the research questions and the chapters of the final report. For each research phase there is stated which research questions will be brought to attention.

### 1.4.1. Research Phases

The methods, research tools and analysis techniques, applicable to assess research questions are outlined as follows: literature research, expert interviews, and case study. The methods are assigned to the different stages of this research. To address the main question and its sub-questions a 5-step approach is developed, which consists of an introduction and five model phases:

*Phase 0:* Introduction
*Phase 1:* Model Concept
*Phase 2:* Model Design
*Phase 3:* Demonstrate
*Phase 4:* Evaluate and Refine
*Phase 5:* Results

The phases of the benchmarking process show some overlap with the phases defined by Camp (1989), who defined a five-stage benchmarking process. The benchmarking process consists of five phases: planning, analysis, integration, action, and maturity. The first two phases are incorporated in the research approach, as the focus is on the development of a benchmarking model. The development of an action plan and the implementation of best practices to close the performance gap are out of scope. It is the responsibility of the asset managers using the system to turn the results of the benchmarks into concrete actions. The focus is mainly on the processes of developing a benchmarking model and the benchmarking model itself. Throughout the research the expert knowledge has been instrumental in achieving the intended purpose. Considering the lack of research performed on the research's subject, expert interviews play a major role in bridging the gap between theory and practice. Interviews with experts help to understand the thinking of asset managers and make sure that the model is in line with their needs. The research phases, its objectives and methods, are outlined in this section. Phase 0 provides an introduction and background information regarding the research problem.

**Phase 1 - Model Concept**
First of all, the methodology to come to a benchmarking model is described. In order to structure and guide the design process, the research approach is based on a sequence of steps. Between the steps iterations take place. The approach of the benchmarking project explains how is dealt with issues that arrised during earlier attempts when creating a benchmarking model. The next step in this phase is the design process in the development of a benchmarking model. The different design phases are brought to attention as they are incorporated in the structure of this research. The design process will guide towards a benchmarking model. The plotted design process contributes to the structure of the conceptual framework, which captures important aspects of asset management in such way that the framework is easy to remember and apply. This conceptual design is a generic framework that is specified later on. First a literature review on benchmark options is conducted to create a conceptual model. The developed framework is based on prior research and applications, and thereafter suitable benchmark options are selected. This selection is carried out by means of analytical thinking. In the next phase a specified framework, the benchmarking model, is presented. The model concept lays a foundation for the model design presented in the next phase.

- *Objective:* construct a conceptual design by selecting theories and concepts which are adjusted based on expert knowledge.
- *Methods:*
  - Literature review: identify potential frameworks and theories that are useful for the benchmarking model. Consistency is ensured by selecting theories that align performance measurement with all aspects of asset management.
  - Interviews: findings from literature review are presented to experts. Subsequently, relevant theories and concepts are selected and adapted to the specific research context.

**Phase 2 - Model Design**
The second phase of the research identifies the major components that are required to design a model for practical use. The framework resulting from phase 1 is refined by aligning theory and practical knowledge on asset management performance. Semi-structured interviews are held to explore the field of asset management. Subsequently, generic theories are translated into a step-wise approach in performance measurement for asset managers working in port-related organisations. A methodology-based framework helps ports in creating opportunities with regard to obtaining efficiency. The development of benchmarks is submitted by a teams of experts. The different steps that need to be taken are part of a step-wise process, serving as a manual to guide the process of performance measurement development. This structured process ensures consistency as for all cases the same process is applied. The benchmarking model provides asset managers a working method and supporting tools. Asset managers have to work with predefined templates for performance measurements and data collection. The primary aim to develop such model is to define the theoretical content and contours of a new method to measure and compare asset management performance.

- *Objective:* design of a model that provides clear guidance to asset managers for the development of performance measurements to benchmark.
- *Methods:*
  - Literature review: identify potential performance measurements. Literature is reviewed to ensure a comprehensive performance measurement system.
  - Interviews: the discussions with experts triggered an iterative process in designing the model. In doing so, the performance measurement system of the benchmarking model is designed in such way that it provides guidance to asset managers. To achieve this, the asset managers verify the model on usefulness, and consequently over-complexity is avoided. Taken into account the needs of asset managers ensures that theory and practice are compatible, which is required in order to enhance consistency.

**Phase 3 - Demonstrate**
The benchmarking model provides asset managers handles and tools in creating benchmarks. The benchmarking model can be seen as a proposed design. Together with asset managers this model is developed in such way that asset managers develop benchmarks in a collaborative way. This design is tested by means of a case study, known as the Proof of Concept, which demonstrates the model and its methodology. The case study research method can be defined as an empirical inquire that investigates application of benchmarking within its real-life context (Yin, 2003). The initiative of benchmarking asset management stems from the collaboration between four ports. The asset managers of the respective ports tested the model by specifying the

templates for a small selection of benchmarks. These benchmarks are obtained for two physical assets: roads and quay walls. In this way benchmarks are performed on the level of assets instead of the asset portfolio. Through the benchmarking model the performance is measured and compared. Consistency is essential and this is achieved as the team agreed on the benchmarks, which are the same for each asset type. Asset managers agreed on mutually established international standards. Listing the varying performances shows which peers manage their assets more efficiently, by scoring relative well on the benchmarks. No attention is paid on how certain improvements can be made. Following the analysis, the associated actions for asset managers are not presented in the model. In this way the risk of exchanging competitively sensitive information is avoided.

- *Objective:* asses the designed benchmarking model on its usefulness and practicability.
- *Methods:*
    - Case study: this research strategy is useful in testing whether the scientific theories and models actually work in the real world. The method closely examines the data within a specific context (Zainal, 2007). To demonstrate the proposed design, a case study on two assets is performed. In the case study performance measurements are identical for both asset types.

**Phase 4 - Evaluate and Refine**

The results are evaluated after the execution of the case study. The framework is assessed on the predefined criteria and requirements formulated in Section 3.2. The benchmarking process and its related results are evaluated by an expert panel in the form of interviews. This model's review is an extra validation with a group of asset managers, asset owners and other experts in the research area. Valuable and significant feedback is taken into consideration for the revised model. This objective judgement is valuable in order to check the completeness, correctness, relevance, and usability. Furthermore, the process towards benchmarks is evaluated, and the hypothesis drawn in Section 3.2 is tested. In other words, comparing expectations versus outcomes of the test phase. Issues are explicitly mentioned, and suggestions on how a solution could or should respond to the issues that arose. The discussion that takes place during a benchmarking process is of value as well, not only the resulting model. Both the assessment of the benchmarking model with the expert panel and the evaluation of the model are incorporated in the revised model. Alterations, such as modifications or additions, are made to the preliminary model design.

- *Objective:* evaluate both the benchmark model and process for validation and verification of the design. Consequently, finalising the design of the benchmarking model following the evaluation results.
- *Methods:*
    - Interviews: review the benchmarking model and results visualised in the dashboard. Interviewees are asked to give their opinion on various aspects such as completeness, correctness, usability, and relevance.

**Phase 5 - Results**

At last, the most important findings of the research are summarised. The main research question and its sub-questions are addressed. For practical purpose a manual will be subtracted from all findings throughout the research. As a result, a benchmarking model that is accessible and understandable for asset managers of ports all over the world can be presented. Furthermore, recommendations for future research are presented.

- *Objective:* publish results, conclusions and recommendations of the research for scientific revelance. Communicate the benchmarking model through a manual and supporting tools for ports for practical relevance.

## 1.5. Report Outline

Figure 1.2 shows the outline of the study by a sequence of design steps. The schematic view presents all research phases, and its corresponding chapters and research questions.

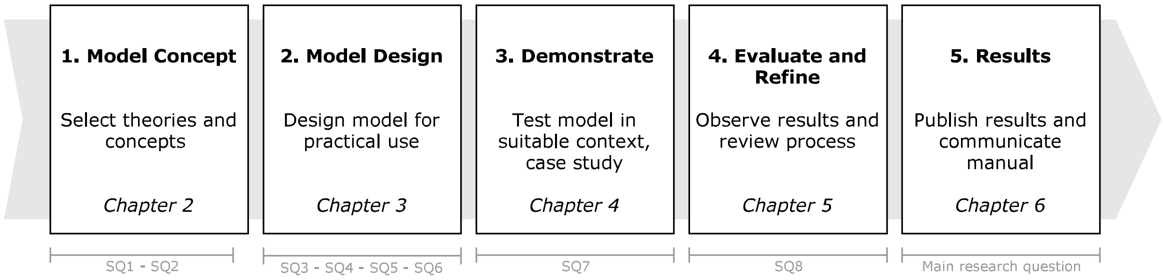


Figure 1.2: Research outline

# 2

# Model Conceptualisation

An overview of previous studies related to the context of this research is provided in Section 1.2.2. The review suggests that studies on the specific context of this research problem are missing. Due to the unique characteristics of the research area, novel research contributions are required to achieve the desired objective.

This chapter outlines and discusses the findings from previous benchmarking projects and research. To define a suitable *benchmarking approach* for the model, the pitfalls of benchmarking are listed. Following these pitfalls a literature review is conducted to find suitable benchmark options from generic literature in order to specify benchmarking for the purpose of this research. From the identified approach a *design process* is presented. The methodology to compile a benchmarking model is a design process with multiple steps which all contribute to a final model. From a custom-made benchmarking process, suitable methods and tools can be identified for each phase. To start with the design process first the design input needs to be determined, including a *conceptual framework*. Literature will be reviewed in order to select theories that form a strong basis for the model design.

## 2.1. Approach of the Benchmarking Project

### 2.1.1. Lessons Learned

Earlier attempts of port authorities to benchmark on asset management performance did not succeed. The collaboration did not result in what was desired, lacking asset managers in providing a appropriate model to measure and compare performance. The desired results are covered by the objective of this research (Section 1.3). The past few years asset managers of various ports have worked on a benchmarking model. An interview with an asset manager involved in the preceding projects regarding benchmarking created understanding of their way of working (Schot, 2019). Lessons learned from previous attempts are taken into account for in the approach of this research. Hereafter, a list of all expected pitfalls and possible solutions to avoid those pitfalls are provided (Elmuti & Kathawala, 2002):

- **Pitfall 1:** *Benchmark is done at too high a level*
  *Issue:* performance measurements on different levels of abstraction can be defined: *i)* Organisational strategic goals, and how the objectives of asset management can be aligned with the vision of the organisation, *ii)* For managing the asset portfolio it is about the optimisation of capital investments and sustainability planning, *iii)* Manage asset systems: sustained performance, cost and risk optimisation, and *iv)* Manage assets: optimise life cycle activities (British Standards Institution, 2008). To understand asset management, it is important to start at the bottom, the operational level. Generic asset management benchmarks are not sufficient. Larger systems should be split into logical units to obtain useful benchmarks. Each unit may be facing different kinds of problems.
  *Solution:* clear scope as the focus is on managing assets. Benchmarks are defined in such way that asset managers can measure and compare their activities, processes and performance. The subsystem of managing (physical) assets is benchmarked.

- **Pitfall 2:** *Outcomes are not linked to underlying activities*
  *Issue:* benchmarking is often comparing numbers while neglecting the activities involved. These activities influence the numbers, and the underlying qualitative activities can explain a gap in the numbers. A bottom-up approach in defining benchmarks for asset managers provides information on (physical) assets under management. Benchmarking is the process of finding what is behind the numbers, not just about your position in the ranking.
  *Solution:* intensive consultations with the users of the benchmarking model (i.e. asset managers). The benchmarking project was managed by a team at (senior) management level. Experts who work on strategic or tactical level were involved. Moreover, for this project asset management departments at the operational level is consulted.
- **Pitfall 3:** *Improper approach and view on the benchmarking process*
  *Issue:* proper view of the benchmarking process is missing. The brainstorm sessions and benchmark development is unstructured, without disciplined guidelines for ensuring standardisation and consistency of the process and its results. The users of the system were not consequently involved in the development phase and the defined performance measurement were of limited relevance. The decisions were made by individuals, not based on agreements. The lack active involvement of all benchmark partners during the process is a potential pitfall. These employees will be the ones ultimately using the benchmarking model (Elmuti & Kathawala, 2002).
  *Solution:* the benchmarking model is obtained by following a structured process, both for development of the benchmarking model and the performance measurements. The structured approach is a result of existing frameworks and brainstorm sessions with asset managers. The benchmarking process and other tools give guidance to the asset managers involved.
- **Pitfall 4:** *Too many performance measurements*
  *Issue:* there are a lot of things that would be interesting to know. Especially when working with experts, who are passionate about their job, many details will be brought to attention. The results deviate too much from the vaunted objective.
  *Solution:* too much details will hinder the analysis. Therefore, each measurement starts with defining what an asset manager really wants to know. By framing the development process, distraction will be avoided. Next to this, the experts working on benchmarks will be steered by people who focus on the overall view and desired results.

### 2.1.2. Benchmark Options

All aspects of benchmarking are discussed in this chapter. The section provides insights into the functioning of benchmarking as it elaborates on performance measurement, definitions of benchmarking, different types of benchmarking, the benchmarking process and the methods. Moreover, there is elaborated on the benchmark procedures and underlying approaches for the development of performance measurement.

#### Generic Definitions of Benchmarking

Benchmarking is an effective tool that supports management in their pursuit of continuous improvement. It is a technique for assessing a firm's performance against the performances of other firms (Sekhar, 2010). The technique is used to find the best practice and to determine which actions can improve the firm's own performance. Along with the increased use of benchmarking, many researchers focused on performance measures and setting targets. According to Meybodi (2009), benchmarking activities need to be integrated into an organisational strategy and the benchmarking process needs to employ a broad range of balanced performance measures which are consistent with an organisation's strategy. In doing so, benchmarking can be used as an effective organisational tool for learning.

Benchmarking is different from performance measurement, which is about collecting and comparing data on performance. The data tells where an organisation stands compared to its position in the past. It can therefore be stated that performance management has a past and present focus. Benchmarking, on the other hand, has a present and future focus. Some of the key elements of performance measurement are encompassed in benchmarking: collecting and collating performance data and comparison of performance data. Other key themes of benchmarking not included in performance measurement are: identification of best practices and implementation for performance improvement (Henning, Essakali, & Oh, 2011).

Benchmarking in general has many advantages. There are two important advantages from the point of view of an asset manager. First, the minimisation of costs and time-savings to adapt best practices of other companies rather than inventing them in-house. Second, stimulation to overcome an organisation's inertia and think differently in the context of new approaches implemented elsewhere (Sekhar, 2010).

With individual measures gaps can be identified. This identification of gaps is a challenging task, since multiple measures are combined in the final stage. Benchmark models can deal with multiple performance measures and provide and integrated benchmarking measure (Zhu, 2014). The process of benchmarking consists of defining valid performance measures for comparison among peer companies, using them in determining the relative positions of peers, and eventually establishing a standard of excellence. To execute this process, an organisation gathers data on its own performance and compares this against the best performance, the benchmark (Benneworth, 2010).

#### Different Types of Benchmarking

The application of benchmarking covers numerous industries, covering a wide range of companies and services. This shows that benchmarking is used for different objectives and scopes. Hence, there is no single way to approach benchmarking. The objective and scope of the research are reflected in the type of benchmarking. Two ways to classify the types is identifying to whom is benchmarked against or to what is benchmarked. There are three types of benchmarking when it comes to the sample selection: internal, external and international benchmarking. This categorisation differentiates on the scale of benchmarking. Identifying to *whom* is benchmarked is necessary to determine benchmarking partners (Sammut-Bonnici, 2015):

- *Internal benchmarking* involves units from the same organisation such as divisions or units in different countries. Comparison of practices and performance takes place between teams. For this type fewer issues are involved in sharing commercial sensitive data. In addition, it is more likely that the data is already standardised.
- *External benchmarking* covers the comparison of organisational performance to industry peers or across industries. The resources required for this type of benchmarking are significant, and the benefits from learning are more significant. Data collection requires a collaboration or the use of publicly accessible data.
- *International benchmarking* is a form of external benchmarking. International benchmarks are becoming more feasible as digital technology has increased the opportunity of collaboration on international scale.

Furthermore, the different types of benchmarking can be classified according to what has to be observed. This shows which units will be analysed to measure and compare peers. Classification of three types based on *what* is benchmarked (Bogan & English, 1994):

- *Process benchmarking* focuses on the daily operations of the organisation. It demonstrates how companies accomplish the process in question. By identifying how peers perform a functional task or objective, insight and ideas are gained. The information affirms and supports decision-making. Usually processes in the lower level of the organisation are analysed. Improvements at this level can be realised quickly.
- *Performance benchmarking* provides a numerical standard at which processes can be compared. Organisations can identify performance gaps and conduct follow-on research to determine methods for improvement.
- *Strategic benchmarking* identifies lessons and strategies which enabled the best practice companies to be successful. For a long-term perspective this type of benchmarking is ideal.

#### Benchmark Process and Methods

Performance measurements are useful in both performance management and benchmarking. In performance management these indicators mostly relate to the organisation itself. However, in benchmarking the indicators of the organisation are compared to the performance of other organisations. For this reason it is important to clearly identify the function to benchmark in the initial stage of the benchmarking process. In essence the performance of any organisation can be benchmarked. There are numerous models of the benchmarking process. According to Camp (1989) the process of benchmarking consists of five stages: planning, analysis, integration, action, and maturity. Each phase of the process involves multiple steps. Depending on chosen benchmarking method, certain adjustments of the process are required. Figure 2.1 visualises the different stages and accompanied steps of a typical benchmarking process. The first stage of the process covers the identification of the function to benchmark and definition the performance measures (O'Rourke, 2012). The process starts with determining the boundaries and the question: 'What actually needs to be benchmarked?', followed by the identification of the peers ('whom'). Explanation of these steps are described in the previous section.

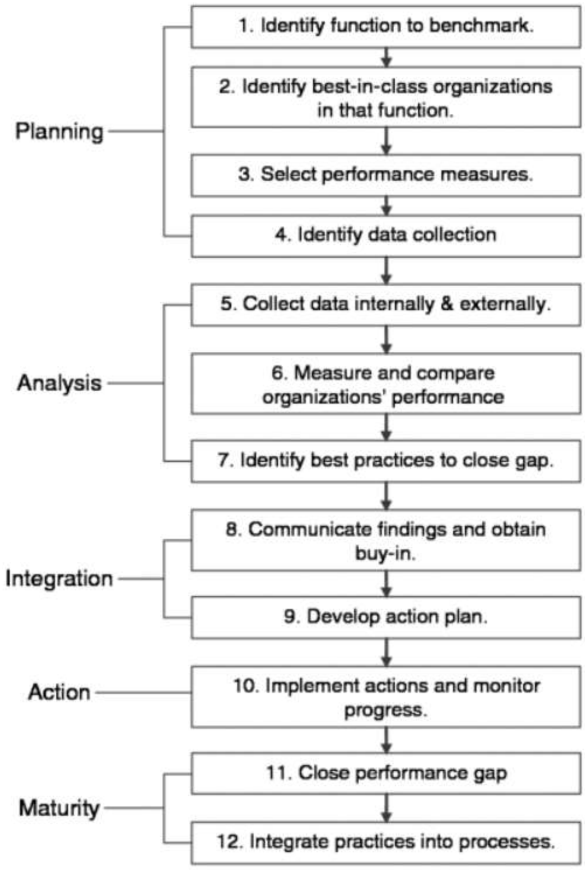


Figure 2.1: Benchmarking process (Camp, 1989)

Next to the visualised process of Figure 2.1, there are numerous models describing the benchmarking process. Although these models differ in the number and name of phases, the journey is essentially the same (Markovic, Dutina, & Kovacevic, 2012). Therefore there is no single way to execute the process, and thus for every specific benchmark study the process should be adapted to fit the purpose of the research. The same applies to the benchmark methods. Although benchmarking is not a new concept, the methods and tools assisting the application of benchmarking are rarely standardised. Following the custom-made benchmarking process, suitable method and tools can be identified. The use of methods and tools within the different phases of benchmarking depend on the specific benchmark study. This research therefore studies previous literature in order to identify which methods are available for each step of the process.

Based on what has to be observed, the benchmarking type is selected. Decision makers need to refine this choice to identify specific aspects of what they want to benchmark (World Bank Group, n.d.). Clear objectives are needed so that appropriate information can be collected and a suitable model can be specified. The collection of information considers data collection and analysis methods. Data collection can be conducted by one or more of the following methods: research, telephone, (site) visit, survey, interview and direct observation (Andersen & Pettersen, 1995). By systematically applying data analysis techniques data can be evaluated. Various types of data analysis methods are available. All methods require specific skills from the benchmark conductor. Particular data analysis methods are used such as: mean, radar graphs, ranking curves, and table displaying organisation results (Markovic et al., 2012). These analysis techniques are applied in order to learn the relations and structures of quantitative or qualitative data.

#### Benchmark Procedures for Developing Performance Measurements

There are different ways to develop performance measurements. Bourne, Neely, Mills, and Platts (2003) developed a categorisation which separates different forms of design processes. They suggested two distinct dimensions for categorisation: the underlying procedure and the underlying approach of performance measurement.

*Procedures for performance measurement*

- ’Needs led’: top-down procedure for developing performance measures. The needs of the involved actors are used as a basis. The measures monitor the progress in achieving these needs.
- ’Audit led’: a more bottom-up approach. Existing performance measures are used as a starting point. The first step is an audit of the existing measures. The information following this audit is collected and used to challenge the status and improving existing measures.
- ’Model led’: this approach uses a prescribed theoretical model of the organisation as a basis for designing what should be deployed.

The procedures could be considered as the ’hard’ issues. The underlying bases of the systems for performance measurements are very different. The identified underlying approach in supportive to the procedure, which says something about the role of the actors involved in the benchmarking process. The role of the conductor of the performance measurement and benchmarking process are covered by this dimension.

*Approaches for performance measurement*

- ’Consultant led’: approach where the majority of work is undertaken by an an individual or group of individuals (usually consultants). The work is almost done in isolation from the rest of the management team. The analysis is performed and presented by the consultant.
- ’Facilitator led’: this approach is different in a way that the majority of work is undertaken by the management team. Workshops are facilitated to make sure they discover and analyse the phases of work together. The facilitator revolves around eliciting information from the composed group.

### 2.1.3. Selected Benchmark Options

This section selects suitable options in benchmarking from the identified options in Section 2.1.2. The selected benchmarking options are combined with additional information on asset management in ports.

#### Type of Benchmarking

Considering the scope and the research’s objective, the type and methods can be selected. From the perspective of organisations, benchmarking is a process of learning from own past performance and that of others in the pursuit of continuous improvement (Malano & Burton, 2001). The framework, and finally the benchmarking model, is a tool that provides insight into the relative performances of ports.

The objective of the benchmarking model is to measure and compare performance of ports on asset management. *Performance benchmarking* enables an organisation to compare processes with numerical standards. The objective of this study, how different ports can be compared through benchmarking, corresponds to performance benchmarking. The strategic aspects, strengthening own strategic planning, is out of scope. The performance following the processes involved with asset management are compared. Different aspects such as frequency and methods for operations will be presented. The strategies, which are on a higher level and which underpin successful processes, will not be presented. Users of the system can identify performance gaps, prioritising action items, and then can conduct follow-on studies to determine methods of improvement. Changing the strategy, serving the long-term perspective, is up to each individual port. The peers are located in different countries, and therefore the benchmarks are of *international* scale. As they are delivering the comparable products and/or services, this could also be seen as benchmarking of competitors. Due to the international nature of these benchmarks, close attention should be paid to generic definitions and measurements.

Performance measurement can fulfil numerous of functions. For this research, the most important function is 'Learning'. To enable learning the ports first need to create 'Transparency', which is another function of performance measurement. The ports asset management departments need to make clear what they supply, and by means of an input-output analysis they can determine their level of efficiency (De Bruijn, 2002). The ports decided that their goal is not only to define clear measurements on performance, it should also support them in sharing knowledge to learn from each other.

**Process and Methods**

As performance benchmarking is assumed, a method needs to be selected to refine this choice and thus identify the specific aspects of what needs to be benchmarked. This will follow from the benchmarking process presented in Section 3.4, a step-wise user guide for asset managers which covers the aspects of the procedure ('model led') and approach ('facilitator led') chosen for this research. The data is collected from open sources (public data presented in annual reports) and closed sources (databases of organisations). The methods for data analysis will follow from the developed benchmarks, a least demanding method is preferred. To quantify the defined benchmarks with data, a mathematical formula is defined. The results should be easy to understand for asset managers having no experience with regard to performance measurement and benchmarks. To evaluate the results, a dashboard is used to communicate the results, which is a practical tool to monitor and analyse key metrics. The dashboard enables users to customise the analysis in evaluating results. In this way asset managers can explore relevant information from different perspectives and various levels of detail. Building a dashboard fundamentally helps the asset managers to interpret data. The users of the dashboard can see at a glance all developments portrayed by the benchmarks. The dashboard is designed for quick analysis and informational awareness (Eckerson, 2010).

**Procedure for Developing Performance Measurements**

For this study the 'model led' procedure will be used, since the organisation will be transformed in theoretical models. Theoretical models will be used to visualise performance as a conceptual framework. The combined theories serve as a framework for benchmarking. In addition, the eventual model should take into account the 'needs' of the system's users. The asset managers' needs are identified and used for the specification of the framework following the 'model led'. The measures are designed to monitor the progress or the organisation towards achievement of this needs.

The underlying approach of this procedure is the 'facilitator led'. The knowledge of both asset managers and literature are combined. In doing so, theoretical models ('model led') and the perspective of experts ('needs led') are covered. The different steps taken to provide a theoretical model of the organisation to understand its operations are presented in Section 2.3.3.

The following theoretical concepts should be taken into account when defining measurements and approaching the organisation as a system:

- *Processes within the organisation:* organisational performance as conceptual framework, where the organisation is the system. Different processes can be defined when defining all relations within an organisation and between different units. For asset management a simplified performance measurements framework can be identified. Conceptual framework for asset management performance, where asset management is the system (the management of assets).
- *Control within the organisation:* a control model for organisations in general. In this way, organisations can be seen as a controlled system. For this research the port is the organisation, a controlled system that interacts with the environment.
- *Focus within the organisation:* on different levels within the organisation objectives are outlined. These objectives should be aligned with the organisational objective, and with the goal of value maximisation. When optimising the system or a subsystem, a challenging task is often finding the right balance between different aspects.

For listed steps different theories are reviewed and selected to provide building blocks for developing performance measurements. These guiding principles will be brought to attention in Section 2.3.3. Information on performance measurement act as input for the template for performance measurement (Performance Measurement or Benchmark template). This template is part of the performance measurements design process. The listed steps and template are further explained in the next section, where the framework is obtained.

## 2.2. Design Process

Several steps are executed to structure the design process. These design steps are based on the process for systems development research by Nunamaker et al. (1990) and the design science research methodology by Peffers et al. (2008). To align the steps taken in this research the model in Figure 2.2 is presented. The steps are very similar to the research outline presented in Figure 1.2, the difference is that the model concept and model design phase are disaggregated. This disaggregation is based on the design framework of Herder and Stikkelman (2004):

- *Model concept:* theories and concepts are the input for the design process. The design input is used to determine the design requirements and design space. The input consists of both theoretical and empirical findings.
- *Model design:* with the design requirements and design space the benchmarking model is designed, and thereafter demonstrated and evaluated by experts.

In practice the steps do not need to be dealt in strict sequential order, as many iterations took place. For each chapter Figure 2.2 is presented, highlighting the elements discussed. All important choices and selected options figure among 'design input'.

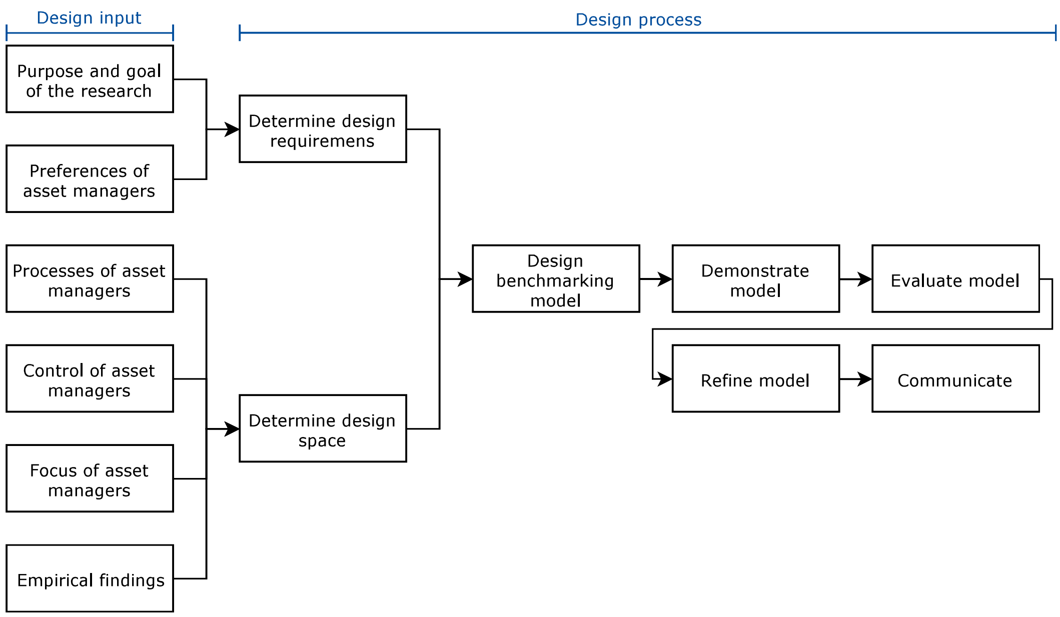


Figure 2.2: Development of the benchmarking model: a methodological guide

## 2.3. Towards a Conceptual Framework

Companies that rigidly stuck to routines, even successful routines, become less able to introduce new methods of doing things. This specifically applies to established companies, which standardised many of their processes. Such companies should be aware of their current processes in order to improve their performance. For identifying and prioritising areas of improvement, it is of importance to understand the dynamics and performance of the system.

The design of a framework is the first step towards a quantified research on the contributions of various factors to the overall performance of asset management. Following the selected benchmark options, theories are collected and adapted to support the benchmarking process. The theories and frameworks in this section are building blocks for the definition of performance measurements or benchmarks. The resulting framework provides a basis for benchmarking on port's asset management performance. Defining the building blocks for a benchmark model starts with the review of literature. First, better understanding of both asset management and performance measurement concepts is created. Second, theories to frame and guide the definition of performance measurements are presented for the acquisition of a conceptual framework.

### 2.3.1. Asset Management Theory

Port-related organisations are heavily reliant on physical assets in order to function effectively. The core part of the discipline known as asset management, is managing assets in such way that they can provide services. Each organisation determines what is considered as value, and how to manage its assets to derive the best overall value.

Asset management enables organisations to realise value from assets in the achievement of its organisational objectives (ISO 55000, 2014). For the visibility and traceability of asset management performance to the organisational objectives, we use the concept line-of-sight (Schoenmaker & Van Der Lei, 2015). This concept pertains the The objectives and its fundamentals should be aligned with the organisational objectives. The concept line-of-sight ensures the visibility or trace-ability of performance measures to the organisational objectives across different organisational levels (Schoenmaker & Van Der Lei, 2015). These set objectives determine what constitutes value. With asset management, value creation is the core principle. Asset management is about effectively and efficiently managing assets by creating a balance between performance, costs and risk. Asset management is based on a set of four fundamentals: value, alignment, leadership and assurance (ISO 55000, 2014):

- *Value:* assets exist to provide value while balancing performance, costs and risk, in accordance with the organisational objectives.
- *Alignment:* asset management translates organisational objectives into their coordinated activities.
- *Leadership:* leadership and commitment is essential for effective asset management within the organisation.
- *Assurance:* the need for effectively governing an organisation is reflected in asset management as it gives assurance that assets fulfil their required purpose. It is a combination of monitoring and auditing (of processes and outcomes).

The asset management system is a set of interrelated or interacting elements to establish asset management policy, objectives and processes. This system is used to direct, coordinate, and control asset management activities. Asset management systems are often too complex and continually evolve to match its context, objectives, and asset portfolio. All levels of assets and their management can be placed in a hierarchy in order to create understanding of the system. The focus of asset management differs at the various levels, and therefore also the concept of continuous improvement asks for a different approach. Figure 2.3 shows examples of priorities that are evident at the different levels of asset management. The asset managers' approach, as considered in this research, is highlighted in the figure.

An organisation manages its assets as a group rather than individually. Such groupings may be asset types, asset systems or asset portfolios. Managing assets as a group often leads to additional benefits as asset managers become experts when it comes to the needs of an asset type. The demonstration as presented in Chapter 4 is carried out with the help of these experts, as they have the knowledge necessary to create benchmarks for the selected assets.

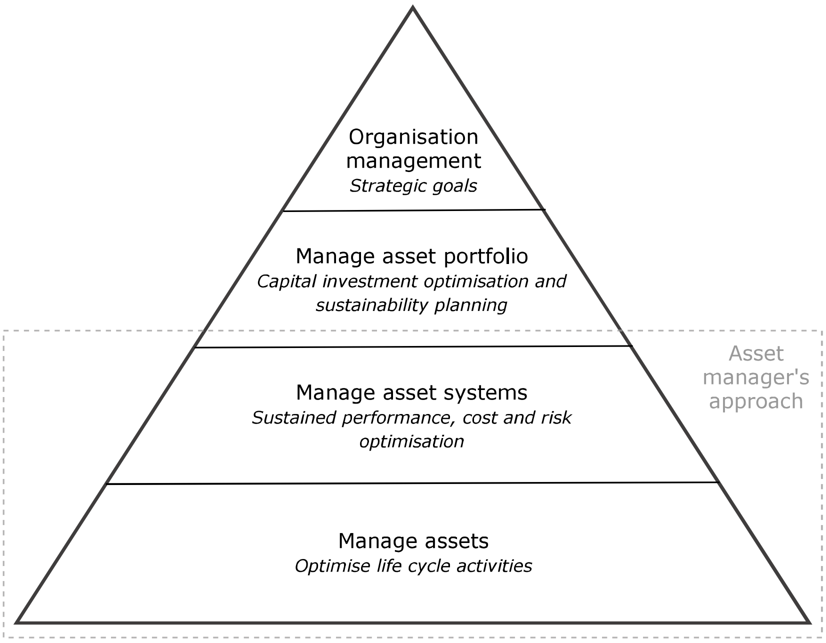


Figure 2.3: Levels of assets and their management, adapted from (British Standards Institution, 2008)

### 2.3.2. Performance Measurements for Benchmarking

The central idea behind performance measurement is a rather simple one: an entity (e.g. organisation, department) formulates envisaged performance and indicates how this performance can be measured by defining performance indicators (De Bruijn, 2002). If it is possible to measure something, figuring out its precise size, degree, or amount, then it is measurable. A measurement is the assignment of a number to a characteristic of an event or object, which can be compared with other objects or events. Performance measurement is actually an elegant way of shaping the accountability: those who are granted a deal of autonomy have to account for their performance and provide an insight into their performance. To make sure that performance measurement is elegant, the information must comply with the following requirements:

- Information is measured systematically and quantified, thus enabling comparison over a certain period
- Information can be easily communicated
- Information can be supplied at the same time each year

For performance management, performance measurements need to be defined following the objectives of an organisation. In the broadest sense, performance management is about linking organisational goals to resources and results. Asset management refers to the application of performance management principles to the management of physical assets (Steudle et al., 2012). The basic principles of asset management and performance management are similar, and a performance-based approach of managing physical assets contributes to proper asset management.

In performance management the measures, will mostly relate to the organisation itself. In benchmarking, the measures are compared to the performance of other organisations with the aim to establish a realistic target for the organisation. In the context of benchmarking, a performance report is not the desired end product. More precisely, performance measurement is a tool used to provide insights, raise questions, and identify other organisations that may be used to learn from and help improving the organisation (Ryus et al., 2010).

The performances measures, or benchmarks, for this study must provide consistency and take into account the various characteristics of the assets and ports to ensure that comparisons are reasonable and accurate. In the design process, comparability must be maintained. Throughput the benchmark process, communication among all participating asset managers is essential to success. The objective of the benchmark development process is to develop and agree on a unified set of indicators or measurements, providing qualitative and quantitative information.

To enhance the quality of the benchmarks, standardisation can be helpful. Designing your own benchmarks can be fraught with ambiguity and inconsistency. The user guide and tools, such as templates, can be used in the design process. The template to guide the construction of a benchmark should address the basics of any measurement and help to put it in context. More technical aspects such as formulas and aspects of data collection, as well as some tests to ensure a sensible indicator, is developed. It is important to document the details of the measure so that the measurement is consistently calculated and presented which allows for meaningful analysis and conclusions.

### 2.3.3. Guiding Principles: Acquisition of a Conceptual Framework

Three theoretical frameworks form the basis of the definition for the performance measurements. By placing the selected measurements in these frameworks, measurements can be developed in a structured way. All generic theories are converted to frames that are suitable for the benchmarking model. Both the fundamentals of asset management and the performance-based approach will be reflected in the guiding principles:

1. Processes of Asset Managers
2. Control of Asset Managers
3. Focus of Asset Managers

The resulting framework is a conceptual structure for developing benchmarks. The framework creates understanding of variable relations and context of the benchmarks.

#### Processes of Asset Managers

The development of appropriate performance measurement, which is useful for asset managers, requires understanding of the system. From an engineering and operations approach, ports can be seen as fixed assets and operational systems. A system is often defined as a set of components that are interrelated among themselves and with the environment. The internal system of a port can be divided in four components: physical assets (infrastructure and superstructure), technology and information systems, labour and human resources, and management and workflow processes (Bichou, 2009). Because of the complex nature of operations in ports, research is usually undertaken at disaggregated operational levels. The selected components for this research are the physical assets. A further distinction is made by focusing on the operational aspects, and not on the strategic and tactical aspects of asset management. However, the results of the performance measurements can subsequently change tactical or strategic decisions.

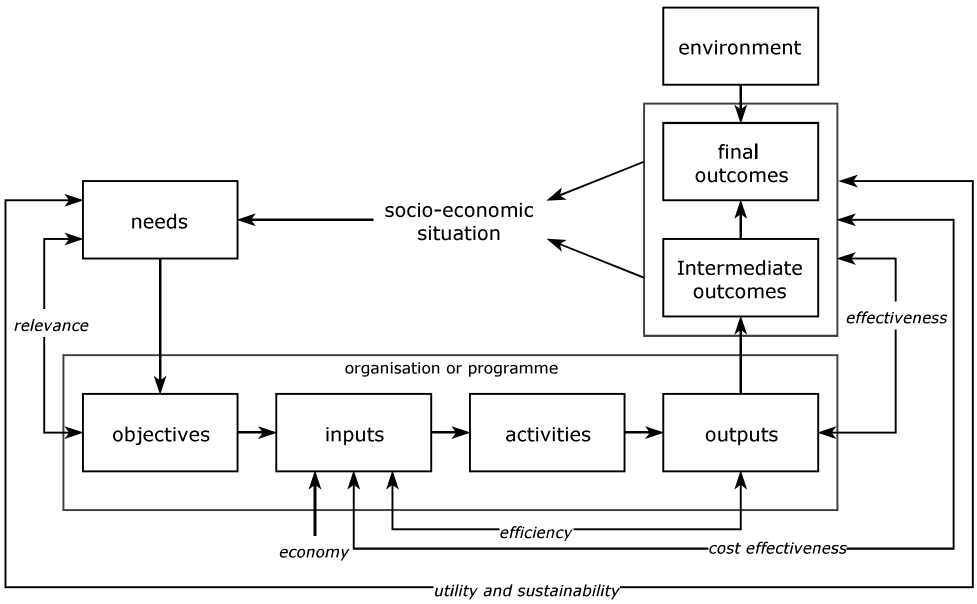


Figure 2.4: Performance: a conceptual framework (Pollitt & Bouckaert, 2011)

It can be challenging to evaluate changes in large-scale organisations systematically. To examine the results of decisions made, even on lower level in the organisation, a conceptual framework as presented in Figure 2.4 can be helpful. Terms such as efficiency and effectiveness can represent the performance of the company. Efficiency is the ratio between inputs and outputs, where effectiveness tells to which extend the desired outcomes result from the inputs. The outcomes are the actual changes, benefits, or effects that happen as result of what is delivered (Pollitt & Bouckaert, 2011).

Mapping the processes within an organisation allows the use of process benchmarking. This framework fits well into an operational approach in improving performance. Bottom-up approaches rely on expert judgement and knowledge of the system, and are data intensive. Process benchmarking focuses on selected production processes in the business rather than on the business as a whole. In this research the production process is not as in many researches production in a manufacturing firm. It concerns all processes involved when managing the (physical) assets in the port industry. Inputs are processed into outputs and the framework systematically present the causal relations. Both on organisational and asset management level the causalities give insights into the practices and related performance.

In the context of asset management systems, asset management objectives are set by the organisation, consistent with organisational objectives and asset management policy in order to achieve specific measurable results (IAM, 2015). Due to the large variety of assets in the port, asset managers are responsible for a certain type or a selection of assets in the portfolio. As a result, they are responsible for managing individual assets over their life cycles. All asset managers within an asset management department together manage the asset system. Due to the complexity and different characteristics of assets in the port, individual assets are clustered within groups of assets with the same characteristics.

The framework in Figure 2.4 can be simplified in a process focused on the elements asset managers have influence on. In this way the overview of the organisation as a system is simplified on a lower level. The input-output diagram in Figure 2.5 is derived from the framework of Pollitt and Bouckaert (2011). The process are the activities of the asset managers. The process is the means by which the system physically converts or transforms inputs into outputs. An important aspect of system design is to create a process that effectively produces the desired outputs and meets system objectives, yet minimises consumption of inputs and maximises the outputs (Nicholas & Steyn, 2012). Next to the inputs and outputs, the environment in which the input-output process is placed needs to be considered as well. The process can be affected by either internal or external influencing factors.

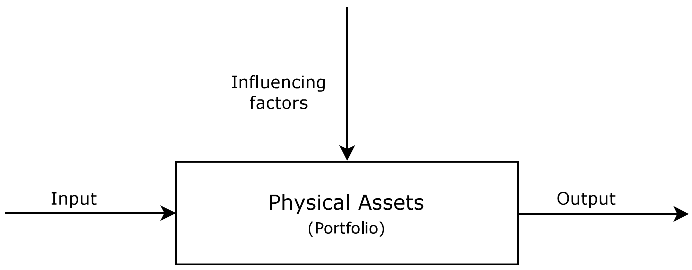


Figure 2.5: A conceptual performance framework for asset management

The input-output diagram represents the process of asset management as the management of (physical) assets. The physical assets undergo a process as a result of decisions made by the managers. The coordinated activities can be seen as a process changing the state of the assets. All involved measurements within asset management can be allocated to the following categories:

- *Input:* or activities. Carried out by internal or external personnel. Next to this, the coordination of asset managers is also input. The activities can be for example costs, methods, frequencies, or hours spent on maintenance. The input depends on the asset management processes, the resources available, and influencing factors that can have influence on decisions made. For example, the impact of tight budget constraints. The input is controllable for asset managers (e.g. maintenance costs).
- *Output:* or results. The result of the activities carried out determined by the input, the influencing factors and the physical assets itself. The technical performances of the assets are examples of the

output (i.e. availability, condition, reliability, or safety). The exact definition depends on the function and other characteristics of the asset. The output can be viewed at different levels: portfolio of assets, subsystem, individual assets, or components of an asset.
- *Influencing factors:* being external or internal influencing factors. The factors are variable conditions outside of management, which can be external or internal, controllable or non-controllable. Examples of external factors are market and economy, national policies, salinity of the water, climate circumstances, utilisation rate (customers), and laws and regulations. Internal factors are for example organisations objective or the age of the physical assets. These factors are reference conditions, factors or circumstances affecting asset management. The factors affect the state of the asset, and the input or output either directly or indirectly.

The framework is a simplified representation of the asset management function and how measurements can be categorised. The framework in Figure 2.5 did not take into account *asset management resources* and *asset management processes*. The capability of asset managers to achieve the best performance is also about using and dosing the appropriate resources. The asset management processes are the methodologies used by each sub-function to implement the activities of asset management. Both the resources and processes should be used in such way that a suitable result in line with the stated company objectives is achieved. As the focus is on the operations of asset management, the contribution to the organisational objectives is not quantified. As mentioned earlier this means that the ability to fulfil requirements or objectives which can be controlled by asset managers is benchmarked. Optimising the assets under management, can be achieved by a quantitative or qualitative method, as appropriate. Finding the best value compromise between conflicting factors such as performance, costs and retained risk (IAM, 2015).

Asset management can be approached as a system, introducing 'system thinking'. This is a way to conceptualise the physical entities and addressing problems with respect to managing those entities. The components of the system are: objectives and performance criteria, environment and constraints, resources, elements of the system, their function attributes and performance measures, and the management of the system for which asset managers are responsible (Nicholas & Steyn, 2012). Performance of subsystems, in which certain elements of the system are clustered, contribute to the overall performance of the organisation. An example of a subsystem is a department within the organisation. This research considers infrastructure, the asset types road and quay wall, which can be seen as a system as well. First, because its focus is total system oriented and it emphasises achieving the overall systems objectives. Second, the asset managers make decisions that optimise the overall-system rather than subsystems.

**Control of Asset Managers**

To create measurements that are useful for asset managers, it is important to define what is in control of the asset manager, or on which factors the asset managers can have influence. The performance measurements should be quantities that can be influenced, or controlled, by the user alone or the user in co-operation with others (Neely, Richards, Mills, Platts, & Bourne, 1997).

The paradigm of De Leeuw (1982) is a class of abstract systems, each consisting of a controlled part, an environment and a controller. The control model especially directs attention to the dual control-relationship between an organisation and its environment. On different levels within the organisation the function of management, as a process, is to control in terms of any directed influence. To create measurements that are provide useful insights for optimisation it is critical to understand the tasks of the asset managers and what falls within their range of control. The paradigm is presented in Figure 2.6. The arrows represent a flow of signals and interactions, showing how the different levels in the control model are linked. As a result, both the control and its link with the environment or context can be identified. The organisation can be seen as a hierarchical system which interacts with the environment. The systems approach of this research allows to conceptualise asset management within the port industry as systems that interact with the environment: the controlled system (assets) and the controller (asset management), and on a higher level, besides being an organisation the port is also a controller.

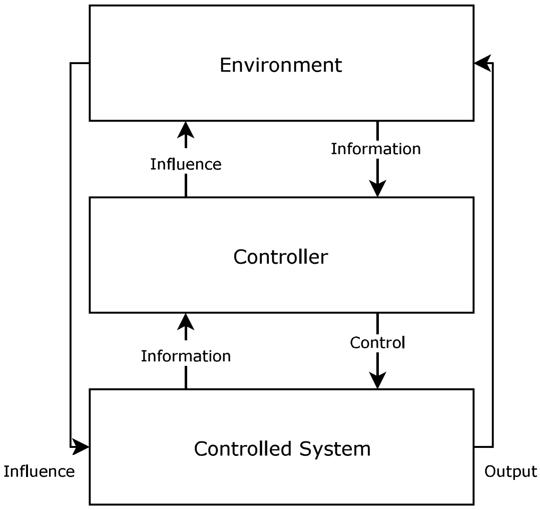


Figure 2.6: Control model (De Leeuw, 1994)

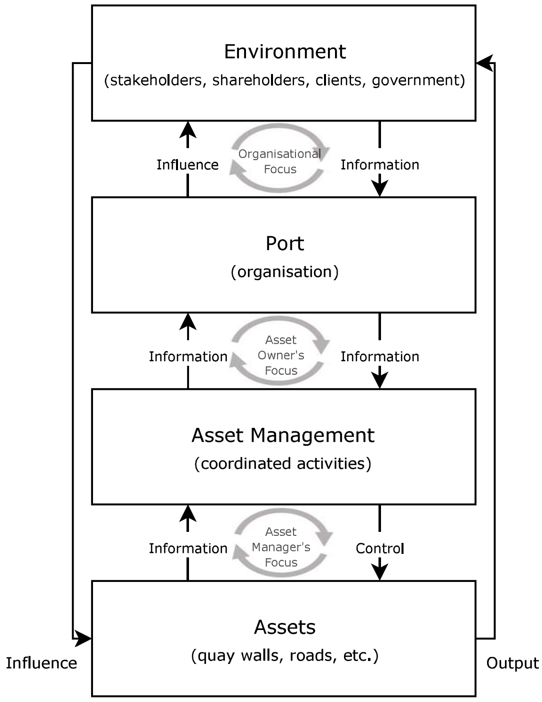


Figure 2.7: Port control model

The conceptual approach offers various concepts for application in real-life situations (De Leeuw, 1976). Applied to the port industry, the control model for an organisation is shown in Figure 2.7. The paradigm is used as a model for analysing and describing the control of activities. For effective control, the controller (asset manager) should specify goals with respect to the controlled system (physical assets). Furthermore, a model should be available, specified with information about the system and its environment. The availability of different strategies and activities to control the system are part of the asset managers' job.

Indicators that asset managers cannot (fully) influence are less legitimate, although managers are often held responsible for them. In many cases decisions of asset managers depend on other people and the cooperation with others (Schoenmaker & Van Der Lei, 2015). Both external and internal cooperation is involved. For example, the requirements following decisions on board level are of influence on the asset management strategy. The maintenance budget is an example of such requirement. Asset managers are forced to prioritise activities as they try to account for the organisational objectives when making plans and taking actions. Since the focus is on the physical assets, the focus is on a smaller part of the model presented in Figure 2.7:

- *Assets:* referring to physical assets, items which have a potential or actual value for the organisation. Items can be parts, components, equipment or functional subsystems.
- *Asset management:* the coordinated activity of the organisation to realise value from its assets. In addition, asset management is about the process that links asset owners, asset managers, and service providers in such way that all decisions are aligned with the organisational objectives.
- *Information (assets - asset management):* influencing factors, the characteristics of the assets and the directed influence of the asset manager contribute to the results in the form of information. Executing inspections or data analysis gives feedback on asset and performance data in the asset management process (Brown & Humphrey, 2005).
- *Control (asset management - assets):* control in general is any manner of directed influence (De Leeuw & Volberda, 1996). This relation shows the asset manager's ability to influence the state of the asset. Asset managers aims to coordinate the activities in such way that the right balance between performance, risk and costs is achieved.
- *Information (asset management - port):* asset managers, together with asset owners, compose a multi-year asset plan based on asset data. Next to this, the costs of asset management are information for a budget forecasting. These relations represent necessary information in monitoring the performance of the overall organisation and information that is of importance to stakeholders, shareholders, clients

and the government.

- *Asset managers' focus:* planning and budgeting. The asset manager identifies the best way to achieve the objectives set by the asset owner. This plan is called the multi-year asset plan.
- *Asset owners' focus:* on corporate strategy an asset owner sets the business value, corporate strategy and corporate objectives in terms of performance, costs and risk.
- *Influence (environment - assets):* this information shows overlap with the external influencing factors in Figure 2.5. For example, the utilisation rate of the assets has impact on the condition of the asset. The life of an asset will be shortened by wear and tear.
- *Output (assets - environment):* the interacting system transforms input into outputs. These results can be communicated as information to the asset management department or as provided service to clients. Performance measures such as availability are required to meet customers' demand.

**Focus of Asset Managers**

The asset owner decides on the acquisition of new assets and the disposal of superfluous assets, and thus deals with investments. Setting financial, technical, and risk criteria are the responsibility of the asset owner. In its classical form, asset management is separated from asset ownership and asset operations (Brown & Humphrey, 2005). In practice, however, the asset manager is closely involved in making decisions on investments. Besides, the asset manager is responsible for translating the criteria into an asset management plan. This plan must support the aim to find the best value compromise between (conflicting factors) performance, costs and risks (IAM, 2015). The asset manager determines what needs to be done to achieve the desired results and tries to find the right balance between the conflicting factors. The balance between the attributes depends on the asset management strategy. For example the strategy of engineering excellence, a strategy which aims to frequently apply preventive maintenance to ensure risk free operations (Wijnia, 2016). It is the role of the asset manager to understand which balancing options regarding the attributes are available, and requires a deep understanding of the asset itself. The service provider is responsible for executing the decisions of the asset manager and provides the asset managers with feedback on actual costs and performance.

A comprehensive definition of asset management can be found in PAS 55 (British Standards Institution, 2008):

*Asset management: the systematic and coordinated activities and practices through which an organisation optimal and sustainable manages its assets and assets systems, their associated performance, costs and risks over their life cycles for the purpose of achieving its organisational strategic plan.*

When measuring the performance of assets under management, a distinction can be made on an attributed level:

- *Performance* measures for assessing physical delivery of assets. For the purpose of asset management, performance can relate to assets in their ability to fulfil requirements or objectives.
- *Costs* measures are financial, developing performance measures for assessing capital cost-effectiveness of asset management system activities.
- *Risk* measures the effect of uncertainty on particular objectives. Where the effect is the deviation from the expected, either positive or negative. Hence, risk is determined through the variation in performance. Risk can also be described as the combination of consequences of an event and its associated likelihood.

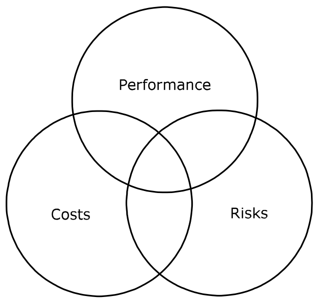


Figure 2.8: Performance, costs, and risk triangle of asset management

## 2.4. Chapter Synthesis

With the defined benchmarking approach the design process for a benchmarking model is identified. To start the design process certain inputs are required. Therefore, a theoretical framework is developed. This conceptual framework supports asset managers in the selection of performance measurements that are suitable for benchmarking. The resulting framework will be refined in Chapter 3 by aligning obtained model concept with the requirements for practical use.

First, by identifying the pitfalls in a literature review, suitable benchmark options have been selected. An overview of the selected methods can be found in Table 2.1.

Table 2.1: Selected benchmark options

| **Benchmarking** | **Selected options** |
|---|---|
| Definition | Technique for assessing a firm's performance against the performances of other firms (Sekhar, 2010). A benchmarking model allows benchmarking to function as a tool that is capable to support decision-making with the aim for continuous improvement. |
| Type | International benchmarking ('whom'), performance benchmarking ('what'). In the context of this benchmarking: international benchmarking of ports on the aspects of asset management. |
| Process | Following the design process as presented in Figure 2.2 the benchmarking process will be defined at a later stage of the research. |
| Methods | Data collection and analysis methods are explored in the model design phase of this research. |
| Procedure | The 'facilitator led' procedure with the use of the underlying 'needs led' and 'model led' approach. Theoretical models and the needs of the asset managers are brought together, which is done in a collaborative way. |

Following the selected benchmark options the generic approach of this research is defined. The benchmarking model for the development of benchmarks follows from the benchmarking process that is identified in Section 2.2. To start with this design process certain information needs to be collected, including the design of a conceptual framework. This information is referred as the design input. In doing so, the approach of the benchmarking model is further specified. The conceptual frameworks cover certain criteria which the benchmarks have to comply with. This entails that proper benchmark should fit within three theoretical frameworks, known as the guiding principles:

1. *Processes of asset managers:* position of the benchmark in the input-output performance measurement framework. The input-output diagram represents the processes involved when managing (physical) assets.
2. *Control of asset managers:* position of the benchmark within the port control model. This concerns control relations between an organisation and its environment. The benchmark should be related to the controllable part of the model.
3. *Focus of asset managers:* position of the benchmark in relation to asset management objectives. The main objective can be stated as the realisation of value while balancing three relevant attributes: performance, costs, and risk.

The guiding principles as laid down above, are combined together in Figure 2.9 on the following page. Benchmarks for performance measurements that fit within this framework are suitable for the purpose of this research. The benchmark should attribute to value creation and should match the involved processes when 'managing assets'. Moreover, the measurements should be controllable, which provides asset managers insights into performance improvement.

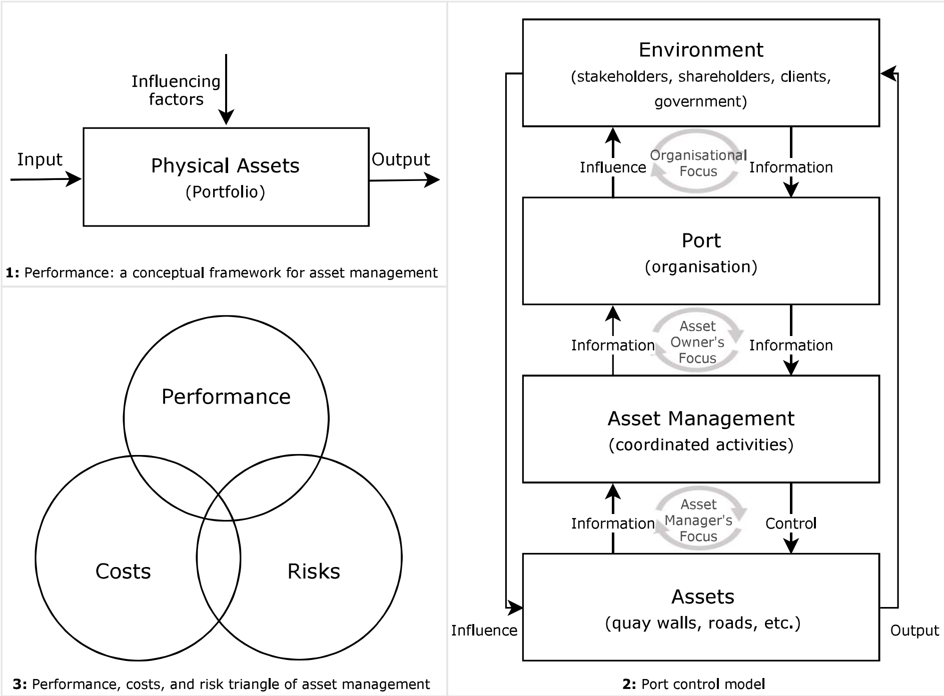


Figure 2.9: The guiding principles

# 3

# Model Design

The previous chapter observed and identified key elements in performance measurements of asset management. This chapter aligns *theory and practice*. The resulting *design of the benchmarking model* provides asset managers a model for practical use. The model connects identified criteria (*what to measure*) with the identified additions to the benchmarking method (*how to measure*). This method is a working method for asset managers to create performance measurements on asset level for international benchmarking. The primary aim in developing such model is to define the theoretical content and contours of a new method for practical use. The design takes into account the potential pitfalls of benchmarking as presented in Section 2.1.1. Throughout the chapter reference is made to these pitfalls.

## 3.1. Theory and Practice

In this chapter theory and practice meet each other in designing a benchmarking model for practical use. Through brainstorm sessions and interviews with asset managers some key principles and theories are selected. This model is basically a theoretical construct, which is more specific and less abstract than a concept, and can be defined as a set of operational measures that allows for the study of theoretical concepts. As a result, the design is a multi-dimensional construct, which consists of multiple underlying concepts. All this contributes to a structured approach of benchmarking and a clear working method for inexperienced users. Theory forms the basis for all relationships between and among variables. These series involve interrelated constructs, concepts, abstractions, variables, definitions, and proposition are assumed with a systematic view of phenomena. Controversies associated with the relationship between theory and practice are discussed with the asset managers. From the practitioner's perspective two questions could arise: 'Why does theory matter?' and 'When am I ever going to use this theory?' (Udo-Akang, 2012). The first question is addressed in Chapter 2. Together with asset managers (i.e. the practitioners) relevant generic theories are selected and adapted to the specific context. Section 3.4 outlines how the theory is used in developing benchmarks.

## 3.2. Design of the Benchmarking Model

The previous chapters and sections observed and identified key elements in performance measurement for asset managers of ports. The identified building blocks in the previous steps of this research contribute to the benchmarking model development, which are the design input. By connecting identified criteria (*what to measure*) and the chosen benchmarking method (*how to measure*), this section presents the model design.

The approach taken in the development of the benchmarking model is based on the model of Herder and Stikkelman (2004). The adjusted model is presented in Figure 3.1. The inputs for the design process are the design requirements and design space.

With the design requirements and space and the design input, a preliminary benchmarking model is built. Based on the feedback of the experts the design of the model is iteratively explored and developed. This preliminary design is demonstrated in Chapter 4 and evaluated by experts during interviews.

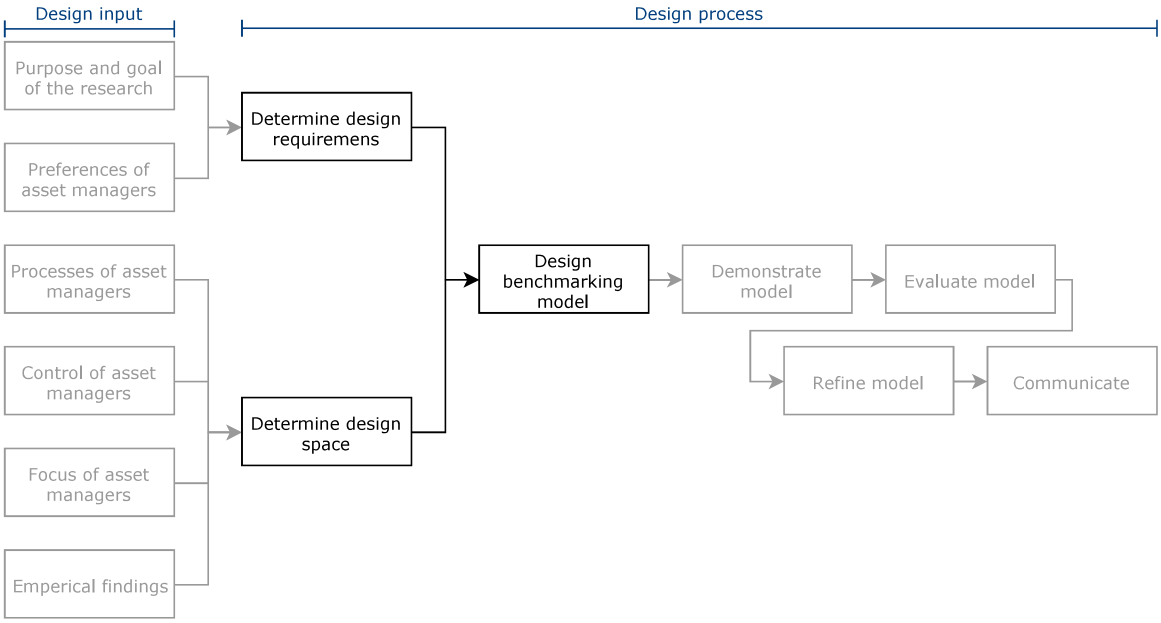


Figure 3.1: Development of the benchmarking model

### 3.2.1. Design Requirements

In model development, the definition of the functions and requirements is made prior to the development to allow for an assessment of the level to which the developed framework accomplishes the predetermined goals.

As limited research is available on benchmarking at operational level, no standards on what to measure and how to put this into operation are developed. The set of criteria is therefore one of the challenges of this research. In addition no appropriate framework is available in dealing with the specific modelling needs for developing international benchmark, focusing on asset management in ports. A framework needs to be developed to address this knowledge gap. Two main design challenges for the model design are identified:

- Which set of criteria indicates asset management performance?
- How to measure performance of asset management?

The newly developed model provides the necessary insight for asset managers. Both theoretical concepts and the needs of the asset manager are sources for the modelling requirements. All requirements are formulated as statements that identify a capability or function needed by the model in order to satisfy the needs of the customer (Bahill & Dean, 2009). Requirements define the functions of the model or its components, and impose the constraints on its design or implementation. The set of requirements is a careful assessment of the needs that a system fulfils.

The users of the system (i.e. benchmarking model) are asset managers or other employees of port-related companies. Specific knowledge on asset management is therefore assumed, but no prior knowledge on benchmarking and development of performance measurements is required. The model is delineated to benchmarks related to physical assets under management, which creates incentives in achieving continuous improvements. One of the sub-objectives of the benchmarking group is to develop an online platform to share knowledge with each other, and with other interested (peer) groups worldwide. To achieve this, an online platform with dashboards should be developed. As a result, information can be shared, and ports can exchange knowledge which enables learning from each other.

The following list of requirements is identified:

1. The model framework should cover all relevant aspects for asset managers that fit within the context of the benchmarks
2. The model should provide the (novel) user clear guidelines in benchmark development
3. The model should be straightforward in order to grasp the essence quickly
4. The model should provide asset managers the expected benefits of benchmarking
5. The model should be generic and suitable for specific cases (e.g. other asset types or benchmarks)
6. The presented results of the benchmarking model should be reproducible
7. The model should be accessible to ports around the world
8. The model results should give insights into performance improvement

*Requirement 1*
The model framework should cover all aspects of asset management. Benchmarks should consider measures that provide information on the performance and process of 'managing assets'. Following the selected benchmark, the performance measurement should be aligned with the principles of asset management. Therefore, the benchmark should be positioned within the guiding principles of asset management: the processes, control, and focus of an asset manager. A decomposition of the benchmark should allow for a clear understanding of the measure and its underlying activities.

*Requirement 2*
The model should be designed in such way that asset managers understand the approach and process of developing benchmarks. A clear working method is highly preferable for asset managers which do not have knowledge on performance measurement and benchmarking. Moreover, the model should be extendable: other ports, asset types, and benchmarks can be incorporated in the benchmarking model.

*Requirement 3*
The model should capture the complexity of asset management in a simplified way. A clear and structured way of working should provide asset managers a method to develop benchmarks. The results following the benchmarking analysis should be presented in such way that it allows asset managers to grasp the essence quickly. Therefore, the visualisation of the benchmarks should be presented in a user-friendly dashboard.

*Requirement 4*
The model is developed in a collaborative way, and should also be designed in such way that asset managers can benefit from the collaboration. The dialogue before, during, and after the benchmark development may be valuable. The users of the model are highly involved during the design phase. The model should enable asset managers to measure, compare, and improve their performance. Furthermore, the model should enable asset managers to share information and gain insights into performance improvement. Following the type of benchmarking, which is performance benchmarking, the measurements should fill the functions 'Learning' and 'Transparancy'. The ports should be able to measure and compare their performance. Consequently, they can reflect on their own processes and performance. The establishment of benchmarks requires standardisation, and therefore international standards should be introduced. This ensures that all ports have the same interpretation on benchmarks and as a result a fair comparison.

*Requirement 5*
The model design should fit within the research scope. The model design should be generic within a specific context, since it should provide a strong basis for international benchmarking on asset management executed by asset managers working at ports. The model will be tested for a more specific context in the demonstration phase: the quay wall and road asset type.

*Requirement 6*
The results that follow from the benchmarking analysis should be reproducible. The model should force asset managers to construct a formula, and formulate the data requirements. As a result, it should be clear how the benchmark is quantified. The model should enable asset managers to process certain data input into output following the defined benchmark. This systematic way of measuring and quantifying should be reproducible.

*Requirement 7*
The benchmarking model should be accessible to ports worldwide. Therefore, the measures should allow for international comparison between different countries and ports.

*Requirement 8*
The results of the benchmarking analysis should contribute to continuous improvement. The data should be collected on a certain frequency in order to monitor the benchmark. The model should link performance measures to processes involved when managing assets. The model should translate the input to certain output, and show asset managers how they can control or influence this process. For competitive reasons the model should be designed in such way that it provides insights, but should not provide applicable solutions which may bridge the performance gap.

### 3.2.2. Design Space

The design space is a space with major invariant characteristics across all design situations (Goel & Pirolli, 1989). It covers both model delineation and a super set of design components, variables, and relations, including different modelling possibilities. The design space is identified parallel to the identification of the design requirements (Herder & Stikkelman, 2004).

#### Delineation

Delineation of the benchmarking model's design is covered in the introduction of this thesis. The design should therefore be delineated to the following areas:

- Focus is on the port industry
- Focus is on asset management
- Focus is on two (physical) asset types: quay walls and roads
- Perspective: both from a theoretic and asset manager's perspective
- Demographic: asset managers, working in ports worldwide, lacking experience in benchmarking

#### Design Variables

The exploratory nature of the research is due to a lack of scientific research on the research area, and the application of benchmarking analysis. Following present knowledge on the research field, suitable theories are selected in the model concept phase. The development of the design space is an iterative process further substantiated by empirical research. The design space consists of the following aspects:

- The asset management theory underpinned by the guiding principles (Section 2.3.3).
- Relevant criteria derived from the benchmarking theory: selected benchmark options (Section 2.1.3) and performance measures for benchmarking (Section 2.3.2).
- Modelling possibilities should be aligned with the scope of the research.

When constructing the benchmarks these design aspects should be incorporated. In this manner, benchmarks can be developed in a structured way covering all aspects that should be considered.

## 3.3. What to Measure

The ports that entered into cooperation for benchmarking differ in many characteristics because of their location, size of the area, and many other varying characteristics. Following those characteristics the performance of assets is influenced by factors at varying degrees. Drawing on publicly available information and information from internal reports, this research illustrates benchmarks on port level. These benchmarks are the port's facts and figures, and the required data for this is easy to access. This information enables seeing benchmarks in context. For example, larger organisations probably own more assets, creating economies of scale. Another example is information on environmental conditions such as salinity of the water, temperature (variations), or degree of utilisation of the assets, that affect the condition of certain assets. By composing an overview of all port facts and figures, asset managers are able to compare themselves on port level.

Measures on asset level are more challenging, and specific knowledge on a particular asset type is required. The entire scope of managing (physical) assets should be considered. Information on port level may provide some colour on this as contextual variables are included which describe the asset's context. These variables are aspects not controlled by the asset managers. Asset management deployment, which is controlled by asset managers, is affected by contextual variables.

### 3.3.1. Benchmarks on Port Level

Prior to the analysis of asset benchmarks, the entire port system of which assets are part of should be considered. Information on the size and activities in the port area describe the context, and geographical conditions are equally important. Hence, locations of the participating ports should be displayed on a map. All definitions of performance measures should be compared to ensure that asset managers have the same interpretation. The following figures are listed:

1. Seaborne throughput
2. Added value (direct and indirect)
3. Number of businesses (companies in the port area)
4. Employment (direct and indirect)
5. Hectares of port area (land and water area)
6. Sea-going vessels
7. Inland vessels

The differences in context are expressed in terms of size, operations, and activity in and around the port area. These quantitative measures of performance are a set of criteria used for grouping ports under similar contexts. Figure 1, 5, 6, and 7 are supposed to reflect the effects of economies of scale or scope (Tongzon, 1995b). Figure 2, 3, and 4 are meant to capture the creation of value and employment. Data on these aspects can easily be obtained, thus incorporated in the analysis. Most of the data is retrieved from publicaly available annual reports.

### 3.3.2. Benchmarks on Asset Level

Specific performance measurements for benchmarking on asset level must be introduced. These performance measures is data obtained by measuring, for example, expenses against certain metrics (i.e. maintenance costs per square meter). All benchmarks should be expressed in a standard unit of measurement (i.e. square meter) in order to present individual performance measures and its relation with other variables. This is called the measure unit for a certain asset type. Quantitative values are expressed per unit of measurement.

The benchmarking model should be unambiguous in a way that the components of the benchmark are clearly specified and reported. This requirement enables a like-for-like comparison between different organisations. Besides the differences on port level, the asset portfolios also differ in many aspects. The characteristics of the asset can relate to function, type, material, environment, and age (IPWEA, 2012). Following the preferences of asset managers, each asset type should be categorised on one characteristic of which asset managers think this has the highest impact on performance. As a result, a predefined categorisation contributing to a fair comparison is drafted. This categorisation is referred as asset classification. The term asset is replaced by the asset type that is benchmarked.

An object-ID is assigned to all portfolio assets. This ID enables organisations to store asset specific data. As there are no global standards it can be expected that ports assign ID's differently, and consequently assets will have different dimensions. For uniformity in measurement the use of standardised units of measurements may offer a solution. The unit of measurement is used as a standard for measures of the same quantity. Any other quantity of that kind can be expressed as a multiple of the unit of measurement. For example, when meter is the unit corresponding to assets, then its costs would be measured by a known currency per meter.

The system of units varies between countries. When considering costs for example, the currency differs, and accordingly this currency unit should be converted into a standardised unit. In this research the currencies are converted with the exchange rate, the differences in price levels between countries are not taken into account (OECD, 2019a, 2019b). There are many other differences that lead to comparability issues. International benchmarking involves more complexities than benchmarking within countries. The information that needs to be used is often not directly comparable. Comparability problems can be both technical and more fundamental. All ports agreed on international standards and definitions to deal with the comparability problems.

**Define Benchmarks for Performance Measurement**

The benchmarks should contribute to continuous improvement, which benefits asset management. The three guiding principles (Section 2.3.3) are leading in the selection of benchmarks. Measurements should fit the frames of the conceptual asset management framework. Therefore, the benchmarks should have certain properties or criteria (*what to measure*), and as a consequence fit within the conceptual framework presented in Section 2.3.3:

- Valuable focus: performance, costs or risk measurement. It should be either one of these three attributes or some combination of these.
- Controllable: select controllable measurements, which are related to all levels of the organisation, in order to obtain benchmark objectives.
- Fit within the conceptual performance framework, which presents the processes involved when managing physical assets: measurements should concern input, output, or influencing factor in the process.

By selecting benchmarks that posses the above-mentioned characteristics proper benchmarks are developed. The measurements should represent performance of processes involved when managing assets. The operational approach of the model ensures that asset managers are supported in the process of continuous improvement when performing the benchmark analysis. This research focuses on a critical few measurements, not the trivial many. For a couple of reasons a small selection of benchmark is made for the demonstration. First of all, one of the reasons for this scope is that the goal of the project is the development of a Proof of Concept. The model is tested in order to demonstrate its feasibility and to verify the model concept. Second, brainstorm sessions and interviews showed that asset managers create benchmarks providing more information than only one single measurement (i.e. benchmark). A profound analysis is prepared by following a structured approach, of which the decomposition of the benchmark in a hierarchical tree is part of. Next to this, asset managers are asked to identify the relation of the benchmark to other benchmarks or variables. In addition, the identification of the context or influencing factors is regarded as important. Last, with this approach *pitfall 2* and *4* are avoided. Too many benchmarks make a project hard to manage, and will therefore diminish the value of the model over time.

During expert interviews and brainstorm sessions there is discussed what asset managers want to know and what measures are of importance from their point of view. Both quay wall asset managers and road asset managers compiled a list of criteria and preference, as presented in Appendix C. Following the preferences of asset managers, and considering the scope and resources available, the following bechmarks are selected:

1. Maintenance Costs
2. Condition
3. Availability

As stated earlier, the goal was to define measurements which reflects the processes involved when 'managing assets'. First of all, maintenance activities can be seen as *input* for certain processes that have a certain impact on the state of assets. The input represents the effort involved when managing assets. Maintenance costs, an example of an input indicator, requires funding for maintenance activities. The *output* is expressed as the performance of the asset, for example the asset's resulting condition or availability. The proposed definitions are subject to change and adaption during the demonstration phase, in which is tested whether it is possible to place maintenance costs, condition, and availability in the benchmarking model.

**Maintenance Costs**
Maintenance within asset management enables the optimal life cycle management of physical assets. The maintenance activities play a significant role in the life cycle management, by taking care of the integrity for the major part of the life. For each asset type the maintenance costs should be expressed in a monetary value per unit. Effective asset management aims to minimise these costs per unit (Campbell, Jardine, & McGlynn, 2016).

The maintenance (and inspection) activities provide the inputs, including (Hatcher, Hunter, & Mitchel, 2012):

- Maintenance costs in $\$/m^2$, $\$/km$ etc.
- Frequency (count) of maintenance activities per asset unit: $count/m^2$, $count/km^2$, etc. or per asset: $count/asset\ ID$
- Timing: dates and times of maintenance activities
- Policy affecting maintenance activities (e.g. minimisation of maintenance prior to major rehabilitation)

Both maintenance costs and frequency are relatively easy to measure and compare. The timing and policy is information that could be interesting in a more detailed comparison. This information is more difficult to quantify and should be plotted in graphs. The maintenance costs can be divided into three types of maintenance (IAM, 2015):

- *Inspection, testing & monitoring:* activities to confirm safety and integrity of assets, and to provide information in determining maintenance and renewal needs. This encompasses periodic visual inspections, sophisticated diagnostic testing and remote condition monitoring systems.
- *Preventive maintenance:* planned activities to prevent or reduce the impact of faults, failures or excessive deterioration. Preventative maintenance is based on risk, and relates to the maintenance regime being applied to an asset (time-based, condition-based, usage/duty-based).
- *Corrective maintenance:* activities performed to repair defects, damage or address a shortfall in performance in order to restore the asset to a defined standard and keep it operational.

The distinction between preventive and corrective maintenance can be clarified by stating that asset managers do preventive maintenance when a task is carried out before a failure occurred. The task can be aimed at preventing a failure, minimising the consequence of the failure, or assessing the risk of the failure occurring. An asset failure means a break down or inability to use the asset. The functional failure is the loss of the intended functionality. On the other hand, asset managers can perform corrective maintenance, which asset managers conduct after the failure occurred. In the case of corrective maintenance, reinstating of the asset functionality is necessary. Corrective maintenance can be the result of a deliberate run-to-failure strategy.

The different types of maintenance are distinguished to cluster the activities of asset managers. Performing maintenance activities enables asset managers to have influence on the performance of assets. Measures such as maintenance costs, frequencies and methods can quantify maintenance.

Maintenance costs as stand-alone measure is interesting as well, since it gives an indication of the (development of the) costs spent on maintenance. For a more in-depth analysis, next to the total costs, the allocation of costs may be considered as well. Costs can be broken down by maintenance type: preventive maintenance costs, corrective maintenance costs, and inspection costs. The allocation of the maintenance costs comprises the port's maintenance concept. In addition, different maintenance methods or activities, and their frequencies over a certain time period can be defined. Sharing this information gives asset managers insights into actual asset management deployment. The conceptual framework of the benchmarking model helps asset managers to understand specific findings and helps explaining them. Therefore, measures that enable a customised selection of assets should be incorporated in the model. Measures such as condition, availability, and age of the assets can be defined to express an input-output relation.

**Condition**
The asset condition is the present state of a physical asset, usually referring to the structural integrity. It can also relate to the appearance. The condition is determined by the degree of damage and deterioration. Different assessment techniques can be used to extract the condition of an asset:

- Visual inspection
- Non-destructive testing
- Destructive testing

As the asset condition reflects the physical state of the asset, it may or may not affect its performance. Performance of the asset is the ability to provide the required level of service to customers (IPWEA, 2012). In the scope of this research the condition tells something about performance of asset management. Ports pursue different policies in describing the desired state of the assets. Therefore, for each asset type, the respective asset managers have predefined requirements for the performance of their assets. Effective asset management aims to maximise the accuracy, condition of the asset should be conform the standards. Asset managers want to deliver a certain level of quality to customers (Campbell et al., 2016). With regard to the condition, asset managers should consider an asset's primary functionality and its expected level of service. The condition of an asset will usually deteriorate over useful life. Particular actions of an asset manager can extend the asset's life, enabling continuity of its function. If the condition of an asset is such that it can no longer serve its functional purpose - a critical condition on the linguistic scale - then corrective actions could be conducted to restore the functionality (Hastings, 2015).

In general, condition gradings on a 5-point scale are recommended as it proved to be the most effective (Abbott, Mc Duling, Parsons, & Schoeman, 2007; Asset Insights, n.d.; IPWEA, 2012). This approach focuses on data collection for managing risks and monitoring performance measures. Performance monitoring and knowing the current condition or performance of an asset may prevent premature failure and costly down time. Factors such as soil type, asset material, and the asset's age are typical factors for consideration as they may influence the condition (IPWEA, 2012).

**Availability**
Availability is broadly defined as the proportion of time that an asset is available for use. Up time is the time in which assets are operational. Down time is the time when assets are not operational. Availability is influenced by various factors. Achievement of availability can be controlled by asset management, which can be expressed by factors that contribute to the achievement of available assets. Examples of such factors are contingency planning and routine maintenance. Down time incurs costs, which are hard to quantify. The amount of costs is an important driver for maintenance actions and the prioritisation of those actions. As many systems do not require 100% availability all the time, 'availability when needed' should be considered (Hastings, 2015). Maintenance can be scheduled to take place in times of low demand. Both the available and required capacity quantification is rather complex. Despite the high level of digitisation that is required, not all information on availability is properly stored in the database. Besides, many assets are designed in such way that the loss of one component does not cause down time, which is known as the redundancy approach. Organisations have their own view on the requirements regarding availability. In the context of this research, availability is an 'output' measure.

Effective asset management aims to maximise the up time, the availability or availability when needed (Campbell et al., 2016). Many factors involved with the availability, and even more when measuring the availability when needed, require at first a proper benchmark of availability. This can be measured as a percentage of total time, starting at the asset level. Factors such as the number and frequency of incidents or preventive maintenance activities can be related to this performance measurement.

### Sub-indicators, Sub-dimensions, and Relations

To further substantiate the selection of benchmarks, asset management of both asset types need to discuss how the context and relations should be specified. The benchmarks can be broken down into several measurements. First, measurements for the quantification of the benchmark itself should be defined at a lower level of the hierarchy, right below the benchmark. Subsequently, other levels in the hierarchy can be defined when considered to be useful. All mentioned measurements can be denoted as sub-indicators. Next to this, sub-dimensions need to be defined for each benchmark. Adding sub-dimensions enables asset managers to customise the analysis, while selecting only a number of all asset available for peer comparison. The abstract definition of the benchmark can be divided into different dimensions with each having its own indicators, and by combining these a measurable concept can be obtained. They are meant to provide additional insight into each benchmark and to create better understanding of the presented results. Besides the detailed analysis, through the identification of sub-indicators and sub-dimensions it might be interesting to probe the relation with other indicators or benchmarks. Therefore, for each benchmark other benchmarks or variables are given. An in-depth analysis can be carried out by quantifying the benchmark through information collection.

## 3.4. How to Measure

The model design offers a methodology (*how to measure*) that enables benchmarking. Both the model concept and model design are developed by listening to the user's needs (i.e. the asset manager). This requires a structured approach, not only for the model within the benchmark development process, but also for the organisational structure and planning of the project.

The organisational structure outlines which knowledge is required for the different steps in the process. Different steps in the process require another composition within the group. Prior to measuring, a number of steps should be taken. Considering framework orientation and context, which can be found in the benchmarking model, the criteria for the benchmark definition are established. Performance is measured with mathematical formulas, and as a result the data requirements can be listed. It is necessary to determine a data collection frequency, as well as dealing with differences between ports and countries. For each step in the benchmark development process, information is gathered and there is decided whether this information is required for the development of an online platform. This web application provides asset managers a dashboard in monitoring results.

In terms of 'how to measure' the developed model offers a methodology that provides asset managers a clear guideline for the development of benchmarks and all essentials needed for a benchmarking model. Different approaches are piloted, and discussions have taken place. The methodology managed to combine different benchmark options, and theoretical frameworks, and matches the needs of practitioners. The generic model is flexible and is appropriate for specific cases. The methodology for practical usage is called the 'user guide'. The manual for asset managers is a benchmarking framework obtained from input provided by experts in the respective research field. This is done in a collaborative way, and as result it forms a strong basis for international benchmarking using grounded theory. The generic working method is well-suited for any specific case.

### 3.4.1. User Guide

The instruction manual comprises of the following elements: organisational structure, planning, working method (manual for benchmark development), and supporting tools. In each step of the process attention is given to the final goal of the project: the exchange of knowledge with regard to asset management for continuous improvement enabled by a web-based benchmarking model. Therefore, in each phase of developing the model emphasis is placed on the requirements for web development. Given the time constraints (i.e. six months), the goal is to develop a Proof of Concept. The aim of creating a Proof of Concept is to verify a certain concept to check whether development can be achieved within a given time frame. With the conclusions drawn from this test further steps will be discussed.

#### Organisational Structure

When developing benchmarks in a collaborative way, an organisational structure with a clear division of the roles between the working group and steering committee is required. The working group has a prominent role in benchmark development. The sub-groups within the total benchmarking group are:

- *Working group*
  The working group develops the benchmarks and all other information required for a benchmark platform. In both sub-groups the researcher is responsible for the alignment of theory and practice. The business or information analyst supports asset managers in the data gathering process.
  - *Generic (main group):* define common goals and requirements of the benchmarking model, port benchmarks, and monitor consistency. Group participants: asset managers, project manager, business analyst, and researcher.
  - *Asset specific (sub-groups):* for each asset type a group of asset managers with specific knowledge on a particular asset needs to be composed. These groups are the sub-groups of the working group. Group participants: asset managers of a certain asset type, business analyst, and researcher.
- *Steering committee*
  The steering committee provides support, guidance and oversight of progress. They monitor the business vision and value of the project.

The organisational structure avoids the pitfall of benchmarks at too high a level (*pitfall 1*) and the pitfall of benchmark outcomes that are not linked to underlying activities (*pitfall 2*). The development of benchmarks are carried out by the working group in which asset managers are represented. The groups composed for this research are presented in Appendix D. For this research two asset types are demonstrated. Therefore, two asset specific sub-groups are identified within the working group, multiple groups could be identified. Figure 3.2 shows the organisational structure of the benchmarking group.

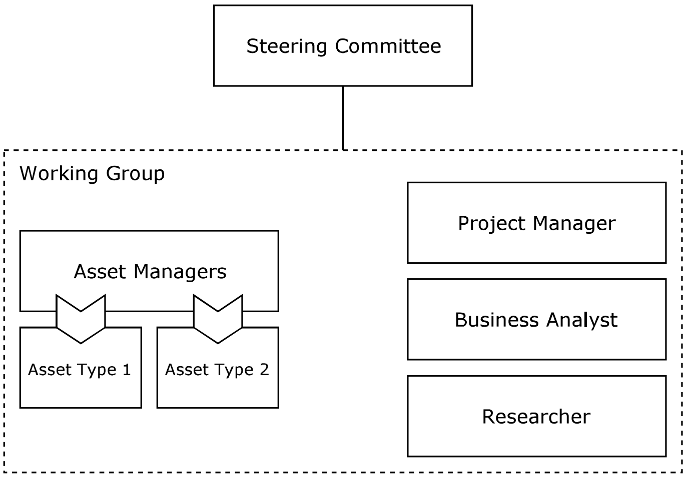


Figure 3.2: Organisational structure for benchmarking in a collaborative way

**Planning**

Due to the exploratory character of the research, the planning is reviewed many times. During the development of the benchmarking model many challenges are faced. Both the process of developing a benchmarking model and the demonstration of this model, provide insight into the formerly unexplored research area. During the design process, the exploration of the research area helped to determine the best research design and selection of subjects.

For the development of the benchmarks in a collaborative way it is important to divide tasks and agree on deadlines. One of the pitfalls states that a proper approach and view on the benchmarking process was missing (*pitfall 3*). This is partly because the users of the benchmaking model were not consequently involved in the process. For this research the generic working group and the asset working groups scheduled a meeting through Skype every two weeks. During these Skype calls the generic model development was discussed, and during the Skype calls with the asset working groups the benchmarks for one asset were developed. In doing so, the users of the system were closely involved in both the design phases and the demonstration phase.

Next to the Skype calls, site visits have taken place, during which a two-day meeting with all working group members were held. These physical meetings at each port created the opportunity to have a look at the port area and its assets. In addition, it offered the chance to focus on the project without distraction and obligations related to their daily job.

Different ways of communication facilitate the collaboration. Asset managers had to discuss various topics, and a platform such as SharePoint was needed as this is a powerful tool for collaboration. This web-based platform enables the benchmarking group to share and review documents. On this platform documents such as asset terminology literature and benchmark templates were stored. In addition, Jira software is used to assign tasks and monitor their completion. This system for issue-tracking allows agile project management, and was mainly used for the development of the dashboard. All information supplied is shared on this platform. Furthermore, the defined feedback is translated into a task for the participants of the working group and the web developers. As soon as the demonstration phase (Chapter 4) was completed, the results of the benchmarking model can be presented in the dashboard, a Proof of Concept, which can be shown to other ports.

**Working Method**

The following information needs to be collected for every port that wants to participate or for adding a new asset type:

- Port
  - *Port data:* data for the benchmarks on port level, the port facts and figures overview. These predefined figures can be found in Section 3.3.1.
  - *Geographic location:* the location of the port is presented on a map. This information is shown in the benchmark overview of each asset type.
  - *Asset data:* the information required for defined asset benchmarks.
- Asset
  - *Asset terminology:* all ports have to agree on asset definitions in order to share asset information in a proper way.
  - *Asset figures:* a selection of facts and figures to understand to whom you are comparing against. This information is presented in the benchmark overview of each asset type.
  - *Asset benchmarks:* definitions on performance measurements for each asset type. These benchmarks are presented in the asset overview, and a more detailed analysis is presented in the benchmark overview. A new asset type, and probably also a newly or adjusted benchmark, requires data gathering following the specific demands.

The working method for benchmark development presents a step-wise and iterative approach. The steps that need to be taken for the development of benchmarks for specific asset types are covered in a working method. This method is a collaborative design validated by experts in the respective research field. Figure 3.3 shows the sequence of steps. For each new benchmark or asset type all steps must be carried out from the start.

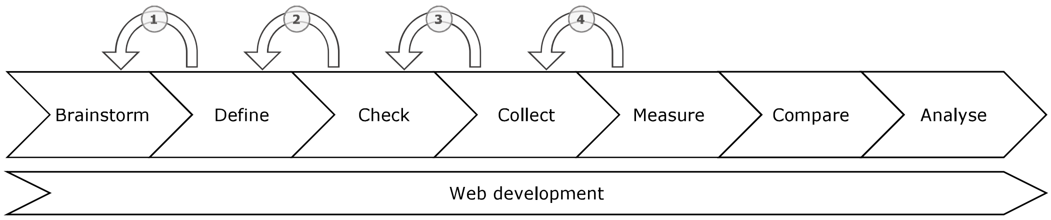


Figure 3.3: Steps in developing benchmarks

Multiple iterations can take place, and if required it is possible to go back to a previous step. The method can be seen as a cyclical process, since all steps can be performed again and again in the same order. The process is structured in such way that it ensures continuous feedback for any necessary re-adjustment. For example, when reviewers in the 'check' phase do not agree on the defined benchmarks, the proposed benchmark should be reviewed and adjusted accordingly. During the process the output of an individual step is continuously reviewed, the steps are often done simultaneously. For instance, it may be helpful to start with collecting data before the final agreement on a benchmark, as data collection is often a time-consuming task. The steps in the benchmark development process are:

- *Brainstorm:* identify and select benchmarks.
- *Define:* specify the selected benchmarks by gathering the relevant information. This encompasses a detailed description of the benchmark and its context. All information concerning the benchmark is divided into five parts: define, measure, analyse, improve, and control.
- *Check:* completed benchmarks are reviewed by asset managers of another asset type. The asset managers provide feedback to each other. In addition, the steering committee and other experts provide the asset working groups with feedback.
- *Collect:* once the benchmarks are finalised the data can be collected.
- *Measure:* performance can be measured once appropriate data for a benchmark is collected. Formulas describe the mathematical relationships expressed in the data. The required data for both calculations

and other features is listed.
- *Compare:* ports can compare their performance, which is measured in the previous step.
- *Analyse:* the performance measurements presented in the dashboard enable asset managers to analyse the results of the benchmarking model.

The following feedback loops can be identified, and may be performed multiple times. The feedback loops have the following functions:

1. *Validation of identified benchmarks:* following a review of the identified benchmarks by the working group or steering committee feedback may be provided.
2. *Validation of defined benchmarks:* the selected benchmarks are defined by the asset managers of one asset type. In the next stage ('check' phase) they will be reviewed by the asset managers of another asset type, through the exchange of feedback between sub-groups of the working group, and by the steering committee. Suggestions will be discussed, and valuable feedback can be used to make adjustments on the proposed benchmarks. Therefore a feedback loop is presented between the 'check' and 'define' phase.
3. *Revise collected data:* the defined benchmarks provide a list of required data. The data needs to be collected, and in case strange or unexpected results are noticed the data sets need to be reviewed. If ports are not able to supply the data, adjustments of data requirements or the replacement of real data by test data may offer a solution.
4. *Verification of calculations:* approved data is verified by test calculations of the benchmarks. These results are presented to the working group. These test calculations in the 'measure' phase will be added to the appendix of the performance measurement template. In this manner, the results on the dashboard can be compared to the results of the test calculations for a verification of the calculations.

The feedback loops allow for validation and verification of the intermediate results. Consequently, internal evaluation of the results along the process is performed. Internal means that the model is continuously reviewed by members of the benchmarking group, namely the working group and the steering committee.

Throughout the process attention is given to the communication of the results. Communicating information is realised by a dashboard functionality (i.e. a graphical display). Dashboards are used because of their ability to provide performance information in a timely and functional display (Star, Russ-Eft, Braverman, & Levine, 2016). Web development, the arrow parallel to all steps in the process, refers to the tasks involved with developing an online platform. The approach to software development that is applied, is agile software development. Which is an approach to software development under which requirements and solutions evolve through the collaborative effort of self-organising and cross-functional teams (Collier, 2012). The approach advocates adaptive planning and iterative benchmark development. These characteristics are reflected in the process for benchmark development, which enables continuous improvement of the benchmarks. In addition, it encourages quick and flexible response to change, which contributes to a efficient process within the time constraints. For each step in the process supporting tools are designed, and these tools guide asset managers in developing benchmarks in a structured way. Consequently, the design of benchmarks is standardised.

### 3.4.2. Supporting Tools

A toolkit provides tools to assist with all facets of the design process, from selecting benchmarks to analysing results. This instructional toolkit draws together an array of instruments used by the asset managers that could serve as a reference point and guidance on benchmark development:

- *Manual:* outlines the way of thinking that is applied to approach the model design, in which theory and practice are aligned. It provides theoretical background and practical insights. The manual consists of a guide for the benchmarking model (incl. working method), supporting tools, required theoretical background, and examples.
- *Performance measurement template:* structured approach of defining performance measurements in a collaborative way. This template is suitable for an asset-related benchmark.
- *Properties file:* all provided columns in the data template are defined in the properties file.
- *Data template:* shape files for the analysis enabled by a web-based model. The data sheet is a standardised template for data collection. Information on data gathering can be found in Appendix I.

- *Web application (i.e. dashboard):* web-based platform for the presentation of the results from the 'measure' and 'compare' phases. Next to this, the platform enables asset managers to analyse the results. An example of an empty overview in the dashboard can be found in Appendix H.

The tools can be linked to (multiple) steps in the benchmarking process. An overview of all steps and the required tools and participants is presented in the chapter synthesis. The framework as presented in Section 2.3.3 is a combination of theoretical constructs to guide the process and takes into account aspects of asset management, which is aligned in with practice in this chapter. Theoretical discussion regarding performance measurements and control contribute to the theoretical constructs that are considered in this research. These theoretical constructs are part of an instruction in the form of a manual for practical use. For critical assets and a selection of performance measurements an in-depth case study tests the proposed working method.

**Performance Measurement Template**

A comprehensive template provides all key elements that should be included when defining performance measurements (Rozner, 2013). To aim for an attitude directed towards a continuous striving for improvements the DMAIC approach is applied. Five interconnected phases cluster all elements of the template: Define, Measure, Analyse, Improve, and Control (Sokovic, Pavletic, & Kern Pipan, 2010). This approach also highlights the importance of a clear definition, *'if you cannot define it you cannot measure it'*. Neely et al. (1997) has collected recommendations for defining performance measures. The resulting framework for performance measurements ensures that measures are clearly defined and are based on an explicitly defined formula and data requirements. The elements proposed by Neely et al. (1997) are incorporated in the performance measurement template acting as a tool for asset managers.

Many iterations on the design of the performance template have taken place. Towards the final template, concepts are discussed and tested. The initial design of the performance measurement template can be found in Appendix E. The final version incorporates all findings prior to the demonstration phase. In Appendix F all parts of the template are further explained. Examples found in the literature are used as inspiration for the template layout and content (Neely et al., 1997).

The background information and observations contained in this appendix constitute an integral and essential part of this research. The template is the result of many discussions and iterations of creating a guide for benchmark development using grounded theory and input from asset managers. This final template can be found in Appendix G. As all benchmarks will be presented in a dashboard for analysing the results, a web development icon is added to highlight what information is intended for web developers.

### 3.4.3. Data Analysis

In this research benchmarking is defined as the systematic process of measuring a port's performance against other ports for the purpose of continuous improvement. In order to do this, all participating ports need to collect proper data in order to measure their performance. Subsequently, the results can be presented in the form of a dashboard allowing for comparison and a more detailed analysis. Benchmarking analysis enables organisations to compare their existing performance against others and gather information which helps them to take action in improving their performance (Ajelabi & Tang, 2010).

The dashboard enables asset managers to measure, monitor, and manage the developed benchmarks. For the presentation of the benchmark results in the dashboard, a certain data input of asset managers is required. The output data is visualised in the dashboards. In order to optimise their performance on asset management, control variables need to be identified. A complete overview of all collected information for the asset benchmarks can be captured in a process model. The dashboard is a tool that processes the input elements to produce the outputs. The outputs are the results of the benchmark model. A model that is able to present the function of the dashboard in a structured way is an IDEF0. The IDEF0 model presents a structured graphical presentation of an activity (Akasah et al., 2017). The basic concept of an IDEF0 can be found in Figure 3.4. The IDEF0 uses two basic elements as its modelling language, i.e., boxes that represent activity and arrows that represent the interfaces. These interfaces are input, output, controls, and mechanisms. The box is joined by arrows representing either data needed or provided by the activity represented by the box (Dick, Hull, & Jackson, 2017). All elements can be combined in one sentence: 'Under control, activity, input makes outputs, using mechanisms' (Šerifi, Dašić, Ječmenica, & Labović, 2009). Below a list of these elements:

- *Input:* something that will be processed by the activity to produce the output. The input arrow represents data that is available to the activity, and is used or transformed aiming at defining output.
- *Output:* the result, i.e. something that is produced when the activity is carried out. The output arrow represents the data that is produced by the activity, i.e. the input is transformed by the activity to produce this output.
- *Mechanism:* the elements that run the system, thus enables the input to be transformed into useful output. Arrows control the way the activity may use outside mechanisms, e.g. algorithms or resources.
- *Control:* the elements that control the activity. The control arrow regulates the way in which the transformation takes place (Dick et al., 2017).

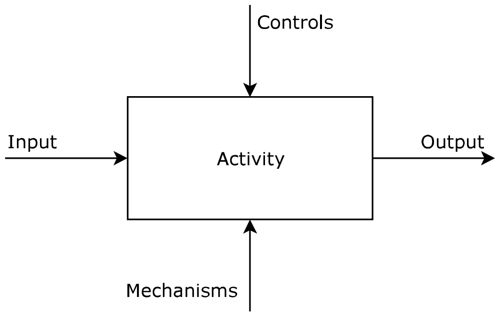


Figure 3.4: Basic concept of IDEF0 process modelling

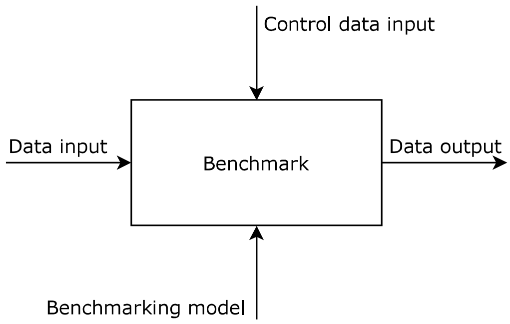


Figure 3.5: IDEF0 modelling of the dashboard

For this research it is a data diagram, which uses the input data to generate benchmark results (output data). The input element can be anything that will be processed by the dashboard. The output is the result of the benchmark analysis. The output arrow exits the box from the right side and represents the data output, the visualisation of the benchmark analysis (Dick et al., 2017). The process as presented in Figure 3.5 represents the transformation of input data to certain output data. This IDEF0 diagram contains the following elements:

- *Input - data input:* the data requirements for the benchmarking model. In the performance measurement templates the benchmarks are defined, and the required data is listed.
- *Output - data output:* the collected data is processed by the benchmarking model. The function of this model is benchmarking. The output data is visualised by using a dashboard. The input data is transformed by presenting the developed benchmarks supported by the benchmarking model.
- *Mechanism - benchmarking model:* the activity performed is the benchmarking analysis. For this function a benchmarking model is needed to transform the input to a desired output.
- *Control - control data input:* the transformation that takes place in the model can be influenced by the asset manager. The data will be collected repeatedly, the frequency is part of the benchmark design and is presented in the performance measurement template. In this manner asset managers can measure and monitor the benchmarks. Asset managers can manage the performed activity by controlling the data input. The results from the benchmark process may give asset managers new insights to adapt their way of working and enhance continuous improvement.

For each asset and benchmark, the processes can be specified. In the performance measurement template the benchmark is defined for one asset type. Following the definitions, the required data will be collected with the data template. The results will be presented in the dashboard. The data input ('input') is processed by the benchmarking model, and the results ('output') are presented in the dashboard. Detailed information on data collection, preparing, and processing can be found in Appendix I. In this appendix there is explained which type of files are used to transform the collected information on benchmarks into dashboard visualisations. Scripts are written to provide asset managers a user-friendly tool to monitor the development of their performance. These scripts can be found in Appendix N. The IDEF0 diagram helps asset managers to answer the question: 'How to interpret results'. The dashboard enables asset managers to compare the measured results, and analysis may contribute to improvement options. Steering on the future results can take place by changing strategy and control the data input.

## 3.5. Chapter Synthesis

In this chapter the design of the benchmarking model is outlined by defining 'what to measure' and 'how to measure'. The benchmarking model is obtained with input from experts in a collaborative way, which forms a strong basis for benchmarking while using grounded theory.

A selection of benchmarks on port and asset level (*what to measure*) is listed in this research, and can be found in Section 3.3. Prior to the analysis of asset benchmarks, it might be valuable to collect information of peers on an organisational level. Benchmarks on port level express the differences between ports in terms of size, operations, and activity in and around the port area. The following figures are listed: seaborne throughput, added value, number of businesses, employment, hectares of port area, sea-going vessels, and inland vessels. These benchmarks do not require any specification in the demonstration phase. Asset specific performance measurements need to be developed for benchmarking on asset level. In this chapter three benchmarks are selected: maintenance costs, condition, and availability. Following the characteristics of particular asset types these benchmark need to be adapted. In the demonstration phase these asset benchmarks will be discussed in more detail.

The user guide (*how to measure*) as presented in Section 3.4.1 outlines the organisational structure, working method, and the supporting tools. With this user guide asset managers should be able to develop benchmarks for a specific asset type. The development of benchmarks consists of seven sequential steps: brainstorm, define, check, collect, measure, compare, and analyse. This method can be seen as a cyclical process, since all steps can be performed again and again in the same order. Moreover, this iterative process allows feedback loops, which enables benchmarks to revise and improve previous steps. In Table 3.1 all steps of the benchmarking process are presented, the check marks show who should execute the process step and which tools are required.

Table 3.1: Tools and participants required to develop benchmarks

| **Process** | | | *Brainstorm* | *Define* | *Check* | *Collect* | *Measure* | *Compare* | *Analyse* |
|---|---|---|---|---|---|---|---|---|---|
| **Tool** | Manual | | ✓ | ✓ | | | | | |
| | Performance measurement template | Empty | | ✓ | | | | | |
| | | Filled in | | | ✓ | ✓ | ✓ | | |
| | Properties file | | | | | ✓ | | | |
| | Data template | Empty | | | | ✓ | | | |
| | | Filled in | | | | | ✓ | | |
| | Web application | | | | | | ✓ | ✓ | ✓ |
| **Participants** | Working group | Generic | ✓ | | ✓ | | | | |
| | | Asset specific | | ✓ | | ✓ | ✓ | ✓ | ✓ |
| | Steering committee | | | | ✓ | | | | |

The final step of the benchmarking process is analysing the benchmark results. For the interpretation of the results an IDEF0-diagram is presented in Section 3.4.3. Figure 3.5 shows how the required input for benchmarking is processed into data output.

The resulting model design is developed in collaboration with experts. Since asset managers (i.e. users of the system) were closely involved throughout the design process the first validation is performed. Each requirement of the model is verifiable by demonstration (Bahill & Dean, 2009). For this reason, in Chapter 4 a case study is sampled to demonstrate the model. Two case studies are selected to specify the model design for two different asset types. The purpose of the case study method is to verify the developed model. In the next chapter the benchmarking process and the interpretation of the results is described. Subsequently, in Chapter 5 there will be discussed what can be concluded from the case study in terms of model verification. Furthermore, an expert panel is consulted to validate the model.

# 4

# Demonstration of the Model

In this chapter the model design is demonstrated. First, the *case study* is defined. Second, the *application of the benchmarking model* is presented. The demonstration of the model has the aim to verify whether the model has practical potential. The Proof of Concept is a small exercise to test the model design. The specification of the model is performed by using the knowledge of experts. The benchmark *results* following the demonstration will be presented, and some thoughts on the interpretation of the results are given.

## 4.1. Case Study

The model is tested by means of a case study consisting of various benchmarks. The application of the model is illustrated by a case study that is representative for the scope of the model. Different ports, assets, and benchmarks are part of the case study. The case study represents an investigation of the ways in which various benchmarks can be modelled by following the steps of the proposed design process. These particular cases are described and contrasted in Table 4.1, where the variables 'asset type' and 'ports' (benchmark partners or peers) variate. Two cases 'Case 1 - Road' and 'Case 2 - Quay wall' are analysed extensively. The chapter discusses the identification of partners and benchmarks for the case study, the case sampling and the construct validity of the sampling. The case study protocol can be found in Section 3.4.1.

### 4.1.1. Identify Benchmark Partners

The benchmark partners are set prior to the demonstration. Four comparative organisations entered a co-operation for benchmarking. The organisations are all active in the same industry, have similar processes, assets, and goals. For this research four ports joined the benchmarking project: Port of Gothenburg, Port of Hamburg, Port of Rotterdam, and North Sea Port. They expressed their interest in the exchange of knowledge through a benchmarking model with the aim to learn from each other and improve their performance. The asset managers of the partnering ports can be divided into two groups: road and quay wall asset managers. Before starting with the description of the benchmarks, all parties should have the same understanding with regard to the wording used, for instance with regard to the different asset types. The asset terminology, on which the respective ports agreed, can be found in Appendix B.

Although the organisations have much in common, there are a number of pronounced differences. Challenges arise due to the diverse corporate cultures and the variation of practices and regulations in many areas. Both for the benchmarking model in general and the specific cases per assets working groups are composed. In addition, a steering committee provided support and guidance. The participants of the benchmarking group can be found in Appendix D.

### 4.1.2. Identify Benchmarks

A distinction can be made between benchmarks on port and asset level. The port benchmarks are basically characteristics of the identified benchmark partner. These benchmarks give context to the benchmarks performed at asset level. The road (case 1) and quay wall (case 2) benchmarks are developed for benchmarking on asset-level. Both asset types are critical for ports, since these assets have the potential to significantly impact the achievement of specific organisational objectives (ISO 55000, 2014). As Port of Gothenburg does not own road assets, the port is excluded from the road case study. The benchmarks covered in the demonstration for both case studies are: maintenance costs, condition, and availability. This selection was already presented in Section 3.3.2. This selection is the result of various brainstorm sessions using different approaches, in which many benchmarks are discussed. Benchmarks are prioritised, and following this selection process the three benchmarks are put forward.

In Section 4.2 both benchmarks on port and asset level will be discussed. The benchmarks on port level are straightforward, and since the focus is on asset management benchmarks, solely the results of port benchmarks are brought to attention. A more thorough report on the asset benchmarks requires attention to the *specification of the model*, supported by an example of the quay wall asset. The model specification comprises of the asset terminology, asset figures, and asset benchmarks.

The identified benchmarks for performance measurement can be found in Section 3.3.2. The theoretical definitions served as a starting point for the definition of the benchmarks that are demonstrated. The benchmark availability proved to be too difficult to develop due to limited resources and time. Attention is paid to both the specification and the process of developing this benchmark. To allow for benchmarking on the proposed performance measurements, the performance measurement template is specified for a specific benchmark and asset type. The definition of the maintenance costs and condition benchmark served as a starting point. Changes and adjustments are made as the result of the benchmarking process.

For the asset benchmarks, next to the specification of the model, the *benchmarking process* is brought to attention. The performance measurement templates of maintenance costs and condition are reported. As mentioned earlier, the condition has not been finalised. The results can be found in the appendices and in the main text an example of the quay wall asset shows how the model is specified for this asset type. The specification is the result of multiple iterations throughout the process. Some points of discussion were crucial for developing the correct benchmarks. The challenges throughout the process are clustered by the following subjects:

- *Definitions:* terms related to asset management. Besides the definitions, particular attention is given to the interpretation of definitions and its applications in actual practice.
- *International collaboration:* international collaboration between ports for benchmarking faces many challenges. The conversations were a succession of language barriers and differences of opinion. These issues occurred mainly during the brainstorm and define phase. In case challenges did arise in a later stage of the process, it was often important to revise the defined benchmark or to collect new data. All meetings were conducted in English. Moreover, documentation of the ports was mainly written in their native language, and needed to be translated into English. Other differences are for example geographical and climatic conditions, organisational tasks and responsibilities, metrics, currencies etc.
- *Resources:* available data, time, and other resources. The limited availability of sources caused significant delays and scope reduction with some planned features not being developed.
- *Operational perspective:* the operational perspective leads to an unique approach, different from the ports own performance management system. For sharing knowledge the hard measurements were considered to be less relevant. At the end, not only the resulting figure is important, but the basis on which it is calculated should be considered as well. Asset managers are often tempted to forget the context and the 'line of sight', since they focus on their own fields of expertise. The tools that support the development process avoid this partially. Next to this, the steering committee provides an independent review in the check phase.

The subjects as mentioned above cover the aspects have made it challenging to find consensus. As soon as the asset managers agreed upon the asset terminology, asset figures, and asset benchmarks, data collection has taken place. How this information is processed into a dashboard with graphs and other visualisations is shown in the IDEF0 scheme of Figure 3.5. Section 4.3 provides a demonstration of the presentation of the results (i.e. data output). A standardised dashboard layout is designed, an following the case study the information on two asset types is presented in this standard layout (Appendix H). Moreover, attention is paid to the interpretation of the results, and how asset managers can control the asset management performance which is reflected in the results.

### 4.1.3. Case Study Sampling

To conclude, two case studies will be presented in the Proof of Concept. Due to time constraints initially, only the data for 2018 is collected, and fictitiously the past three years. As a result, the functionality of the platform can be demonstrated as it should enable asset managers to monitor the performance measurements. Table 4.1 provides an overview of all characteristics of the case studies. Test data is generated to observe whether the benchmarking model stores and displays the data properly. More information of the fictitiously data can be found in Appendix I.

Table 4.1: Characteristics of selected cases

| | **Case 1** | **Case 2** |
|---|---|---|
| *Asset type* | Road | Quay wall |
| *Ports* | Port of Hamburg,<br>North Sea Port,<br>Port of Rotterdam | Port of Hamburg,<br>Port of Gothenburg,<br>North Sea Port,<br>Port of Rotterdam |
| *Benchmark* | Maintenance Costs, Condition, Availability | Maintenance Costs, Condition, Availability |
| *Year* | 2018, and fictitiously: 2015-2017 | 2018, and fictitiously: 2015-2017 |

## 4.2. Application of the Benchmarking Model

For both case studies the benchmarks on port level are identical. The benchmarks on asset level are discussed separately. For the benchmarks on asset level the performance measurement template is specified. This iterative process is part of the process in developing measurements to benchmark as presented in Figure 3.3. All required information to analyse the benchmarks in the final phase of this process is incorporated in the template. In the following sections the required input is presented.

### 4.2.1. Benchmark Ports

As described in the working method, which is part of the user guide in Section 3.4.1, particular information is required for port benchmarks. Consequently, the following information is collected in order to benchmark on port level:

- *Port data:* for the figures as predefined in Section 3.3.1 the associated data is collected.
- *Geographic location:* for each port the geographical location is presented on a map.
- *Asset data:* asset data requirements follow from the demonstration of the asset benchmarks.

The benchmarks on port level are presented in Table 4.2. The information is collected with one of the supporting tools, a data template for port benchmarks. Furthermore, the geographical locations are presented in Figure 4.1.

Table 4.2: Ports facts and figures, 2018 [2]

| **Port** | **Seaborne throughput (million tonnes)** | **Added value (million euros)** | **Number of businesses (# companies)** | **Employment direct and indirect (# jobs)** | **Port area incl. water (HA)** | **Sea-going vessels (# vessels)** | **Inland vesels (# vessels)** |
|---|---|---|---|---|---|---|---|
| *Rotterdam* | 469 | 45,600 | 2,300 | 385,000 | 12,713 | 29,476 | 107,000 |
| *Hamburg* | 138 | 21,800 | 600 | 268,689 | 7,083 | 8,088 | 10,000 |
| *Gothenburg* | 41 | 7,900 | 320 | 22,000 | 584 | 6,600 | 0 |
| *North Sea Port* | 62 | 12,600 | 700 | 94,544 | 9,059 | 8,412 | 36,650 |

[2] Sources: Port of Gothenburg (2017, 2019); Port of Hamburg (2019a, 2019b, 2019c); Port of Rotterdam (2019a, 2019b). Non-public information is provided by the asset managers following internal documents of the respective ports.


Figure 4.1: Locations of participating ports

### 4.2.2. Benchmark Assets

The aim of the Proof of Concept is to develop three benchmarks for both asset types: maintenance costs, availability, and condition. General definitions are obtained from literature and expert knowledge. The definitions on the benchmarks as presented in Section 3.3.2 are used as basis in establishing the measurements.

As described in the working method, which is part of the user guide in Section 3.4.1, particular information is required for asset benchmarks. Consequently, the following information is collected to benchmark ports on asset level:

- *Asset terminology:* both for the road and quay wall relevant definitions are listed.
- *Asset figures:* these supporting figures are presented in the overview of the benchmarks of an asset type.
- *Asset benchmarks:* for both the port roads and quay walls there is tried to specify three benchmarks: maintenance costs, condition, and availability.

The process of developing measurements for practical purpose is demonstrated in this section. An explanation is therefore provided on information collection for the asset terminology, asset figures, and asset benchmarks. This demonstration is supported by examples of the quay wall asset case study.

**Asset Terminology**

Organisations involved in the management of assets rely on asset data and information as key enablers across their asset management activities. Each well-organised organisation has specified a consistent structure and format in collecting and storing asset information (IAM, 2015). As organisations have their own asset information system and interpretation of the standards. Therefore, asset managers agreed upon international asset information standards for the benchmarking model. These standards are covered in the asset terminology. Some of the definitions, such as the asset description, are reported prior to the benchmark development process. While other definitions are brought to attention during the meetings for benchmark development. The asset information standards are guidelines for consistent collection of asset information. These standards are mechanisms by which asset data is converted into asset information. For this research the standards ensure that the correct data is collected following the data requirements. Standards include asset description, asset classification, asset characteristics, and asset attributes. Consequently, the asset terminology ensures that the information is maintained at appropriate levels of quality.

Appendix B encompasses the asset terminology of both the road and quay wall asset. In order to measure the performance in the same units the *unit of measurement* is defined in the asset terminology. For roads all performance measures are standardised to square meter (i.e. the unit of measurement). For quay walls this is the metric (running) meter. The *asset classification* provides asset managers a predefined categorisation.

In doing so, assets with comparable characteristics will be presented in the benchmark overview. The unit of measurement of quay walls is (running) meter, which represents the length. Therefore, asset managers decided that the height to be characteristic on which the assets are clustered in order to define a classification. For roads it appeared to be less straightforward.Four characteristics were identified being material, foundation type, soil type, and traffic intensity. From this list material type in selected as the road asset classification. A complete and more detailed overview of all assets terms and definitions can be found in the asset terminology.

**Example 4.2.1: Quay wall terminology**

**Specification of the benchmarking model**

This example contains the definitions of some terms relating to the asset management of quay walls. For the purpose of the international benchmarking model the definitions in Table 4.3 are applicable.

Table 4.3: Quay wall terminology

| Term | Definition |
|---|---|
| *Quay wall* | Earth-retaining structure at which ships can berth (De Gijt & Broeken, 2013). |
| *Quay wall classification* | Quay wall assets are classified based on construction height. The construction height is the height from the lowest low water line (LLWL) up to the construction depth. The assets are classified in four classes based on construction height ranges: $x \leq 5$, $5 < x \leq 10$, $10 < x \leq 15$, and $x \geq 15$ meter. |
| *Quay wall type* | Quay walls fulfil varied functions, and construction methods therefore also vary. Based on the construction method, four basic quay walls can be distinguished: gravity walls, sheet pile walls, structure with relieving platform, and open berth quays. |
| *Sheet type* | Construction sheets are part of the vertical construction of the quay wall. Categorisation is based on type and material of the construction: concrete, concrete sheet pile, steel combined wall, steel sheet pile, and wooden sheet pile. |
| *Construction year* | Year of construction refers to the year in which the construction of the quay was completed. For quays this is the year they started to use the asset. |
| *Unit of measurement* | Per (running) meter ($m$). The size of the asset is the length expressed in meters. Consequently, the performance measures are data obtained by measuring against this metric. |

**Benchmarking process**

- *Definitions:* the list of definitions followed from the discussions on asset benchmarks. One of the asset managers wanted to include a jetty. The other asset managers did not agree, and therefore a clear definition of a quay wall became necessary.
- *International collaboration:* in the database information is stored per asset ID. Several options are possible for a break down of the asset portfolio on asset level. The sizes of assets differ, within a port and between ports. Therefore all measures are expressed per unit of measurement.

**Asset Figures**

Asset figures contribute to the context of benchmarks on asset level. This information is presented in the benchmark overview of each asset type. Characteristics that are brought to attention are, among others: utilisation of assets, economies of scale, and obsolescence of the asset portfolio. In Example 4.2.2 there is demonstrated how the asset figures are defined for the quay wall asset. In addition, the geographical location of the ports is included as it indicates the environmental conditions of the assets.

**Example 4.2.2: Quay wall figures**

**Specification of the benchmarking model**

For each asset type the geographical locations of the participating ports are presented, as stated in Section 4.2.1. Besides, some figures are selected and defined providing contextual information. For the quay wall asset the following figures are included in the Proof of Concept:

- *Average construction height (m):* for the classification of the quay wall asset, each quay wall is equipped with its construction height. The averages provides an indication of the construction height, which is an important characteristic of a quay wall. A high construction height may relate to heavy loads (or heavy structures).
- *Quay wall length (km):* the sum of the lengths of all quay wall IDs. The total amount indicates how many square meter the road asset managers of a port have under management. Major differences in size may be interesting, as large organisations possible benefit from economies of scale.
- *Average age of all quay walls (years):* for each (running) meter road the age, being the current year (2018) minus the construction year of the foundation, is given. For each port the average age of all quay wall assets in the portfolio is calculated.
- *Throughput per quay wall (tonnes/km):* the quantity of cargo that passed through a port on a yearly basis from arrival at the port to loading onto a ship, or from the discharge from a ship to the exit from the port complex. Throughput is usually expressed in tonnes. For quay walls the total yearly throughput is divided by the sum of all quay wall lengths. The resulting values indicates the utilisation rate of the quay wall asset. Note: this figure gives just an indication as many aspects such as the type of cargo, construction type of the quay wall, and the distribution of the goods, are not taken into account.

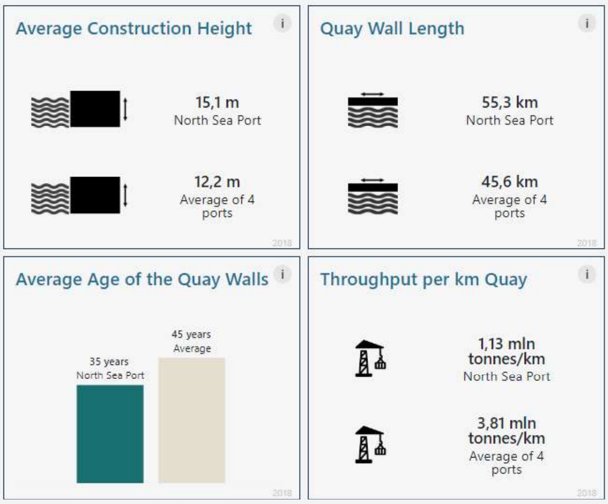


Figure 4.2: Screenshot of quay wall figures presented in the dashboard

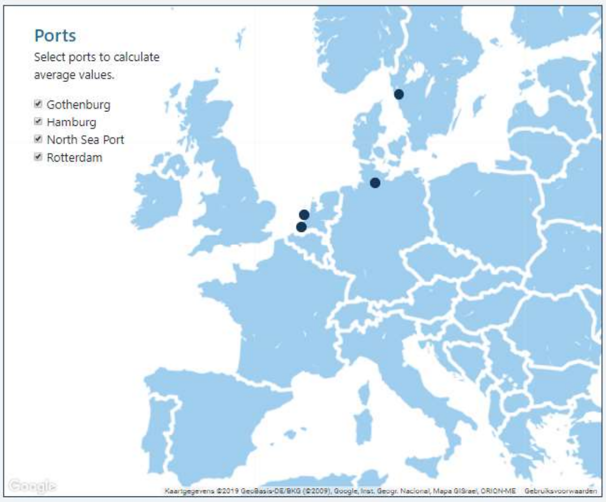


Figure 4.3: Screenshot of the geographical map presented in the dashboard

**Maintenance Costs Benchmark**
This performance measurement allows for information-sharing on maintenance concepts by allocating costs by maintenance type, and presenting corresponding methods and its frequencies. Asset managers want to minimise costs at an appropriate performance and risk level.

The completed templates for this benchmark can be found in the appendix:

- Road: Appendix J
- Quay wall: Appendix L

**Example 4.2.3: Quay wall maintenance costs**

The completed template can be found in Appendix L. The information is the input for the dashboard overviews. This form is an extensive report of benchmark development. Many iterations have taken place to come to this final result. In this example some interesting results on the maintenance costs benchmark development will be presented. These results are the outcome of the *specification of the benchmarking model* for a certain asset type and benchmark. Furthermore, some points of discussion are brought to attention. Subjects of discussion during the *benchmarking process* further sharped the benchmarks and are brought to attention.

**Specification of the benchmarking model**

▶ **Define**

- *Definition:* average maintenance costs per meter of quay wall (€/$m$). Identification of both the total costs and the costs per maintenance type: preventive maintenance, corrective maintenance, and inspections.
- *Position of the benchmark within the asset management theory:* the benchmark is a costs ('focus') measure, which is an input ('processes') indicator. Within the port control model it can be positioned as expenses of asset management. The maintenance strategy indicates which resources are available and used to control the assets ('control'). On operational level, the maintenance costs are the result of chosen maintenance types, methods, and frequencies.
- *Hierarchical tree:* costs per standard unit of measurement, and also the shares on maintenance costs, and related methods and frequencies. Figure 4.4 shows a screenshot of the hierarchy as presented in the template. Next to the break down of the maintenance costs, a list of filters for customised benchmark analysis is presented, and some other factors which should be considered.

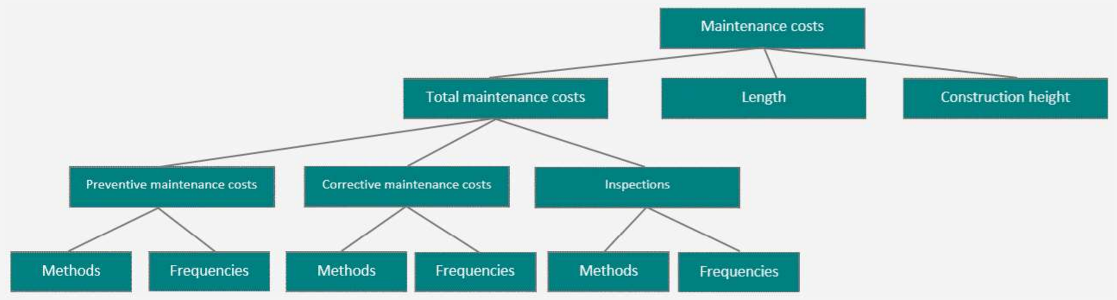


Figure 4.4: Hierarchical view of maintenance costs benchmark

► **Measure**

- *Mathematical formula:* maintenance costs is calculated by using a weighted average formula (Equation 4.1). The weighted average is calculated by multiplying the maintenance costs per meter by its weight, which is defined by the length of a single asset divided by the total length of all assets. The summation of these values divided by the total weight of all assets, is the average as presented in the dashboard. With this information the allocation of the costs based on the maintenance types can be defined as well. Asset managers stated that they find it important to share information on the maintenance methods or activities. Therefore, a list of all maintenance methods is compiled. These methods are grouped into clusters based on the maintenance type. To limit the number of maintenance methods, methods are defined in such way that they are clustered as well. Comparable methods will therefore have the same label.

$$Average\ maintenance\ costs = \sum_{i=1}^{n} \left( \frac{preventive\ maintenance\ costs_i + corrective\ maintenance\ costs_i + inspection\ costs_i}{length_i} \right) * \left( \frac{length_i}{\sum_{i=1}^{n} length_i} \right) \tag{4.1}$$

- *International comparison:* all definitions as stated in the template have been agreed upon. As a result, international standards on asset information are drafted. The standard units of measurement enables asset managers to compare the costs per meter. Next to this, maintenance methods are compared and clustered as they differ across countries and ports. Furthermore, all expenses are in euros, which means that Gothenburg has to convert their costs from krona to euro.
- *Data requirements:* following the detailed definition of the benchmark and its context, the necessary data to measure, compare, and analyse the maintenance costs benchmark is listed. Data includes information on the size of the asset, asset characteristics, environmental conditions, and maintenance strategy (costs, methods, and frequencies). The first rows of the table can be found in Figure 4.5, accounting for one-fifth of the data requirements.

| Data | Field name | Definition |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *Quay ID* | *Quay_ID* | *Asset id of the quay* |
| *Quay type* | *Quaytype* | *Quay type as defined: Quay type as defined: Sheet pile, Sheetpile with relieving platform, Gravity wall, Open berth quay, Not applicable* |
| *Length* | *Length* | *Length of the quay wall (m)* |
| *Construction height* | *Const_Hght* | *Construction height of the quay wall* |
| *Construction year* | *Constr_Yea* | *Year of construction (year start using quay)* |
| *Maintenance cost* | | *Sum of all costs of all types of maintenance (preventive, corrective, and inspections)* |
| *Preventive costs* | *Prev_Main* | *Costs related to maintenance done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.* |
| *Hydrophobing concrete* | *pre_Coat_S* | *Hydrohobing, frequency of this preventive maintenance method* |

Figure 4.5: Screenshot of data requirements table

► **Analyse**

- *Dashboard:* maintenance costs can be analysed by comparing quay walls of different ports over different years, and over different types of costs. A predefined classification is presented based on the construction height ranges. Three types of tables and charts are used to express the data:
  - Line graph: graph containing points that are connected by a line. This graph shows the changes in average maintenance costs over the years. By combining the lines of the different ports the development of the costs can be compared.
  - Pie chart: to show the allocation of the maintenance costs over the three maintenance types, being preventive maintenance, corrective maintenance, and inspections.
  - Table: methods and frequencies of the maintenance methods per type of maintenance.

► **Improve**

- *Useful insights:* the dashboard is designed in such way that asset managers can quickly grasp the essence of the results of the benchmarking model. Asset managers can compare their maintenance strategy, an can improve their own results by controlling the data input. Later on, in the presentation of the results, there will be explained what asset managers can do to optimise their performance with the obtained insights. For maintenance costs, for example, this is the implementation of a (more) preventive or corrective maintenance strategy. Benchmarking maintenance costs this will give insights into (cost) efficiency.

► **Control**

- *Data:* to benefit from the developed benchmark each port should provide information on a yearly basis. As a result, asset managers are able to control the process and monitor their own and relative performance. In this manner the changes in maintenance costs over the years can be measured, monitored, and managed.

**Benchmarking process**

- *Definitions:* preventive vs. corrective maintenance. In an earlier stage, asset managers agreed upon a general definition. In the phase of collecting data, it appeared that asset managers did not have the same understanding. A few asset managers stated that corrective maintenance is in place when the asset is almost out of function. A more precise definition stated that corrective maintenance is carried out after the failure. Failure is defined as the situation in which an asset does not meet its requirements. Those requirements differ per port and asset type.
- *International collaboration:* the climate conditions differ per port. Therefore, differences due to geographical location are presented in the model, although it remains difficult to take into account all differences. For example, from the on-site visit of Port of Gothenburg it appeared that quay walls are equipped with ice protection.

- *Resources:* the required maintenance is highly influenced by the utilisation of the asset. The throughput per quay wall is difficult to obtain as this information is currently not stored on asset level. Next to this, the type of cargo and the construction of the quay wall should be incorporated as well. Due to the complexity of the relation and as data is not (sufficiently) available, the utilisation is left out of scope for the Proof of Concept. For road asset intensity would be a suitable indicator. Therefore, intensity is taken in consideration as well. Here the proportion of heavy traffic should be leading. This data was hard to obtain as not all ports report the traffic data. Besides, factors such as designed capacity should be included.
- *Operational perspective:* at first only the maintenance costs were considered. During the process it became clear that asset managers want to know what is behind the numbers, the allocation of preventive and corrective maintenance costs, and also the methods and frequencies.

**Condition Benchmark**

To allow for benchmarking on the state of the assets, the performance measurement template is specified for the condition benchmark. Consequently, the asset managers can monitor their relative condition development over the years. The benchmark provides information on the condition shares of their asset portfolio. Asset managers aim to maximise their performance, of which condition is an measurement. The desired output in terms of conditions depends on the requirements for that asset. Moreover, it will concern a balance of performance, costs and risks. This second benchmark enables asset managers to monitor the relation between maintenance costs and condition. The resulting graph is an example of an input-output analysis.

In general, a 5-point grading scale is preferred for condition measures. Since there are no international standards on condition, the ports agreed on definitions as presented in the chapter. By comparing the condition measurement systems of the participating ports, an international standard is developed. For this agreement both definitions and visual inspection photos are compared. All involved asset managers agreed upon a 4-point scale. In Example 4.2.4 the condition benchmark is presented for the quay wall asset. In this example additional information on the newly introduced condition standard is given.

The completed templates for this benchmark can be found in the appendix:

- Road: Appendix K
- Quay wall: Appendix M

**Example 4.2.4: Quay wall condition**

The completed template can be found in Appendix M. The information is the input for the dashboard overviews. This form is an extensive report of benchmark development. Many iterations have taken place to achieve this result. This example set outs the key findings of the condition benchmark. The results are the outcome of the *specification of the benchmarking model* for the condition benchmark. Furthermore, some remarkable findings with regard to the process are brought to attention, providing insight into the *benchmarking process*.

**Specification of the benchmarking model**

▶ **Define**

- *Definition:* condition of the quay wall is the present state of the asset, usually referring to the structural integrity. It can also relate to appearance, and therefore the visual condition (result of inspections) is also taken into account. The condition score is based on the degree of damage and deterioration, extracted from visual inspection, or destructive or non-destructive testing. The condition rating is standardised to a 4-point scale. The linguistic scale ('new' to 'critical') can be converted to a numerical value (4 to 1). These linguistic and numerical scales are indicated with a colour. The following categories are identified:

| *Linguistic scale* | *Numerical scale* | *Colour coding* |
|---|---|---|
| New | 4 | Green |
| Good | 3 | Yellow |
| Poor | 2 | Orange |
| Critical | 1 | Red |

- *Position of the benchmark within the asset management theory:* the benchmark is a performance and risk ('focus') measure, which is an output ('processes') indicator. Within the port control model it can be positioned as information or feedback which asset managers receive from their asset portfolio. The state of the assets should be in line with their condition requirements. Asset managers are able to control ('control') the condition of the assets by executing maintenance or other types of activities. The condition of the assets is of importance as the port has to fulfil commitments to their clients. Critical assets require immediate repair or replacement, and can not be used by clients. Risks in terms of safety and maintenance costs can be related to insufficient conditions.
- *Hierarchical tree:* asset condition rating per standard unit of measurement (length), which can be broken down by the condition of the asset components. Figure 4.6 shows a screenshot of the hierarchy as presented in the template. Next to the condition benchmark break down, a list of filters for customised benchmark analysis is presented, and some other factors which should be considered.

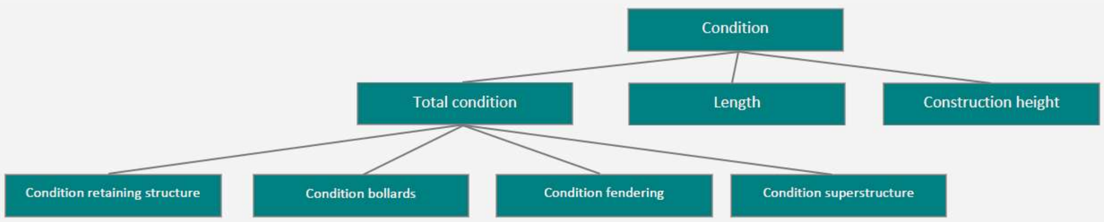


Figure 4.6: Hierarchical view of condition benchmark

► **Measure**

- *Mathematical formula:* condition is calculated by multiplying the individual condition of each asset by its length. The sum of these products is divided by the total length of all assets (Equation 4.2).

$$Average\ condition = \left( \frac{\sum_{i=1}^{n} condition_i * length_i}{\sum_{i=1}^{n} length_i} \right) \tag{4.2}$$

In doing so, the average condition is determined by taking into account a weight, which is in this case the length of the asset. The asset condition is composed of the condition of four asset components: retaining structure, bollards, fenders, and superstructure. The formula of the asset condition is the sum of the condition of each individual component multiplied by a certain weight (Equation 4.3).

$$\begin{aligned} Condition_i = {} & weight_{retaining\ structure} * condition_{i,retaining\ structure} \\ & + weight_{superstructure} * condition_{i,superstructure} \\ & + weight_{bollards} * condition_{i,bollards} \\ & + weight_{fenders} * condition_{i,fenders} \end{aligned} \tag{4.3}$$

The condition of each (set of) component(s) is multiplied by a weight. The weights are attributed based on the importance of the component when considering the condition (its state and functioning) of the asset. The following weights are assigned, all together equalling to 1:

- $weight_{retaining\ structure} = 0.50$
- $weight_{super\ structure} = 0.25$

– $weight_{bollards} = 0.15$
– $weight_{fenders} = 0.10$

The weight parameters are set, and by multiplying these values with the corresponding asset component condition, the asset's condition can be obtained. Following the asset conditions and its length, the condition shares can be presented as well. For each asset component a definition and photos of the four condition ratings are included. In Figure 4.7 an example of a bollard in 'good' condition is presented.

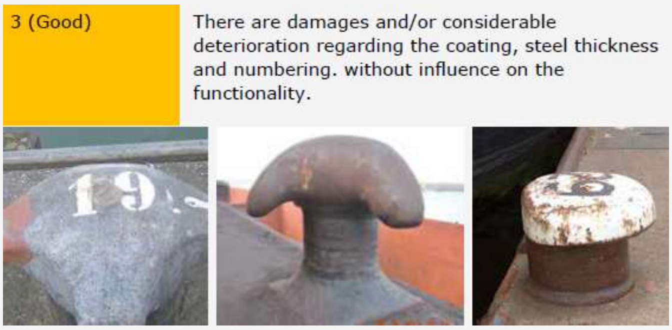


Figure 4.7: Screenshot of bollard condition table

- *International comparison:* asset managers agreed upon a condition scaling. These linguistic scales are described in detail and photos that present the conditions of each component are added. The standards in asset terminology also applicable here.
- *Data requirements:* following the detailed definition of the benchmark and its context, the necessary data to measure, compare, and analyse the condition benchmark is listed. Data including information on the size of the asset, asset characteristics, environmental conditions, and condition ratings (asset and component conditions). The first rows of the table can be found in Figure 4.8. Note that around one-third of the data requirements is presented here. Next to the data for the condition benchmark, the data requirements of the maintenance costs benchmark are included. One of the graphs combines these benchmarks.

| **Data** | **Field name** | **Definition** |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *Quay ID* | *Quay_ID* | *Asset ID of the quay* |
| *Quay type* | *Quaytype* | *Quay type as defined: Sheet pile, Sheetpile with relieving platform, Gravity wall, Open berth quay,Not applicable* |
| *Length* | *Length* | *Length of the quay wall (m)* |
| *Construction height* | *Const_Hght* | *Construction height of the quay wall* |
| *Construction year* | *Constr_Yea* | *Year of construction (year start using quay)* |
| *Condition* | *Cond_Total* | *Condition of the quay wall. Weighted sum of all elements for which a condition is defined. Ranges: 4 (green), 3 (yellow), 2 (orange), 1 (red). Note: green is the perfect/new condition. In Appendix IV can be found more information on the categories* |
| *Condition retaining structure* | *Cond_Retai* | *Condition of the retaining structure.* |
| *Condition bollards* | *Cond_Bolla* | *Conditions of the bollards.* |

Figure 4.8: Screenshot of data requirements table

► **Analyse**

- *Dashboard:* asset managers should monitor the state of their assets as it provides information on their performance when it comes to managing assets. The dashboard allows to measure, monitor, and manage the performance measurement. The performance of the asset is the ability to provide the required level of service to customers. Condition is one of the indicators that measures this performance. Factors such as the age of the asset can be used to customise the benchmarks and enables comparing apples to apples. Thee types of tables and charts are used to express the data:

- Pie chart: illustrates the break down of the asset conditions. The segments represent each condition category's contribution to display parts of a whole, being the asset portfolio. For each port a pie chart is drawn.
- Line graph: two line graphs can be found in the condition benchmark overview. The first graph depicts the development of the yearly average condition. This graph enables asset managers to compare changes over the years for the participating ports. The second line graph type is a graph which combines two benchmarks, showing maintenance costs and condition. This graph is a dual axis chart, which uses two axes to illustrate the relationship between the two benchmarks, and has different magnitudes and scales of measurement.

► **Improve**

- *Useful insights:* the dashboard is designed in such way that asset managers can quickly grasp the essence of the results. Asset managers can compare the conditions of their portfolio, and the input-output relation of maintenance costs and condition. Asset managers can influence their own results by controlling the data input. Later on, in the presentation of the results, there will be explained what asset managers can do to optimise their performance with the obtained insights. An example of an action can be the adjustment of the condition requirements. Or when it appears that ageing assets are relatively expensive, more frequent replacement of assets can be considered.

► **Control**

- *Data:* to benefit from the developed benchmark, each port should provide information on a yearly basis. In this manner, asset managers are able to control the process and monitor their own and the relative performance. Consequently, changes in conditions over the years can be measured, monitored, and managed.

**Benchmarking process**

- *Definitions:* part of definition is the benchmark's position within the asset management theory. Asset managers have different views on the position of the benchmark within the triangle of performance, risk, and costs. Both the quay and road asset managers consider the benchmark as a performance indicator, where the quay group added risk.
- *International collaboration:* a new standard on asset condition is introduced for this research, since the respective ports held different standards for condition rating. Initially, the condition definitions were textual, and later on photos were added to specify the conditions more clearly. During a site visit in one of the harbour areas, the asset managers noticed a critical quay wall. This finding was not in line with the results as presented in the dashboard. Therefore, the data was reviewed, and definitions were sharpened.
- *Operational perspective:* the performance of managing assets from the view of asset managers requires a different approach. Different from previous research, the focus was therefore on the performance of the asset manager when it comes to managing assets. For this reason the condition was preferred as output indicator. Asset managers stated that the life cycle management of assets is one of the central themes in their job, and monitoring the asset condition is therefore of significant importance. In this research the contribution to the number of port calls or throughput, which is suggested in previous research, is therefore not considered as a suitable indicator.

**Availability Benchmark**

The availability benchmark is selected because this indicator aligns the operations of asset managers with the needs of the port's customers. Asset managers have an important role in the provision of capacity. Ports aim for minimal disruption to ship and client operations while taking commercial value and contracts into consideration. Within the scope of this research it concerns the availability of the quay walls and roads. The optimum coordination with clients regarding repair and maintenance work should minimise disruption. The availability of an asset is the percentage of time that assets are available for use. There are different causes for the case when an asset is not available for use. For example, reduced availability can be caused by maintenance activities, regular operations, or externalities. The responsibility and ability of asset managers to control this benchmark is limited. For the purpose of this research the capacity of assets is required. As mentioned in Section 3.3.1, the availability when needed should be considered as many systems, or assets, do not require 100% availability all of the time. The 'availability when needed' benchmark entails new challenges, as it requires information on the demand and actual use of asset.

The availability measurement is a complex measurement as it requires a detailed definition. Moreover, the road and quay wall asset managers are not able to collect all the information. The involvement of other port employees working in other divisions is unavoidable. A start is made with the specification of the performance measurement template. Considering the time constraints and limited available resources, this benchmark is not finalised for the Proof of Concept. Example 4.2.5 discusses the difficulties that arose when specifying the performance measurement template.

**Example 4.2.5: Quay wall availability**

As the availability measurement is disposed at an early stage, an old template was used for this measurement. The components of the final template are brought to attention to show which issues arise when developing the availability benchmark. All benchmarks have to meet certain requirements which are covered by the template.

**Specification of the benchmarking model**

▸ **Define**

The availability benchmark is defined as the total time that a quay can fulfil its function. The time that the asset is not available for use can be caused by failures (unplanned), as well as by planned maintenance and operations. The availability of the berths determines whether a ship can dock at a quay. The benchmark is a performance ('focus') measure, which is an output ('processes') indicator. The asset managers are able to control ('control') the availability by, among others, performing corrective maintenance to minimise down time, or preventive maintenance to prevent down time. The break down of the benchmark in a hierarchical tree confirmed the benchmark's complexity. First, many factors that may influence the availability are beyond the control of the asset manager.In addition, it is difficult to quantify the availability (when needed), partly caused by ambiguous definitions.

▸ **Measure**

The availability of the quay wall can be measured by a proportion of time that assets can fulfil its function (when needed). People from other departments are asked to help with data gathering. It soon became apparent that limited information on this benchmark is available. The down time of assets is always reported, let alone the cause for this down time. For the quay wall asset, the availability is also related to the availability of the berth. Many port operations that affect the availability are the responsibility of other divisions within the organisation. Dredging and traffic control are examples of such operations.

▸ **Analyse**

For now, given time constraints of further developing a Proof of Concept, there is decided not to work further on this benchmark. Developing this this benchmark requires great efforts and close involvement of other departments.

▸ **Improve**

The limited responsibility and ability to influence this benchmarks makes it less relevant to present this benchmark. As stated in the IDEF0 diagram it is of importance that the transformation from input to output can be controlled by the asset managers.

▸ **Control**

Currently, a lot of effort is needed to collect data when monitoring the benchmark. Furthermore, the For monitoring the benchmarks a lot of effort is needed to collect the data. Furthermore, ports were not able to collect the correct data as it was not stored (properly) in a database.

## 4.3. Presentation of Results

In Section 4.2 the used input for the benchmark analysis is presented. This information is processed by the benchmarking model and the results can be found in the dashboard. The data processing is reflected in the IDEF0 in Figure 3.5. Once a benchmark is defined, and performance measures as described are calculated, the question remains of how to interpret these performance measures. Performance measures are sensitive to the data set which is used to test a model, and it is important to consider how they are influenced by the characteristics of the particular data input required for analysis.

Due to time constraints not all data is real, and the used information is yet fully validated. Test data is generated to see whether the benchmarking model stores and displays the data properly. Moreover, the Proof of Concept was built to show asset managers of other ports what the system would look like. Although the data is not representative, the theoretical relations are evaluated in order to create understanding of how the results can be interpreted. The results of all port and asset benchmark analyses as presented in the dashboard can be found in Appendix O. This section elaborates on the maintenance costs and condition benchmark for the quay wall asset, respectively Example 4.3.1 and 4.3.2.

**Example 4.3.1: Quay wall maintenance costs results**

The average costs per meter of quay wall are presented in the first graph of the maintenance costs benchmark. The resulting average is the weighted average of the sum of costs for preventive maintenance, corrective maintenance, and inspections. From the four participating ports, North Sea Port has the best performance when considering the single measure maintenance costs. There is assumed that all asset managers want to minimise costs. For other ports it may be beneficial to compare their performance relative to North Sea Port's performance in more detail.
Figure 4.9 shows a screenshot of the graph. This graph is customised by adjusting the 'port' filter, as Port of Hamburg and Port of Gothenburg are removed from the list.
Validation and verification of the calculations and its results is an important part of the benchmark. Validation concerns whether the benchmarks show the results as intended. The verification on the other hand, is a sanity check on the calculation used. The benchmark relies on the retrieval of the required data which are then processed by the predefined calculations into performances scores. These results are thereafter graphically displayed in the dashboard. From selecting the data up to the interpretation, every step should be clearly addressed in the benchmarking model. It is therefore crucial to have valid and verified calculations. A quality of the benchmark development process is that it allows for continuous feedback.


Figure 4.9: Average maintenance costs in dashboard

Port of Rotterdam has higher costs compared to North Sea Port. The average costs for Port of Rotterdam are [redacted] €/$m$, while North Sea Port has spent only [redacted] €/$m$ in 2018. This single measure must be seen in context and in relation to other measures. Factors such as asset characteristics and environmental conditions may cause higher costs.
The IDEF0 as presented in Section 3.4.3 shows how the input is processed into output, and that asset managers have the ability to control the data input. Figure 4.10 depicts the conceptual IDEF0 diagram for the example of maintenance costs.

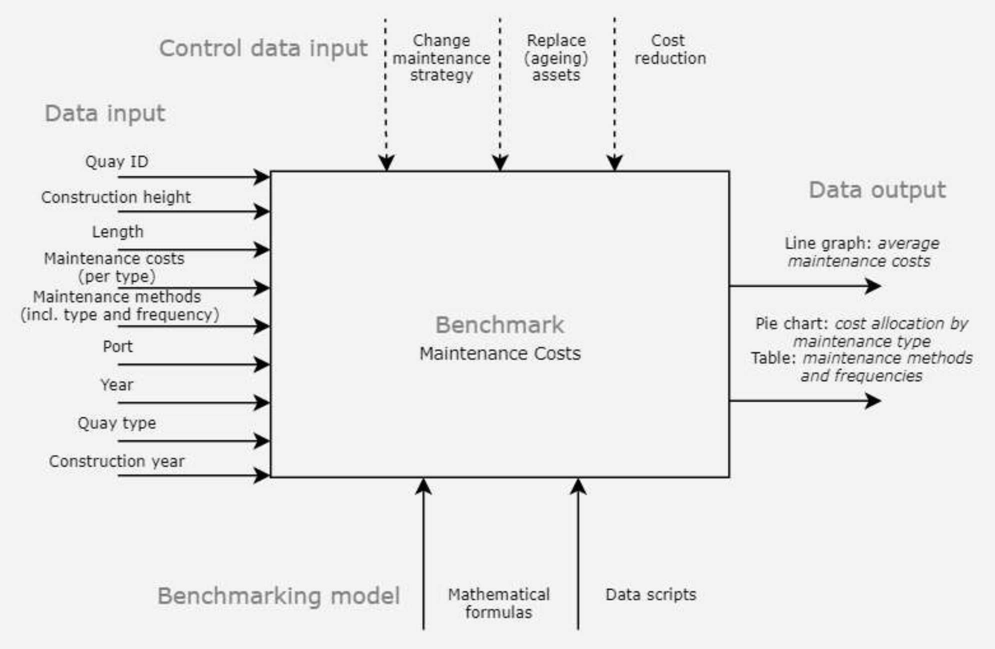


Figure 4.10: IDEF0 maintenance costs quay wall asset

The dotted arrows at the top of the box show a couple of examples of actions that could be done when an asset manager decides to act on the benchmark results. The maintenance could possibly be lowered by changing the maintenance strategy, replacing (ageing) assets, or reducing costs by changing the asset requirements.

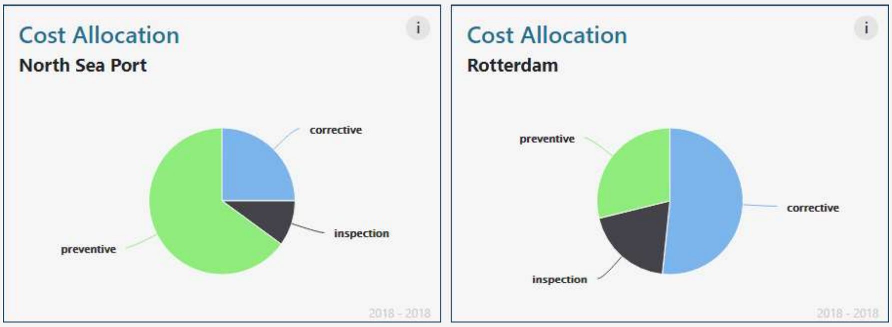


Figure 4.11: Cost allocation by maintenance type in dashboard

Revision of the maintenance strategy can be done by evaluating the maintenance costs in more detail. The cost allocation tells something about the executed maintenance strategy. In Figure 4.11 the cost allocation of both North Sea Port and Port of Rotterdam is depicted. North Sea Port has a more preventive maintenance strategy. Port of Rotterdam could adapt their strategy by carrying out preventive maintenance at a higher frequency. The failure risk or performance degradation may reduce, and prevent high costs for corrective maintenance. Next to lowering the costs through preventive maintenance, maintenance performance can be improved through better technology. The maintenance methods and its frequencies can be found by clicking on the cost shares. In this manner, ports can learn from each other by comparing the maintenance strategy on maintenance type, method, and frequency.

**Example 4.3.2: Quay wall condition results**

The average condition is presented in the second graph of the dashboard. This graph shows how the condition develops over the selected years. Port of Gothenburg is appointed as best performer on the assumption that asset managers want to maximise the condition. The second-best performer is Port of Rotterdam. As the costs in Gothenburg are significantly higher, in this example Port of Rotterdam and North Sea Port are selected as peers.
A customised graph in which the condition of North Sea Port and Port of Rotterdam is shown, can be found in Figure 4.12 (note: the same filter is applied as for the graph in Figure 4.9). The average condition of North Sea Port and Port of Rotterdam shows an increase over the couple few years, respectively a 15.9 and 6.0% increase in the period 2015-2018.


Figure 4.12: Average condition in dashboard

The IDEF0 as presented in Section 3.4.3 shows how the input is processed into output, and that asset managers have the ability to control the data input. The conceptual IDEF0 diagram is specified for this example in Figure 4.13.

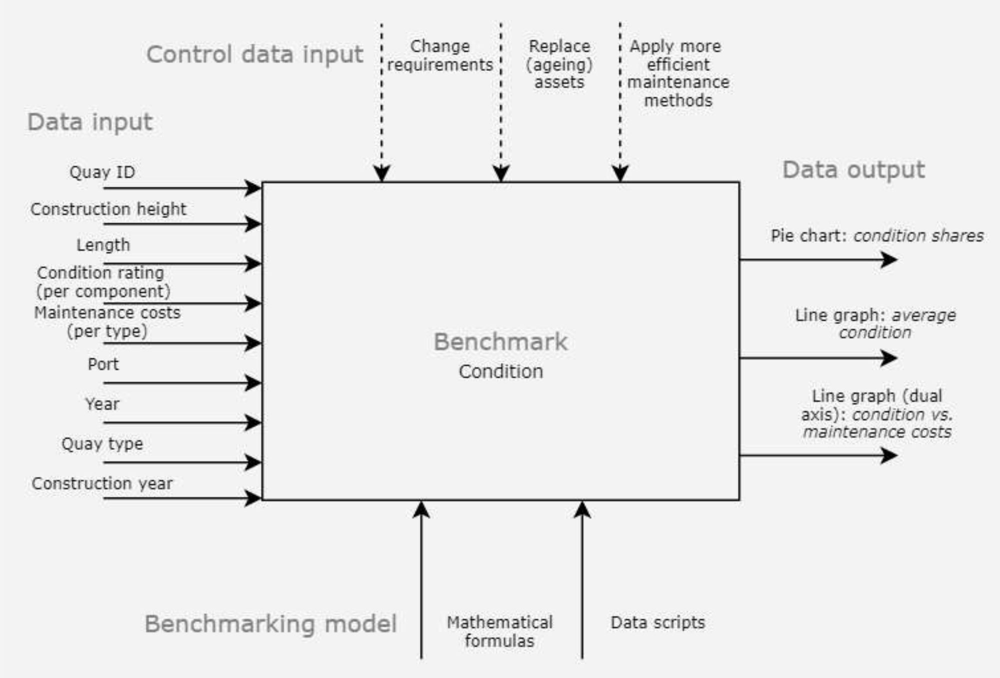


Figure 4.13: IDEF0 condition quay wall asset

As the benchmark condition is the second benchmark, this benchmark is plotted in a dual axis graph with the maintenance costs benchmark. As a result, the input-output relation of maintenance costs and condition can be monitored (Figure 4.14). The maintenance costs of North Sea Port increased with 11.6% over the 2015-2018 period, while the costs for Port of Rotterdam increased with 14.3% over the same period. This may imply that North Sea Port has improved the condition more efficiently with regard to costs.


Figure 4.14: Condition vs. maintenance costs in dashboard

The dotted arrows on top of the IDEF0 box are suggestions for control variables. Both ports should ask themselves whether they want to continue the condition ratings at higher costs. One of the actions they can do is adjusting the asset requirements, for example by accepting a lower condition level at lower costs. Besides, the increase in costs for the Port of Rotterdam is relatively high. More efficient maintenance or inspection methods may offer a solution.

## 4.4. Chapter Synthesis

The aim of this chapter is to test the benchmarking model in practice by means of a case study. Benchmarks are developed by following the steps as presented in the model design phase (Section 3.4.1). In this study, two cases are examined consisting of an asset type, the ports that manage the assets, benchmarks, and years. In each case the same benchmarks are developed and examined for the same years. The differences are reflected in the asset types, and the asset managers that manage the assets. The asset managers represent the ports that participated project as discussed in the case study.

In some cases a difference between the perspectives of road and quay wall asset managers is observed. This is mainly caused by differences in assets' characteristics. Both for the quay wall and road asset type there is decided not to proceed with the availability benchmark. This is particularly due to time constraints and limited data available. Further research on the availability benchmark might be interesting.

Overall, the case study proved proper functioning of the benchmarking model. Benchmarks for the port and asset level are performed. The benchmarks on asset level provided two suitable performance indicators. Both the maintenance costs and condition benchmark can provide insights into the performance of 'managing assets'. The measurements enable ports to measure, compare, and analyse their performance. As test data is used, the obtained results need to be interpreted with caution. Nevertheless, the preliminary results and the corresponding theoretical relations seem to be promising.

Given the time constraints the goal was to develop a Proof of Concept, which demonstrates that the model has practical potential. The demonstration concerns only a small number of variables and is not complete as test data is used to present the model, which is generally the case for a Proof of Concept.

In conclusion, it can be stated that the Proof of Concept laid a strong foundation given that:

- The benchmarking model provides asset managers a *clear working method* and supporting tools.
- The presented benchmark results, and the process itself, provide asset managers *valuable insights*.

The real value of mutually created benchmarks lies in the dialogue that is created before, during, and after the benchmark. Throughout the process asset managers exchanged knowledge and they learned about their performance. An example is that asset managers found out that they improperly store asset information on their information system.

# 5

# Evaluation of the Model (Process)

Both the benchmarking model (*what*) and the involved processes (*how*) are evaluated in this chapter. The model is verified through an *assessment on the predefined requirements and design.* In addition, experts are interviewed. They were asked to give feedback in terms of usability, clearness, completeness, and the satisfaction of needs. Both the working method and the corresponding results are evaluated by an expert panel. This review of the model is an *expert validation* to assess the developed model. The validation is conducted with different types of actors: asset managers, asset owners, and other experts in the research area. Interviews, in the form of a workshop, are conducted with this group of reviewers. Furthermore, the process of benchmarking is evaluated in this chapter. This *process evaluation* discusses the challenges and pitfalls of the benchmarking process. Valuable and significant feedback is taken into consideration in the *revised model.*

## 5.1. Evaluation of the Model

The model is tested with a Proof of Concept in Chapter 4. Both the model design and benchmark results, as presented in the previous chapter, will be evaluated in this section.

### 5.1.1. Verification: Assessment on Predefined Requirements and Design

*Verifying the model - building the model right: ensuring that the model complies with its requirements conform to its design (Bahill & Dean, 2009).*

The model, including the guidelines and frameworks, and the final results in the dashboard should be assessed on the predefined criteria. The model design introduced two main design challenges:

- Which set of criteria indicates asset management performance?
- How to measure performance of asset management?

The model design provides asset managers a guideline for the development of a specified benchmarking model. A particular specification is defined following the selection of an asset type and corresponding benchmark. The proposed method describes an iterative process towards a benchmarking model, and more specifically, the development of benchmarks in a collaborative way. The model guides the asset managers by means of a template that covers the criteria for asset management performance. Asset managers are forced to create relevant benchmarks in a structured way. The model incorporates an user guide and supporting tools, which supports asset managers in the challenging process. By following the steps of the working method, asset managers are able to make performance measurable. In this manner design challenges of this research are addressed.

Besides the design challenges, particular design requirements are listed in Section 3.2. Verification is done by testing the model by means of a case study in the demonstration phase. The verification of requirements is evaluated in this section. Several weaknesses regarding case study verification as a methodology are identified (Lee, 1989; Yin, 2003; Zainal, 2007), most notably a lack of controllability, replicability, and generalisability. Therefore, the case study methodology was composed of two sub-cases. The iterative approach of the benchmarking process ensures a thorough and careful application, and therefore rigorous case study results. Throughout the process, the steering committee provided feedback to make sure that biased views which influence the direction of findings and conclusions are avoided. Although the case study consists of two assets (sub-cases), it remains difficult to provide a basis for scientific generalisation. The structured way of benchmark development makes it easier to replicate results. This characteristic of the model is investigated by a workshop, which is presented in Section 5.1.2. All data is managed and organised systematically, allowing for scaling of the benchmarking model. Moreover, the findings from the case study can be used as an example for other asset types and benchmarks, which will make the establishment of other benchmarks less time consuming.

Furthermore, the weaknesses and associated issues are less relevant for this research since the purpose of the case studies is to validate the function of the developed design within a specific context. This is in contrast to case studies of other studies that usually have the purpose of forming a base for scientific generalisation (Yin, 2003). The objective of validation through a case study is to understand and test the functioning of the benchmarking model. The case studies enable the opportunity to explore the model design. The results following the case study do not necessarily allow for generalisation.

Following the results of the case study, the model is assessed on the predefined requirements:

*1. The model framework should cover all relevant aspects for asset managers that fit within the context of the benchmarks*
Asset management theory is incorporated in the performance measurement template. The benchmark needs to be positioned in context by following the guiding principles. The structured approach obliges asset managers to identify benchmarks that are valuable when it comes to 'managing assets'. All benchmarks are part of the involved processes when managing assets. Besides this, the performance measurements are (partly) controllable as they are positioned within the delineated part of the port control model. As asset managers were closely involved in the design process, they had the opportunity to point out relevant aspects. The asset manager's design perspective has delineated the theory of asset management to an operational level. Throughout the benchmarking process, by following the process steps, asset managers are steered to develop benchmarks that allow for an in-depth analysis. The hierarchical break down of the benchmarks provides asset managers a clear outline of its components and context. The benchmark results are presented in the dashboard, and allow for a detailed analysis of the benchmarks.

*2. The model should provide the (novel) user clear guidelines in benchmark development*
The design of the model is aimed at fulfilling different functions: developing, assessing, comparing, and giving insights into improvement potential. The framework has a supporting role as the involved actors are required to make decisions. Structuring the process is useful when the group appears to be trapped in 'either/or mentality' (Kaner, 2007). The performance measurement template enables asset managers to frame the benchmarks. Members of the steering committee reviewed the completed templates and agreed on the developed benchmarks. Following the benchmark development process, the results are presented in the dashboard. As a result, the model has proved that, by following the guidelines of the benchmarking model, appropriate performance measurements for international comparison can be generated. The model clearly outlines which information is required for web development, and therefore the results are in line with the defined benchmarks.

*3. The model should be straightforward in order to grasp the essence quickly*
The model simplified complex systems and processes of asset management. With a simplified representation of the asset management theory, asset managers are able to construct relevant benchmarks. Asset managers are inexperienced when it comes to performance measurement systems. The developed benchmarks take into account organisational objectives, by which operational measures that contribute to this are established. This is achieved through creating understanding of the context of the benchmarks. The detailed information in the performance measurement template is narrowed down to a concise representation of the benchmark in the corresponding dashboard. The dashboard functionalities enable asset managers to grasp the essence quickly.

*4. The model should provide asset managers the expected benefits of benchmarking*
The collaborative approach resulted in the process quality of the model. Before, during, and after the benchmark development, asset managers exchanged knowledge. The collaborative design method allows for par-

ticipatory decision-making, which is one of the qualities of the model. The group's effort in evaluating and refining the logic is an iterative process. The essence of this type of thinking is critical reasoning (Kaner, 2007). The acquisition of the benchmarks brings benefits in terms of transparency, standardisation, and learning. By changing the perspective on internal processes, transparency is created. The collaborative design of benchmarks obligates asset managers to develop international terms for standardisation of asset information on a global scale. The benchmarking model enables asset managers to benchmark their performance based on a couple of indicators. Following the collaboration asset managers shared knowledge, which may continue in the future.

*5. The model should be generic and suitable for specific cases (e.g. other asset types and benchmarks)*
Through a case study the model design is tested in practice. For the case study a selection of benchmarks are specified for two asset types. First, the quay wall and road group developed the maintenance costs benchmark parallel. Both groups were able to develop the benchmark within the model framework. Subsequently, the condition benchmark is developed. There was no need for adjustment in the standardised template which confirms that the model is suitable for various benchmarks and assets. The acquisition of the availability benchmark did not succeed because of limited availability of resources and time. To determine whether this benchmark would fit within the framework, follow-up research is recommended.

*6. The presented results of the benchmarking model should be reproducible*
The case studies showed that comparable benchmarks can be developed. The differences, in the developed benchmark for the two asset types, are mainly due to the differences in asset characteristics. All findings on benchmark development are reported, and data is managed and organised systematically, enables by the structured and standardised working method. The standardised working method is also reflected in the similarities between benchmarks of the two case studies. The reproducibility of the benchmark will be discussed in more detail in Section 5.1.2 when experts reviewed the model.

*7. The model should be accessible to ports around the world*
The demonstration of the model is conducted by ports located in different countries within Europe. Within the framework of the benchmarking model, the differences between ports and countries are brought to attention. In doing so, the model takes into account the differences between countries. The developed performance measurements allow for international benchmarking between ports. All decisions that are made are reported, and therefore the platform is accessible by other countries. The model supports asset managers in the development of benchmarks, and the results are presented on an online platform.

*8. The model results should give insights into performance improvement*
The in-depth analysis of the benchmarks supported by the model enables asset managers to understand the benchmark results. As a result, asset managers can identify possible causes for the difference in performance scores. The detailed analysis provides information on 'which knobs to turn' to get the desired performance. Asset managers can derive this information by comparing their performance to the performance of the best performer.

The developed model, and its corresponding guideline, achieved the necessary degree of compliance with the design requirements. The model can be expanded in order to maximise the benefits of the benchmarking model (*requirement 4*) and give significant insights into performance improvement (*requirement 8*). Relevant factors that have a significant impact on the benchmark results are left out, because of time and resources delineation of this thesis. The model is perceived as user-friendly by the asset managers that participated in the case study, and the model proved its success as the results are presented on an online dashboard. To allow for generalisation, an objective opinion of the developed model is required. Workshops are held for experts' validation of the model. Both the working method (*requirement 1, 2,* and *6*) and the dashboard results (*requirement 3* and *8*) are assessed in the workshop sessions.

### 5.1.2. Validation: Expert Interviews

*Validating the model - building the right model: making sure that the model does what it is supposed to do (Bahill & Dean, 2009).*

The model is evaluated by 'internal' experts (i.e . participants of the benchmarking group) throughout the design process. For an objective and unbiased evaluation of the model, 'external' experts are asked to participate in workshop sessions. In essence they are asked whether these external experts consider the built model as 'right'. The model's working method and results are brought to attention during workshops. The workshop participants are all active in the field of study. Participants are selected in terms of the department and position within the port's organisation, their experience an knowledge on specific subjects, and their ability to be objective. As a result, this expert panel forms a representative group composed of asset managers, asset owners, and other experts in the research area.

The experts who form the panel work in various departments, either operational, tactical, or more strategic. Based on their expertise and viewpoint they are clustered in different sub-groups. Consequently, the model is assessed on its applicability to novel users, suitability for other benchmarks, and its contribution to organisational objectives. Appendix Q elaborates in more detail on the set-up of the workshops. In this appendix the purpose, participants, and the procedure of the workshop can be found. This section describes the overall reflection of the benchmarking model. By clustering the workshop observations two parts can be distinguished: the working method and the benchmarking results.

**Evaluation of the Working Method**

The workshop participants, which are mainly asset managers, are asked to review the model design. They received particular information concerning the purpose of the benchmarking project. This section provides a concise outline of the observations of the workshop. The experts have a positive opinion of the model, and believe that sharing knowledge on an operational level creates new opportunities. The development of benchmarking in a collaborative way enables asset managers to learn from each other. The model facilitates this process in a clear and structured way (*requirement 2*).

Asset managers are asked to specify the template for a benchmark. The participants, which can be seen as novel users, find it hard to complete the template on their own. This emphasises the importance of cooperation. The model is established in such way that benchmarks are defined through a collaborative way of working. Showing the templates for the maintenance costs and condition benchmark creates better understanding of the working method (*requirement 6*). Participants agreed on the specification of the benchmarks in the case study, in terms of correctness, completeness, and relevance.

The aspects of asset management are covered by the guiding principles. The model focuses on departments that are responsible for managing (physical) assets (*requirement 1*). Although the experts perceive the finished templates as complete, they believe that further development in a constructive way can be useful. The interaction with other departments could be addressed. The port control model pays attention to the organisation as a system. It might be valuable to pay closer attention to the interactions that take place, as this contributes to the alignment of asset management and organisational objectives. In doing so, the input can be transformed to output on a higher level in the organisation. The feedback relating to the 'line of sight', which refers to the translation of organisational goals to asset management objectives, is coming from experts with a more strategic position (Schoenmaker & Van Der Lei, 2015). Because of the operational perspective of the research, the focus was more on practice. Nevertheless, the 'line of sight' is reflected in the port control model.

The intention is to expand the model by adding other asset types, were this research can serve as a starting point. The demonstrated model is presented to asset managers of the waterways asset. The asset managers of this asset type are responsible for dredging activities in the port area. After the presentation, dredging asset managers were brought together for a discussion of the applicability of the benchmarking model. They indicated their interest in developing benchmarks, as they believe that the model is suitable for performance measurement related to their activities. This proves that the generic method could be applied to the development of other asset types (*requirement 5*). More information can be found in Appendix P. Moreover, information on adding other asset types is further detailed in the recommendations of this research.

**Evaluation of the Benchmark Results**

The benchmarking model's results as presented in the dashboard is submitted to the experts. The experts confirmed that the dashboard provides ports valuable indicators which enables asset managers to benchmark their performance on managing assets. The model is stimulating asset managers to rethink their own strategy, and is perceived as a user-friendly tool. The relative performance can be easily extracted from the dashboard (*requirement 3*). In contrast to other performance measurement systems, the underlying activities and processes are brought to attention. As a result, the dashboard gives interesting insights into the operations, which is perceived as refreshing by the asset managers. The benchmarks results are substantiated by the presentation of the underlying activities (*requirement 8*).

In order to formulate an opinion on the differences in performance, more detailed information on the context is desirable. Important characteristics with regard to the distinction between assets is included in the analysis. Additional options to customise the analysis ensures a fairer comparison. The importance of factors such as the utilisation rate of assets are brought to attention. Examples of factors that should be included according to experts are traffic intensity, which applies particularly to the road asset, and climate conditions. Asset managers are positive on the attention that is paid to the underlying information of the benchmark results.

Asset managers pointed out that they would like to receive more steering on how to link the results to actions for performance improvement. For competitive reasons it is decided to not present too much information on solutions in the model. Next to this, it was noted that the results are mainly presented in separate graphs. This means that for each benchmark separate overviews are generated. The graphs that are included can be customised on only a few characteristics. It might be interesting to add more combinations and supporting graphs. The relation between benchmarks, such as an efficiency score, could make it more easy to interpret the relation between input and output measures of the processes involved when managing assets.

## 5.2. Evaluation of the Model Process

The development of the benchmarks is performed by following the steps as presented in the guideline of the model design. The working method provides asset managers tools to perform an iterative process for benchmark development. To avoid pitfalls associated with previous benchmarking projects, these are identified prior to the design and demonstration of the model:

- *Pitfall 1:* Benchmark is done at too high a level
- *Pitfall 2:* Outcomes are not linked to underlying activities
- *Pitfall 3:* Improper approach and view on the benchmarking process
- *Pitfall 4:* Too many performance measurements

This section evaluates the process of benchmarking, and the corresponding challenges arose throughout this process for verification. Consequently, it becomes clear whether and how the design helped the asset managers to prevent or overcome the pitfalls and other obstacles. In other words:

*Which challenges came across and how is dealt with these challenges?*

Some of the challenges that came across confirm what early research indicated already. These challenges are generic 'in the world of benchmarking'. Benchmarking is perceived as a time-consuming and complex task. For asset managers that participated in the case study it was often difficult to find time to work on the project, as their participation in the project was an addition to their daily job. The collaborative and international nature of the project entailed many challenges. For each benchmark the process started with a brainstorm session. The different perspectives of asset managers are explored in the form of group discussions. In practice, it is hard for people to shift from expressing their own opinions to understanding the opinion of others, particularly when international differences are in play (Kaner, 2007). Expressions such as *'I thought we all agreed to stick to this idea?'*, *'We are wasting time'*, and *'We are stuck'* came by. By sharing thoughts in the templates and following the iterative process, eventually the asset managers managed to come to an agreement. The frameworks and tools of the benchmarking model helped asset managers in structuring their ideas and selecting suitable benchmarks. The following decision rules are introduced throughout the process:

- *Literature is the guiding principle:* discussions on definitions were often resolved by recalling literature. One of the characteristics of the model is based on literature, which laid a strong foundation.

- *Majority vote:* within the benchmarking group the majority rule is decisive, and decisions are refined in such way that all participants eventually agree.
- *Person-in-charge decides following the discussion:* according to the organisational structure, on each level a team leader is appointed. The steering group has the final vote in the selection process of the benchmarks. During the development of the benchmarks the members of the working (sub-)group make their own decisions.

The project's time constraints put pressure on decision-making. The decision rules are a mechanism to ensure a decision is made, and as a result it speeds up the process. The transformation of ideas from brainstorm sessions and discussions (divergent thinking) to final results (convergent thinking) is shown schematically in Figure 5.1.

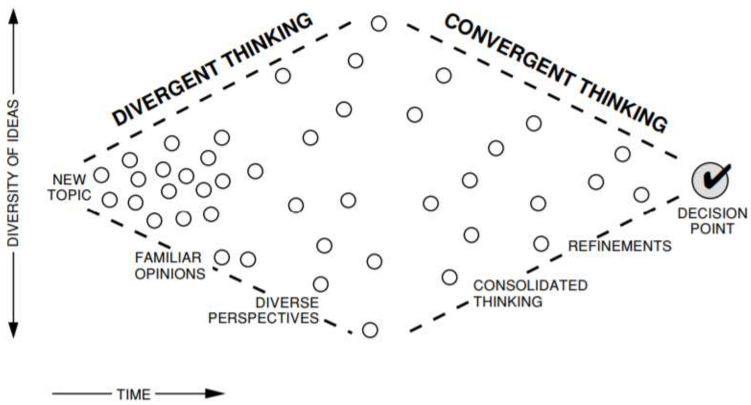


Figure 5.1: Dynamics of group decision-making (Kaner, 2007)

Next to generic examples of challenges associated with benchmarking, some challenges that came across are more specific to the research topic. These challenges were raised in Chapter 4. In Table 5.1, which is presented on the next page, most notable examples are summarised. The challenges are classified according to the subject, in the same way as in the demonstration phase: definitions, international collaboration, resources, and operational perspective. For each challenge a brief description of how is dealt with this challenge is provided. Moreover, the role of the benchmarking model in tackling this problem is described. Last, for each associated pitfall there is stated whether the pitfall is avoided.

The development of benchmarks is particularly challenging because this is done in collaboration with an international group of asset managers, which are inexperienced at performance measurement and benchmarking. Besides, the approach of this research entered into a novel field of study. As illustrated in the table hereafter the design of the model supported the asset managers throughout the process. One of the pitfalls (*pitfall 3*) the model could not prevent from happening concerned a challenge related to data collection. Due to time constraints and limited availability of resources asset managers were not able to collect the correct data. The data that is collected needs to be revised and validated, before sound conclusions on the results can be drawn. The same challenge is associated with another pitfall which concerns plurality of ideas and therefore the deviation from the vaunted objective (*pitfall 4*). The model managed to avoid this pitfall.

Time constraints, as mentioned earlier, put constraints on the development of the benchmark results. The collaborative development of benchmarks proved to be a challenging and time-consuming task. Therefore, it is recommended to further discuss whether the benefits outweigh the effort it takes to develop benchmarks. Furthermore, even more important, the available sources and priorities of the asset managers should be mapped. Chapter 6 presents recommendations regarding subsequent stages of the design development. The difficulties with regard to collecting the desired information also relates to the complexity of asset management. Many factors that affect the performance of asset management are outside control of asset managers. To monitor these factors asset managers have to consult external parties.

Table 5.1: Faced challenges throughout the benchmarking process

| Subject | Challenge | How is dealt with this challenge? | Role of the benchmarking model | Associated pitfall | Avoided? |
|---|---|---|---|---|---|
| Definitions | Differing interpretations of definitions on asset information (e.g. asset definition, asset types, preventive and corrective maintenance). | Asset terminologies introduce the definition international standards, particular for benchmarking on asset management. In case of disagreement, findings from theory are decisive. | By following the steps of the benchmarking model asset managers have to agree upon definitions on asset information. Besides, the scientific definitions serve as a basis. | Pitfall 3 | Yes |
| | Asset managers of road and quay walls have a different view on the definition of risk. | The model allows for asset specific results. All reporting (asset terminology, templates, and dashboards) is clustered per asset. | The organisational structure includes a sub-group for each asset type. In addition, information is collected per asset type. | Pitfall 3 | Yes |
| International collaboration | Asset information is stored differently, and therefore it is not possible to match data. | Introduction of a unit of measurement per asset type. Moreover, a standardised template helps asset managers to collect data a similar way. | The benchmarking model provides templates for data collection, and the unit of measurement is defined in the asset terminology. Asset managers of the concerning asset type make the final decision. | Pitfall 3 | Yes |
| | Agreement on condition ratings as they differ per port. | Condition ratings have been shared and discussed. A new categorisation, a 4-point scale, of conditions has been introduced. | The model ensures that mathematical expressions and data requirements are listed. The identification of the differences across countries and ports are part of the performance measurement template. | Pitfall 3 | Yes |
| | Condition definitions need to be aligned with reality. During the site visit it appeared that the definitions were interpreted differently. | The definitions on condition are described in more detail, and photos are added. | Site visits are included in the planning. The iterative nature of the approach, including feedback loops, enables asset managers to review the model and adapt benchmarks in a later stage. | Pitfall 3 | Yes |
| Resources | Quantification of information on asset utilisation, an influencing factor, was not straightforward enough. | Different ways of including the road intensity and the utilisation of the quay wall are discussed. Eventually, there is decided to exclude the utilisation. | The iterative process ensures that intermediate results are reviewed. The process guides asset managers in not getting caught in too much details and to focus on the result instead. | Pitfall 4 | Yes |
| | Data collection is time consuming and difficult. In a later stage of the research, asset managers proved being unable to collect the required data, upon which they agreed. | For some data points test data is used instead of real data. Due to time constraints this was the most effective way to accomplish the goal: a Proof of Concept. | During the process, the model requires asset managers to discuss which data is required. In this case asset managers agreed on data they actually could not deliver. The model is not designed to deal with this kind of data issues. | Pitfall 3, Pitfall 4 | No, Yes |
| Operational perspective | Ensure that the results of the maintenance costs benchmark brings valuable insights. | A break down of the benchmark is included next to costs, as well as maintenance type, methods, and its frequencies. | The benchmarking process is defined as an iterative process with feedback loops. In this way intermediate results are revised. | Pitfall 2 | Yes |
| | Brainstorm sessions started with output indicators on port level, such as throughput. | By having a closer look at the involved processes when managing assets, the throughput indicator did not fit within the framework. Therefore, there is decided to develop output indicators that should be monitored by asset managers: conditions. | The guiding principles capture the principles of asset management. These guidelines ensure that only benchmarks that are suitable for the measurement of the performance of managing assets are allowed. Only benchmarks in the context of this research fit within the model framework. | Pitfall 1 | Yes |

## 5.3. Revised Model

Lessons are learned from the evaluation of both model and process characteristics. Despite that the model is proved to be appropriate, a number of shortcomings are identified. Novel users are represented by asset managers who developed the first benchmark, maintenance costs, and the expert panel that was consulted for the validation of the model. Both groups expressed their interest in a more detailed guideline which provides additional information on the approach. Examples of the developed benchmarks, maintenance costs and condition, are constructive for further development. The user guide should therefore be extended with:

- *Approach:* explanation of the approach, such as the scope of the project, and the focus on benchmarks regarding the performance of 'managing assets'.
- *Example benchmarks:* example of previously conducted benchmarks.
- *Time planning:* providing insights into the time required for the development of a benchmark, which can be derived from the demonstration phase.
- *Extensibility:* a working method which helps asset manager in further developing existing benchmarks. In doing so, the framework incorporates this requirement in a structured way.

Recommendations for further research and an extension of the model are addressed in the recommendations section of Chapter 6. Asset managers expressed their interest in a more detailed version of the current benchmarks. Factors such as utilisation rate, climate conditions, internal versus external costs, Purchasing Power Parity (OECD, 2019b), and activities other than maintenance work are mentioned by the expert panel. This constructive feedback can be found in the recommendations section as well. In this section recommendations are made to further development the model.

## 5.4. Chapter Synthesis

The validity of the model is explored through both validation and verification: assessment on predefined requirements and design, expert interviews, and evaluation of the process. This is done by evaluating the results which followed from the case study and empirical research.

First, the model is assessed on the predefined requirements and design, which state what is needed to accomplish the predetermined goal. A successful Proof of Concept proved the model is capable to provide guidance in both what to measure and how to measure. The model guides the asset managers in both the selection (*what to measure*) and specification of the benchmarks (*how to measure*). By following the steps of the working method, asset managers are able to develop a benchmarking model. Having made this observations, it can be stated that the design challenges of the research are addressed. Moreover, the model achieved the necessary degree of compliance with the design requirements.

According to asset managers and other experts the model provides a suitable method for collaborative benchmarking. Information on performance is obtained through an in-depth analysis, using both quantitative and qualitative data. The model is not yet suitable to provide accurate insights into performance, since the results are dependent on multiple characteristics which are not included. However, the insights gained from the benchmarking process and results are considered to be valuable. The results are indicators of relative performance, which stimulate ports to have a critical look at their current operations. Asset managers believe in the possibility of further developing the benchmarks, which provides an in-depth analysis. Asset managers are willing to share knowledge and are open to learn from each other. This process can be supported by the obtained benchmarking model. In conclusion, the model is sufficient for basic analyses and is perceived as added value by (prospective) users of the system. The observations and remarks from experts are processed and included in an updated version of the user guide [3].

[3] A user guide for asset managers is provided to the respective ports. This guide outlines the benchmarking model in a practical way. The document is not publicly accessible as it concerns an extract of this report. Besides, in contrary to the thesis' content, it contains confidential information.

# 6
# Results

The *main findings of this research* are substantiated in Section 6.1 by answering the research sub-questions. Followed by answer to the main research question in Section 6.2, in this section the final conclusions of this research will be summarised. Second, the findings of this research lead to *recommendations* on which will be elaborated on in Section 6.3. Last, a *reflection* is provided in Section 6.4.

## 6.1. Main Research Findings

This section summarises the conclusions and findings of the research on the development of an international benchmarking model for asset managers working at ports. The main question answered in this study is:

*How to compare different ports on aspects of asset management through benchmarking?*

To provide a structured answer to the main research question, eight sub research questions are formulated. First, the sub-questions are addressed followed by an answer to the main research question.

***Sub-question 1:*** *What are theories and applications of generic benchmarking, and what does literature provide in order to specify benchmarking for the purpose of this research?*
From literature review it can be concluded that benchmarking is a widely used method with a large variety of applications. Due to its broad application, benchmarking models can be established for specific assignments. This can be achieved through the adaption of generic options of the benchmarking types, processes, methods, and procedures. Hence, generic options are identified for the approach of this research. For creating the benchmarking model a custom-made design process is developed, since existing models in the literature did not comply with the needs of asset managers. Moreover, performance measurement of asset management (in ports) has received relatively little attention in previous research. In order to acquire a framework for performance measurement existing frameworks are adapted to the specific context of the research, which is done by consultation of experts.

***Sub-question 2:*** *Which framework for benchmarks can be developed for the purpose of this study?*
For the purpose of this research a performance measurement framework is developed. Due to the lack of knowledge on the study's research area, additional knowledge is obtained from experts. Through a literature review and the consultation of experts three theoretical frameworks have been selected. The conceptual frameworks cover certain criteria which the benchmarks have to comply with. Suitable benchmarks can be positioned within three guiding principles, as presented in Figure 6.1:

1. *Processes of asset managers:* position of the benchmark in the input-output performance measurement framework. The input-output diagram represents the processes involved when managing (physical) assets.
2. *Control of asset managers:* position of the benchmark within the port control model. This concerns control relations between an organisation and its environment. The benchmark should be related to the controllable part of the model.

3. *Focus of asset managers:* position of the benchmark in relation to asset management objectives. The main objective can be stated as the realisation of value while balancing three relevant attributes: performance, costs, and risk.

The developed framework provides asset managers a conceptual framework for creating measurable, controllable, and valuable benchmarks.

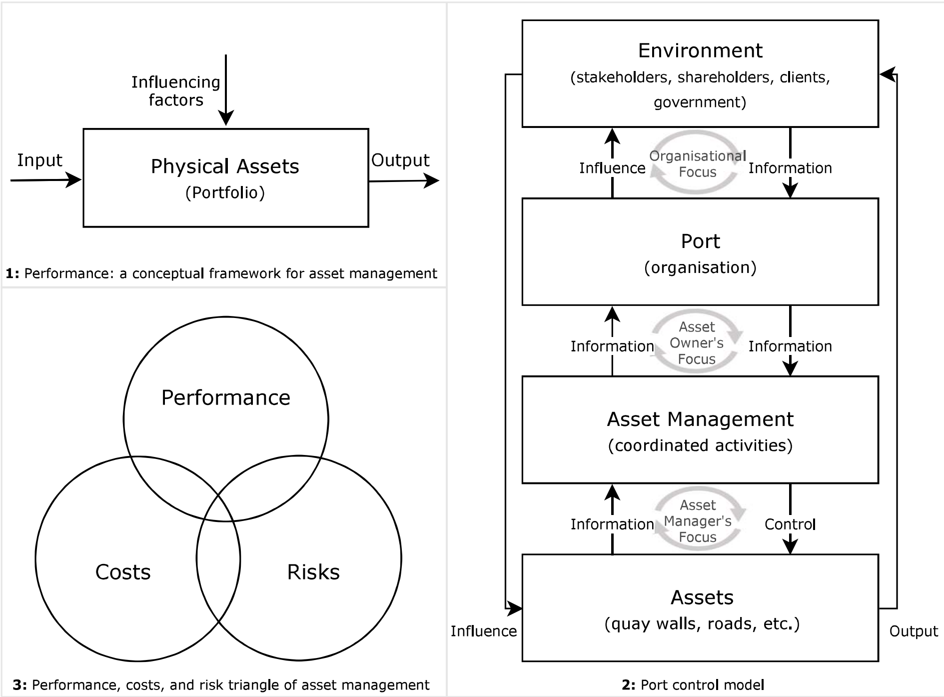


Figure 6.1: The guiding principles: a framework for benchmarks

***Sub-question 3:*** *Which performance measurements can be obtained to measure asset management regarding port roads and quay walls?*
For the identification of criteria for suitable benchmarks, different approaches are explored (Appendix C). The approach that is applied in this research considers single measurements. These measurements are both interesting as stand-alone measurement as as benchmark. Moreover, particular attention is paid to various factors underlying a port's performance. For asset managers this implies that both the asset management activities and the asset's context are included in the definition of the benchmark. A structured approach of defining benchmarks that are suitable for benchmark analysis is laid down in the performance measurement template. The comprehensive definition ensures that a more profound analysis of the benchmark is feasible.

Following brainstorm sessions and discussions with asset managers a list of performance measurements is identified, and thereafter asset managers the benchmarks were asked to prioritise the listed benchmarks. The benchmarks which are given priority are assessed on the criteria of the conceptual framework. As a result three benchmarks which are representative for the performance of 'managing assets' are selected for a case study. The small selection covers both input and output measurements with distinct attributes. Three benchmarks, identical for each asset type, have been listed: *i)* maintenance costs, *ii)* condition, and *iii)* availability.

***Sub-question 4:*** *How can input of the benchmarking model be used to determine the value of performance measurements?*
In this study benchmarking is defined as the systematic process of measuring port's performance against other ports for the purpose of continuous improvement. In order to execute this process, all participating ports need to collect proper data for performance measurement. In the case study benchmark are defined in a performance measurement template. This tool enables asset managers to assemble the required information in a structured manner, as is good practice in developing and using performance indicators (Rozner,

2013). The structured template contains, among others, a hierarchical tree which entails decomposition of the measurement. Furthermore, a mathematical formula is provided in order to quantify the benchmark, and subsequently the data requirements can be identified. Once all ports managed to collect the required data, results can obtained. To accomplish this, a dashboard is used as a tool to process the input data. Asset managers are required to define the involved input-output processes. The data processing functionality of the dashboard can be depicted in an IDEF0 diagram, as presented in Figure 6.2, which leads to a structured graphical presentation of this activity (Akasah et al., 2017). As a result, the benchmarking model enables asset managers to develop benchmark in order to measure, compare, and analyse their performance. In addition, the concept has another convenient feature, the asset managers are able to create understanding on how to improve their performance. Steering on the performance measurement results can take place by changing control ('control data input').

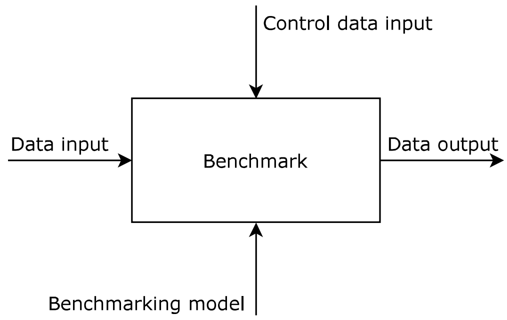


Figure 6.2: Transforming inputs into performance measurements (outputs)

***Sub-question 5:*** *Which data needs to be collected to conduct the analysis with the benchmarking model?*
A structured approach is applied to assemble data from different sources. As it concerns an international collaboration for benchmarking between different ports the data does not match automatically. First, is determined what information is required to ensure fair comparison. The model is concerned with the processes involved when managing assets. The ports are the overarching systems with multiple subsystems, one of which is asset management. As a result, information on port level provides context for benchmarks on asset level.

In this research particular attention is paid to the differences across organisations (i.e. ports) and countries, as these differences may lead to lead to comparability issues. Differences may result from both technical and more fundamental aspects related to the ports and its assets. Each port handles their own structure and format in collecting and storing asset information (IAM, 2015). However, uniformity in definitions and interpretations of these definitions is essential for securing that information is maintained on appropriate quality levels. In this research is shown, based findings from expert consultation and the case study, that international comparison on asset level was hardly possible because of the lack of uniform definitions and performance measurement methods. International standards and definitions are introduced to deal with the comparability issues. Asset managers agreed upon international asset information standards, such as the asset description, classification, characteristics, and attributes. Moreover, since assets have different dimensions, the unit of measurement is introduced as a standard for measures of the same quantity. These standards are compiled per asset type in the so-called asset terminology, securing that information is maintained on appropriate quality levels.

Prior to the analysis of asset benchmarks, the entire port system of which assets are part of should be considered. Information in terms of size, operations, and activity in and around the port is listed. The port data concerns particularly publicly accessible data, and is therefore easy to obtain. The focus is this research is on the benchmarks on asset level. An 'apples with apples' comparison is pursued through standardisation of asset information laid down in the asset terminology. For all asset types the data is collected per asset ID, and the corresponding number of units. Consequently, performance can be expressed per standard unit of measurement and is prevented that asset of different sizes are compared.

The required information varies by benchmark and asset type. For standardisation of the benchmarks a structured approach for benchmarking is therefore established. This research presents a step-wise method in development of asset benchmarks, the sequence of the steps is presented in Figure 6.3. As a result, this research provides asset managers with a clear working method, which is highly preferable for asset managers lacking in experience and knowledge on both performance measurement and benchmarking. With this method, asset managers are supported in collecting the right data, and subsequently in performing the benchmarking analysis. The method can be seen as a cyclical process, since all steps can be performed iteratively, as instant feedback turns teaching moments into concrete adjustments. Throughout the process attention should be paid to web development, which suggests that data should be collected standardised formats which can be processed by the data processing functionality of the dashboard.

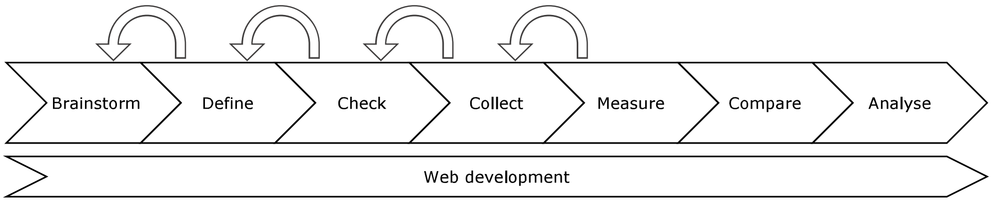


Figure 6.3: Benchmark development process

***Sub-question 6:*** *Which benchmarking model can be acquired to benchmark asset management performance?*
The design is approached from both a theoretical and asset manager's perspective. Accordingly, the research is delineated to the performance of 'managing assets'. This operational performance refers to the measurable aspects of processes involved when managing assets. The benchmarking model is based on theoretical frameworks and methods, which have been adapted through intensive consultation of asset managers, i.e. the end users of the system. As a result, the perspective of the asset manager is considered throughout the design process.

The resulting model provides a method generic for specific cases, which implies that different compositions of ports, asset types, and benchmarks can be handled. The model design provides inexperienced asset managers a guideline for collaborative benchmark development. The structured process ensures consistency, as for all cases the same method is applied. The methodological guide comprises of the following elements: organisational structure, planning, working method, and supporting tools. The working method is a step-wise method for benchmark development (Figure 6.3. Throughout the process supporting tools are provided to standardise the benchmarks.

***Sub-question 7:*** *What are the performances of ports in terms of relative efficiency following the case study analysis?*
The presented benchmarking model enables ports to measure and compare their performance on aspects of asset management. This model is tested by means of a case study consisting of two distinct asset types, namely the road and the quay wall asset. Due to time and resource constraints it was not feasible to collect real data solely. To observe whether the model stores and displays the data properly it was required to generate sample data and incomplete data sets are supplemented with test data.

Information on performance was obtained through an in-depth analysis, using both quantitative and qualitative data. Although used (test) data is not representative, the theoretical relations are discussed in order to create understanding of how the results can be interpreted. This information is presented in an easily analysable and comprehensible form. As a result, the dashboard provides interesting insights into the operations, which is perceived as refreshing by the asset managers. The results that are presented in the dashboard are not yet suitable to provide accurate insights into performance, since the results are dependent on multiple characteristics which are not included in the Proof of Concept. This last point also pertain to one of the study's limitations. This study being a case study within a specific context, the findings might not be generalisable to other contexts.

In conclusion it can be stated that the benchmarking proved to be a useful method to provide insights into ports' relative performance as the results of the benchmarking model can be linked to the underlying activities of asset managers. The results provide directions which solution should take in order to control and improve performance. The demonstration has shown that, whilst executing the benchmarking process, insights into asset management performance are obtained before, during, and after the benchmark.

Although the model has delivered a successful Proof of Concept, certain criticism can be made in regarding the efficiency aspect. The model did not provide relative efficiency measurements. In multiple brainstorm sessions the efficiency indicator, which is in theory the output divided by the input, is discussed. This required the selection of a wide range of measurements. As the results are not that scale-able, and depend on many different factors efficiency cannot be distracted. Besides, it appeared from intensive expert consultation, that the efficiency score should not be the priority. The in-depth analysis of a small selection of measurements on performance enable asset managers to share knowledge. As a result of this in-depth analysis, asset managers are able to link the results of the benchmarks to the underlying activities. In Appendix 2.3.2 more information on the considered approaches for performance measurement can be found, including the efficiency scores as presented in Section C.2.1.

***Sub-question 8:*** *To what extent do the performance measurements and the proposed benchmarking model provide insight into the performance of asset management?*
A case study research method is applied to test the model design. Although the specified benchmarking model is not yet complete, the results are promising. The gained insights from both the benchmarking process and results were considered as valuable. The benchmarks results as presented, enable asset managers to monitor and analyse indicators. These indicators reflect the relative performance of asset managers.

The facilitation of close involvement of asset managers throughout the process is a process quality of the model. Hence, it is recommended to continue the collaboration for further development. The asset managers that are able to control the benchmark results, should be closely involved when developing new or more detailed benchmarks. In order to draw any conclusions on existing benchmarks, additional information on the context and asset characteristics is desired. Furthermore, it is of importance to be aware of the fact that asset manager individually are responsible for the benchmark analysis. In order to attain the benefits they should conduct customised analyses, and subsequently translate the findings and insights into performance into concrete actions.

## 6.2. Conclusions

This section presents the final conclusions of this research by an answer to the main research question. Next to this, most notable findings of this research will be presented. The aim of this research was to design a benchmarking model for asset management in the port industry in order to measure and compare performance, and to provide asset managers insights into performance improvement. This model should provide asset managers a design process to obtain performance measurements for benchmarking on the aspects of asset management. Consequently the model should provide more insights into asset management performance and contribute towards continuous improvement. It thereby answers the main research question:

***Main research question:*** *How to compare different ports on aspects of asset management through benchmarking?*

The findings from this study illustrate the complexity of obtaining a benchmarking model which is relevant for operational purpose. In order to align both theory and practice, a benchmarking framework by integrating findings from literature review and expert consultation. In doing so, a generic model for practical use is obtained, which is suitable for specific cases in the context of asset management in ports. This study is an integrated approach of four streams in literature: benchmarking, performance measurement, asset management, and ports. Besides the unique combination of these topics, the benchmarking model is novel for the following reasons:

- *Operational perspective:* the perspective of the user of the system, the asset managers, left a significant mark in the model design. The model framework ensures that benchmarks reflect the performance of 'managing assets' in ports.
- *In-depth benchmarking analysis:* previous benchmarking models generally focus on single measurements, where this research provides a benchmarking model for conducting an in-depth analysis. Close attention is paid to explanatory and contextual variables.
- *Collaborative design:* as limited research is available, the benchmarking model is obtained through consulting asset managers. As a result, the benchmarking model is retrieved in collaboration with experts by adapting existing theories. Because of the international nature of this study, asset managers agreed on international standards for benchmarking.

The benchmarking model provides a tool for assessing and comparing the performance of asset management in ports. The development of this model addresses two design challenges:

- Which set of criteria indicates asset management performance?
- How to measure performance of asset management?

A benchmarking framework, which is obtained from input of experts in the research field in a collaborative way, lays a solid foundation for international benchmarking by using grounded theory. The set of criteria which indicates asset management performance is reflected in the guiding principles. Benchmarks for asset management performance are positioned within three theoretical frameworks, which cover the following aspects of asset management: the processes of asset managers, control of asset managers, and the focus of asset managers. In order to measure the performance a benchmarking model is designed to provide asset managers a guideline for the specification of the benchmarking model.

Furthermore, this study identified the needs of the asset managers. In doing so, this research is the first step towards a quantified research on the contributions of various factors that reflect the overall performance of asset management. Further, demonstration by means of a case study has shown what information is required for benchmarking in a specific context. The *benchmarking process* facilitates a benchmark development process which is done in a collaborative way. As a result, asset managers share knowledge before, during, and after the benchmark analysis.

The *benchmarking model* provides a standardised approach on the definition of benchmarks. In doing so, a reproducible and standardised method is provided. The model is scaleable as multiple benchmarks for different asset types can be created. The benchmarking model is based on theoretical frameworks and methods, which have been adapted through intensive consultation of asset managers, the end users of the system. As a result, the perspective of the asset managers is considered throughout the design process. Next to the quantification of the benchmark (a 'single performance measurement'), the model facilitates asset managers with a framework that enables them to link the results to underlying activities, and furthermore the benchmark can be seen in its context.

## 6.3. Recommendations

This study is built on several assumptions for simplification that may lead to less reliable results. The recommendations for further research will be discussed in Section 6.3.1. This section describes the limitations of this research and the opportunities to conduct future research. Subsequently, in Section 6.3.2, the recommendations for Port of Rotterdam, North Sea Port, Port of Hamburg, and Port of Gothenburg, will be presented.

### 6.3.1. Recommendations for further Research

This section presents the recommendations for further research in the field of benchmarking on asset management in ports. Despite that the benchmarking model meets the research objectives set out in Section 1.3, several shortcomings can be identified. Each limitation is described with potential future research avenues.

The restrictions in time and resources played a significant role in the decisions made with regard to the scope, and therefore only a small exercise is conducted in testing the model. The case study comprises two asset types and succeeded to create two distinct benchmarks for each type. This being a case study within a specific case context, the findings might not be directly generalisable to other cases. Follow-up research is recommended to determine whether other asset types and benchmarks can be developed. For example, the availability benchmark which is excluded from this thesis research. In order to finalise this benchmark additional time and resources are required. However, the benchmarking model and its process proved to be effective in providing a structured guideline. The theoretical underpinnings of the model, i.e. the conceptual framework and structured processes, facilitate a structured approach on benchmarking. In doing so, this model is able to have a supporting role in further case study research.

This study started at the operational level of the organisation, and more specifically with the processes related to asset management. An interesting step for further research is the involvement of other (asset management) departments. In this manner a benchnmarking analysis can be performed from a more aggregated view. The asset management benchmarks results should be aligned with the organisational objectives, subsequently the relation between operational and organisational performance can be evaluated.

All above mentioned contribute to the idea of an extensive benchmarking (i.e. 'growth model'), in which the port as an organisation is observed. This researched focused only a small part of the operations involved in the port industry. To provide a comprehensive analysis, the benchmarking model could be extended. Various ways, in different directions, to expand the model can be identified:

1. *More profound analysis:* further development of road and quay wall benchmarks as presented in the case study. For a more detailed analysis various elements can be added to the benchmarking model: other explanatory and contextual variables, benchmarks, and ports. Moreover, other asset types (e.g. waterways asset) should be considered as well.
2. *Horizontal expansion:* other departments on operational level within the organisation, i.e. at same level in the hierarchy of the port model.
3. *Vertical expansion:* include the performances of departments on a higher level in the hierarchy of the port model, for instance by starting with asset owners.
4. *Port performance:* further development of the model in both horizontal and vertical direction offers new opportunities. Eventually the performances of the port, as overarching system, and its subsystem (e.g. asset management) can be mapped. In case different subsystems within the port control model are identified, subsequently it might be considered to identify and analyse relations or links among these subsystems and their performances. The relationships can be considered for systems either on the same or at a different level within the port system.

This 'growth model', provides a systematic approach, i.e. a road map for further development of the model. Following the Proof of Concept estimations can be made concerning the required time, and resources, and the feasibility. For some of the listed options, it may be required to adjust the theoretical framework as its main part is asset management specific.

Another limitation of the study is that, partly due to restrictions in time, it did not lend itself well for quantification. The case partly made use of test data and the obtained results should be interpreted with caution. Therefore it is not possible to draw conclusions from the relative performance. Moreover, in case more data can be collected, statistical analysis should be included in order to draw conclusions with regard to the averages. The averages as presented in the demonstration, by means of a case study, showed averages as results of the benchmark analysis. In case more ports are incorporated in the analysis, depicting the minimum and maximum value of the benchmark results can be interesting. An outlier can affect the average of a data set by skewing the results so that the mean is no longer representative for the data set. Moreover, it is recommended to include statistical analyses in further research. For example a standard deviation, as this is a measure of the spread of scores within a data set. The standard deviation could be introduced in order check whether the average is representative. If all numbers all close to the average a low standard deviation is observed. Further research can be geared towards this analysis consisting of larger amounts of data, and by incorporating statistical methods.

### 6.3.2. Managerial Recommendations

This section discusses the recommendations for the ports that have facilitated and contributed to this research. Following a successful Proof of Concept, further implementation of the model is recommended. Next to this some remarks should be considered.

Managerial recommendations relate to the retention and further development of benchmarks. The recommendations for the respective ports can be captured with the following sub-questions:

***Sub-question 5:*** *Which data needs to be collected to conduct the analysis with the benchmarking model?*

- *Data availability:* this study is primarily based on the available data acquired from different data sets. The scope of the Proof of Concept is delineated following restrictions in time and resources. The results in the dashboard are not yet suitable to provide accurate insights into performance, since the results are dependent on multiple characteristics which were not included in the Proof of Concept. Considering the small exercise that is considered in the case study, it is recommended to improve the data quality. The collected (available) data needs to be revised and validated as well, before sound conclusions on the results can be drawn. Besides, test data is used to deal with incomplete data sets. This data should be replaced by real data. As the data requirements are clearly stated, asset managers should anticipate to ensure that they are able to collect the data more quickly for the coming years. This study clearly outlines which data is needed, and how it should be collected.

***Sub-question 7:*** *What are the performances of ports in terms of relative efficiency following the case study analysis?*

- *Total life-cycle costs:* in this research the assets' costs are solely based on maintenance activities and inspections. Other costs involved when managing assets, and moreover the investments costs should be considered as well. To incorporate the investments costs port employees are required to join the project, or to share the required information. Consideration of the whole life of an asset provides sound basis for decision-making. Furthermore this contributes to a like-for-like comparison between the asset's costs.

***Sub-question 8:*** *To what extent do the performance measurements and the proposed benchmarking model provide insight into the performance of asset management?*

- *Profound analysis:* further development of established benchmarks and adding new benchmarks is desirable to receive all benefits. Due to time constraints not all desired information is included in the analysis. By placing the benchmarks in a broader context, a more in-depth analysis can be performed. Aspects that should be considered are, among others, the utilisation of the assets, climate conditions, detailed information asset characteristics. These factors are of major impact on the benchmark results. The focus should be on the underlying activities and information of the measurement, not on the stand-alone benchmarks. The following steps for existing benchmarks are recommended:
  - Utilisation of the asset in relation to its capacity or construction.
  - Environmental conditions such as temperature (fluctuations, extreme whether conditions, etc.) or salinity classes in water.
  - Extended asset attributes: more detailed information on, the asset type, construction, etc.
- *Development of benchmarks for the waterways asset:* the intention is to expand the model by adding other asset types, were this research can serve as starting point. The demonstrated model is presented to the asset managers of the waterways asset, who are responsible for the dredging activities in the harbour area. they indicated their interest in developing benchmarks, as they believe that the model provides suitable guidance for benchmarks related to their activities.

For all recommendations it is highly desirable to investigate the possibilities for data collection. Throughout the process multiple iterations have taken place. A major share of these iterations has taken place as consequence of the issues related data collection, which is perceived as time consuming.

## 6.4. Reflection

In order to obtain a benchmarking model for asset management within the port industry this research is conducted in close collaboration with asset managers. Although there was a clear goal right from the start, this still needed to be worked out. During the specification of the project the scope it soon became apparent that the research needed more scoping. A selection of around eight benchmarks was initially listed, which is narrowed down to three benchmarks, namely maintenance costs, condition, and availability. Due to the unexplored nature of the research field the design aspects were as least as important as the quantitative analysis, as this analysis can not be carried out properly without an appropriate method. The main lesson to be learned here is that it is important to answer the question 'why' do we want to measure it, and it is therefore important to discuss why a certain goal is set. In the case of this research it has been identified that it is of particularly importance that asset managers understand the results following benchmark analysis, because then, they can learn from the obtained results.

This research is conducted as part of a running-project, which concerns the collaboration of four European ports which decided to work on the development of a benchmarking model. The aim of this project was to create an online platform to share knowledge among peers (i.e. ports) worldwide. Considering the tight deadline it was required to react quickly and flexibly. The deliverables of this research were a necessary part of fulfilling the ultimate goal: the development of a Proof of Concept. One of the main tools is the performance measurement template, which provided a structured approach of defining benchmarks. In order the serve the asset manager's need a first draft of this template is delivered an early stage of the project. Since, this research sheds light on the aspects of a formerly unexplored research field, valuable insights were obtained throughout the collaborative design process. Consequently, it turned out that adjustments were necessary to develop suitable benchmarks. Multiple discussions with asset managers have taken place during the project, which showed that a rethink on issues was required and highlighted that the template was not comprehensive. The lack of steering came forward as one of the main issues. The progress is highly reflected in the differences between the the initial and final version of the template, respectively presented in Appendix E and G. The example of the template demonstrates the fact that it was not always that effective that the research was carried out in parallel with the project. The platform that is created had a very strict deadline, as this final product had to be presented on at the WSDS 2019 (Workshop on Dredging and Surveying) in May. This tight deadline created many challenges which were difficult to address, but on the other hand, the commitment to meeting the deadline also sped up the process. As a result, quick and efficient decision-making has taken place, which was essential for this goal. Despite the benefits, I would recommend to have more time to prepare the research. In this manner a more structured and detailed approach can be applied in an earlier stage of the project.

Besides the more academic lessons, I have learned a lot on personal level. During my academic career I worked, at various organisations within different industries, either as work student or intern. This internship was actually unique because my research was commissioned by four organisations, namely Port of Gothenburg, Port of Hamburg, North Sea Port, and Port of Rotterdam. The international character and involvement of various actors, are aspects I find most interesting and challenging. Moreover, it further sparked my enthusiasm on the shipping industry. I have had the opportunity to visit the participating ports, including round trips in the ports' harbour areas. Since Holidays were not included in my thesis planning, these trips provided me a lot of energy and an increased motivation! Another aspect I liked was the project's complexity and scale, which confronted me with my bad habit, of being too much a perfectionist and demanding. Moreover, I always seek to quantify my reasoning. Carrying out this research taught me how important it is to have a good design, in which qualitative aspects might be of major importance. To conclude, I would like to say, that I have learned a lot during my assignment and I have enjoyed the work a great deal!

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# Appendices

# A

# Scientific Paper

RESEARCH

# Benchmarking the performance of ports on asset management

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**Abstract**

Over the past decade, the complexity of operations in the port area has increased significantly. Considering the challenges the ports are facing, the need for asset management efficiency within the port industry is imperative. Both the challenges the ports are facing and the willingness to ensure continuous improvement have contributed to a growing interest in benchmarking. Four European ports entered into a cooperation to realise a platform for benchmarking. Currently, limited research is available on methods for assessing and comparing asset management performance. This research aims at filling the gaps in literature by developing an international benchmarking model for ports. In doing so, it provides asset managers a structured approach to develop benchmarks in order to measure and compare performance. By combining existing frameworks and the consultation of experts in the research field, a model design is obtained in a collaborative way. The model is demonstrated by means of a case study. Following this demonstration it can be stated that the benchmarking model provides asset managers a clear working method and supporting tools. The presented benchmark results, and the process itself, provides asset managers valuable insights into performance. Consequently, it provides support in the development of future benchmarks.

**Keywords:** Benchmarking; Ports; Asset management; Performance measurement

## Introduction

As global trade has increased over the past decade, vessel sizes and cargo volumes surged, which places additional pressure on the ports' assets. The flows of cargo are mainly facilitated by maritime shipping, with port infrastructure acting as the main gateway. As it pertains to asset management, operations have become more complex due to various developments: increase in throughput, bigger ship sizes, ageing assets, increasing complexity of the harbour area, rapidly changing world (e.g. energy transition, globalisation, and digitisation), and major developments in legislation and regulation. Due to the complexity of the competitive port industry, ports are becoming increasingly interested in solutions that can significantly contribute to optimising the current operations, promoting efficiency and cost reduction, all without requiring major investments in new assets. Currently, the dominant approach of ports to manage assets is based on their own historical performance. Ports prefer to minimise the disclosure of confidential information of competitive value, as they are afraid information go in hands of competitors (Stana, 2010).

The challenges ports are facing, as well as the willingness to ensure continuous improvement contribute to the growing interest in benchmarking among ports. Benchmarking creates the possibility for ports to identify and learn from best practices elsewhere in the world (Elmuti & Kathawala, 2002). It is a tool for the assessment of performance, and set up partnerships to share knowledge on specific cases.

Port performance is generally conceptualised as driven by straight forward criteria, such as throughput. Research in the field of port benchmarking predominantly focuses on the performance of ports, where the performance is looked upon from a more holistic point of view. Macro indicators quantify aggregate port impacts on economic activity. A number of studies on the subject of port performance and efficiency are conducted (Bichou & Gray, 2004; De Langen, Nijdam, & Van Der Horst, 2007; Talley, 1994; Tongzon, 1995). These studies identified the various factors underlying a ports' performance. Other studies have focused on several ways to measure port efficiency, and depending on which aspects of port operation are evaluated measurements are identified. All studies remain on a high level of abstraction while using macro performance indicators. Moreover, in the maritime and port literature most attention is drawn to competitive benchmarking, rather than comparing the performance of operations and processes (Bichou, 2007). However, a series of papers explored the performance of ports from an operational perspective. This existing literature on micro performance indicators predominately focuses on the context of terminal operations, or logistics and supply chains. Research on benchmarking the performance of asset management is often restricted to maintenance activities, which cover's only a small part of the asset manager's job (Hyman, 2004).

In the context of port performance and benchmarking, the perspective or standpoint (customer, operator, regulator, etc.) one has to consider when undertaking port performance measurement and benchmarking is debatable (Bichou, 2007). The standpoint considered in this research is the perspective of the asset manager. From the perspective of asset managers 'hard' quantifiable factors should not be in isolation from the more tacit and qualitative underpinnings of the way an asset management department functions. In existing research the underlying factors of performance measures receive relatively little attention.

So far the possibilities of an appropriate method for assessing and comparing ports' asset management performance have not been researched yet. The scientific contribution of this paper is the integrated approach of four streams of literature: benchmarking, performance measurement, ports, and asset management. This study's aim is to explore the asset management perspective by reviewing literature and the consultation of experts (i.e. asset managers). By combining both findings from literature and expert knowledge, a model is designed which forms a solid basis for international benchmarking with regard to asset management performance in ports. In doing so, this research is merging two methodologies: performance measurement, i.e. selecting metrics and designing a measurement system, and benchmarking against peers. The design challenges are reflected in two questions that need to be addressed: Which set of criteria indicates asset management performance? Second, how to measure performance of asset management?

These questions are addressed using insights from the field of port asset management. A benchmarking analysis is performed based on a case study on the Port of Rotterdam, North Sea Port, Port of Hamburg, and Port of Gothenburg. Asset managers of the respective European ports have entered into a cooperation in order to create a platform. Currently, comparison is hardly possible because of the lack of uniform definitions and methods of measuring performance. The main question that needs to be answered in the context of this research is:

*How to compare different ports on aspects of asset management through benchmarking?*

In addressing this question, the study contributes to practice as well as academic research. The relevance of this paper is that it outlines both the unexplored nature of asset management performance in literature, and the lack of appropriate benchmark frameworks. The models serves a practical purpose as it connects identified criteria (*what to measure*) and a corresponding method (*how to measure*) in the development of benchmarks. Based on the case study, this research describes the practical application of the model design (*specification of the benchmarking model*), the challenges of collaborative and international benchmark development in practice (*benchmarking process*), and the insights obtained from benchmark analysis (*presentation of benchmark results*). Following a case study, the research offers deeper insights into aspects involved when benchmarking asset management performance. Given time constraints the goal of the respective ports was to develop a Proof of Concept.

This paper is structured as follows. First, a literature review outlines the present knowledge by combining these findings in a comprehensive framework for performance measurement. This conceptual framework covers aspects of the different streams of literature which are considered: benchmarking, performance measurement, ports, and asset management. Second, the methodology used to design and test the model is outlined. Furthermore, in order to define the theoretical content and contours of a method for practical use, the benchmarking model is presented. Subsequently, the case study is introduced, which illustrates the practical application of the model. The case study draws on publicly available data and information of internal databases of the ports. In the next section validity of the model is explored through both validation and verification. This is done by evaluating the results obtained from empirical research in the form of a case study. Last, the paper discusses the findings, their implications for research and practice, and concludes.

## Literature review

This section provides insights into the functioning of benchmarking as it elaborates on performance measurement, definitions of benchmarking, different types of benchmarking, the benchmarking process and the methods. In addition, there is elaborated on the benchmark procedures and underlying approaches for the development of performance measurement. Furthermore, this section presents a conceptual framework for performance measurement which is used as basis for the model design. This framework covers certain criteria which performance measurements have to comply with.

### Benchmarking theory

Benchmarking is an effective tool that supports management in their pursuit of continuous improvement. It is a technique for assessing an organisation's performance against the performance of other organisations (Sekhar, 2010). Benchmarking is used to find the best practice and to determine which actions can improve the firm's own performance.

Along with the increased use of benchmarking, many researchers focused on performance measures and setting targets. Papers typically address aspects of departmental benchmarking along with limited success stories. According to Meybodi (2009), benchmarking activities need to be integrated into an organisational strategy and the benchmarking process needs to employ a broad range of balanced performance measures which are consistent with an organisation's strategy. In doing so, benchmarking can be used as an effective organisational tool for learning.

In general, the benchmarking tool has many advantages. There are two important advantages from the point of view of an asset manager. First, the minimisation of costs and time-savings to adapt best practices of other companies rather than inventing them in-house. Second, stimulation to overcome an organisation's inertia and think differently in the context of new approaches implemented elsewhere (Sekhar, 2010).

Although benchmarking in general is perceived as effective, it does has limitations which should be considered to overcome potential pitfalls. The lessons learned from previous applications are taken into account for in the approach of this research. Hence, a list of expected pitfalls is provided (Elmuti & Kathawala, 2002):

- *Pitfall 1:* Benchmark is done at too high a level
- *Pitfall 2:* Outcomes are not linked to underlying activities
- *Pitfall 3:* Improper approach and view on the benchmarking process
- *Pitfall 4:* Too many performance measurements

Challenges that will come across and the specific context of this research call for a particular approach. The aspects of benchmarking are discussed through the selection of suitable benchmark options. The objective is to measure and compare performance of port asset management. Performance benchmarking enables asset managers to compare processes with numerical standards (Bogan & English, 1994). The peers are located in different countries, and therefore the benchmarks are of international scale. Due to the international nature of these benchmarks, close attention should be devoted to generic definitions and measurements. Performance measurement fulfils the function of learning, and therefore ports first have to create transparency, which is another function. For the development of the benchmarking model a custom-made design process is required as existing models do not comply with research's objective. Bourne, Neely, Mills, and Platts (2003) developed a categorisation which separates different forms of design processes. They suggested two distinct dimensions for categorisation: the underlying procedure and the underlying approach of performance measurement. For developing performance measurements the 'model led' procedure will be used, since the organisation will be transformed in theoretical models. Generic theories are adapted and converted to frames that represent the criteria of performance measurements. The combined theories serve as a conceptual framework for benchmarking. In addition, the eventual model should take into account the 'needs' of the system's users. The asset managers' needs are identified and used for the specification of the framework following the 'model led'. The performance measures are designed to monitor the progress or the organisation towards achievement of this needs. The underlying approach of this procedure is the 'facilitator led'. The model design of this research is obtained in a collaborative way, by means of consultation of experts to ensure that they discover and analyse the design together. Accordingly, the users of the system (i.e. the asset managers) are closely involved in the development phase. Following the selected benchmark options as presented in this section the generic benchmarking approach is defined.

### Conceptual framework

The design of a framework is the first step towards a quantified research on the contributions of various factors that reflect the overall performance of asset management. Following the selected benchmark options, theories are collected and adapted to support the benchmarking process. The resulting framework provides a basis for the identification and definition of performance measurements, known as the benchmarks. From an engineering and operations approach, ports can be seen as a fixed assets and operational systems. A system is often defined as a set of components that are interrelated among themselves and with the environment. Because of the complex nature of operations in ports, research is usually undertaken at disaggregated operational levels. In the port context, asset management is a subsystem of the overarching port system. The selected components for this research are the (physical) assets. A further distinction is made by focusing on the operational aspects, and not on the strategic and tactical aspects of asset management. Pollitt and Bouckaert (2011) suggest the use of a conceptual framework for performance measurement. This research mainly concerns the operational and process results of this framework. Organisations acquire inputs with which to conduct activities in pursuit of their objectives. Within the port system different control relations can be defined. The control paradigm of De Leeuw (1982) is a class of abstracts systems, each consisting of a controlled part, the environment, and the controller. The suggested control model can be adapted to different contexts. In order to create measurements that are useful for asset managers, it is of importance to define the control relations, subsequently the parts of the system over which asset managers have influence. The performance measurements should be quantities that can be influenced, or controlled, by the user alone or the user in co-operation with others (Neely, Richards, Mills, Platts, & Bourne, 1997). Moreover, control activities should be in compliance with the objectives as stated in the port's asset management plan. This set of objectives determine what constitutes value and defines the right balance between the conflicting factors, being performance, costs, and risk (IAM, 2015). Since organisations have different strategies, asset management objectives differ across ports, and thus have a particular view on what is the best value compromise. Benchmarks results on the aspects of performance, costs, and risk can be obtained to provide insights into the asset management performance. It will then be up to each port or asset manager individually to decide what and how to improve. To conclude, relevant criteria for performance measurement can be derived from the literature findings. A conceptual framework is used to address the criteria of asset management performance (Figure 1).

This framework covers the criteria which the benchmarks have to comply with, which entails that proper benchmarks should fit within three theoretical concepts, the so-called guiding principles:

1 *Processes of asset managers:* position of the benchmark in the input-output performance measurement framework. The processes involved when manag-

ing assets are reflected in an input-output diagram, in accordance with the performance theory of Pollitt and Bouckaert (2011).

2 *Control of asset managers:* position of the benchmark within the port control model. This concerns the control relations between an organisation and its environment. The benchmark should be related to the controllable part of the model. The paradigm of De Leeuw (1982) is adapted for analysing the control activities within the port. For effective control, the 'controller' - asset manager - should specify performance measures with respect to the 'controlled system' - physical assets under management. A port control model is obtained, in which the control of the asset manager is restricted to a small part of the overarching system.

3 *Focus of asset managers:* position of the benchmark in relation to asset management objectives. The main objective can be stated as the realisation of value while balancing performance, costs, and risk attributes.

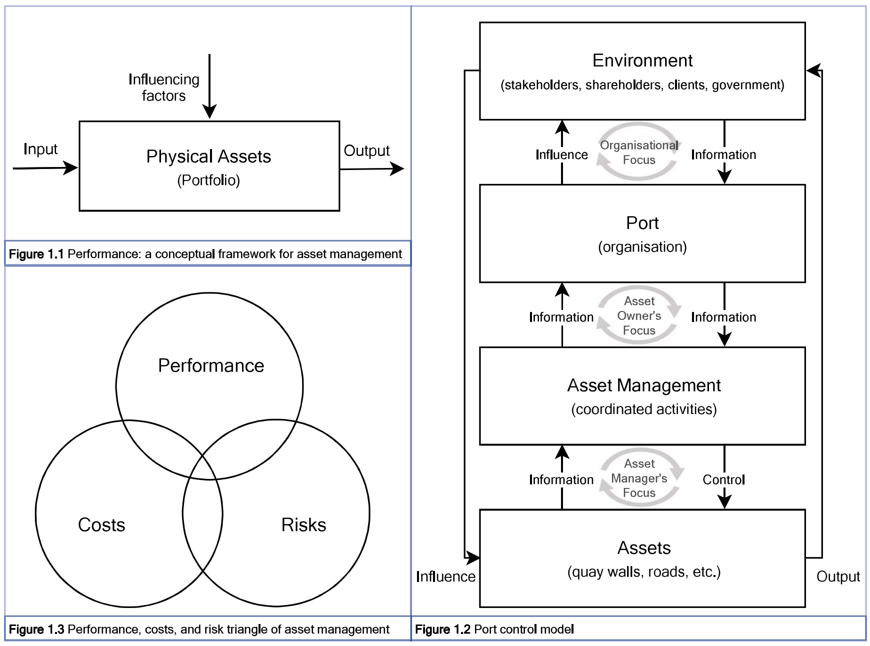


**Figure 1 The guiding principles.** Three frameworks for performance measurements. *Source:* Authors' own elaboration

The benchmark should attribute to value creation, and should match the involved processes when managing assets. Furthermore, the measurements should be controllable, which provides asset managers insights into performance improvement. Following the defined criteria both benchmarks on port and asset level (*what to measure*) are listed in this research.

## Methodology

The design steps of this research are based on the process for systems development research by Nunamaker, Chen, and Purdin (1990), and the design research methodology by Peffers, Tuunanen, Rothenberger, and Chatterjee (2008). The study is conducted and reported according to the diagram presented in Figure 2. The theoretical framework covers elements of the design input, which is used to determine the design requirements and design space. The structure of the model is clearly reflected in the research's methodology, which is chosen because it illustrates the need to define design requirements and space (Herder & Stikkelman, 2004). Drawing on findings from interviews, a benchmarking model for practical use can be obtained. The analytical approach to the findings is rooted in the explanatory nature of the question, namely *what* measurements define asset management performance and *how* can we measure this performance.

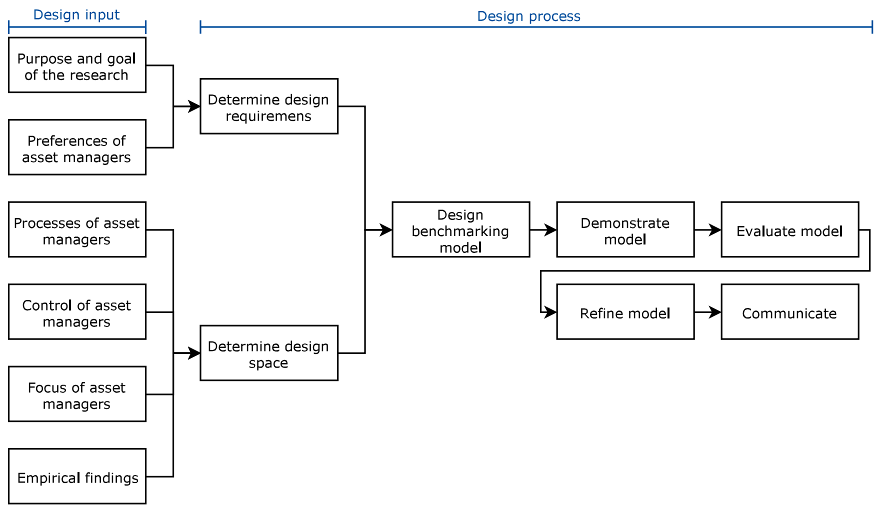


**Figure 2 Design of the benchmarking model.** A methodological guide. *Source:* Authors' own elaboration

To illustrate how the model can be applied to benchmark the performance of asset management, the model is demonstrated by means of a case study. The case setting concerns a small exercise to test the model design. The aim of conducting the case study - a Proof of Concept - is to verify a certain concept to check whether development can be achieved within a given time frame (i.e. six months). Thereafter, the case study is evaluated by assessment on predefined criteria and requirements. Moreover, experts were asked to provide feedback. The main criteria for approaching respondents was that the respondents had to be directly involved in the asset management activities. With the conclusions drawn from this test further steps will be discussed.

## Model design

Having identified the relevant theoretical concepts and a design process, the findings from both literature and expert consultation can be tailored to the specific needs of asset managers. In this section a benchmarking model is obtained, which connects identified criteria (*what to measure*) with a method (*how to measure*) for benchmark development. In model development, the definition of the functions and requirements is made prior to the development to allow for an assessment of the level to which the developed model accomplishes the predetermined goals. However, most of these topics have already been discussed in the approach, particular attention is paid to the design space and requirements.

The design space is a space with major invariant characteristics across all design situations (Goel & Pirolli, 1989). By defining this space the design is delineated to the following areas, which correspond to the research's scope: the focus is on asset management within the port industry, where the case study is focusing on two particular asset types, being port roads and quay walls. Moreover, the design is approached from both a theoretical and asset manager's perspective. Last, the model should take into account that asset managers working in ports worldwide, lacking experience in benchmarking, are going to work with the model.

The design requirements identify a capability or function needed by the model in order to satisfy the needs of the 'customer' (Bahill & Dean, 2009). The design requirements follow from the objective of this paper: *the design of a benchmarking model for asset managers active in the port industry in order to measure and compare performance, and assist ports with the identification of improvement potential of the ports' own performance.* The aim is to develop a generic design process to develop measurements in benchmarking ports on the aspects of asset management. The model should provide clear guidance in benchmark development for specific cases that fit within the design space. One of the sub-objectives is to develop an online platform to share knowledge with other interested (peer) groups worldwide. To achieve this, online dashboards are used to communicate the results, as dashboards can be designed in such way that they provide quick analysis and create informational awareness (Eckerson, 2010). In doing so, the model should provide insights into asset management performance and, eventually, contribute towards greater efficiency.

### What to measure

Following the defined criteria both benchmarks on port and asset level (*what to measure*) are listed in this research. The benchmarks on port level express the differences between ports in terms of size, operations, and activity in and around the port area. These figures provide both information on identified benchmark partners and context for the benchmarks on asset level - which are the measurements for asset management performance.

Each port handles their own structure and format in collecting and storing asset information (IAM, 2015). International comparison on asset level is hardly possible because of the lack of uniform definitions and performance measurement methods. Therefore, asset managers agreed upon international asset information standards, such as the asset description, classification, characteristics, and attributes. Moreover, since assets have different dimensions, the unit of measurement is introduced as a standard for measures of the same quantity. These standards are compiled per asset type in the so-called asset terminology, securing that information is maintained on appropriate quality levels. For this research three generic benchmarks are identified to benchmark on asset level: maintenance costs, condition, and availability. Asset types possess different characteristics, and therefore the generic benchmark are adjusted accordingly.

### How to measure

This research created a user guide (*how to measure*) to guide asset managers in the process of benchmark development. This instruction manual comprises of the following elements: organisational structure, planning, working method, and supporting tools. The organisational structure suggests a clear division of roles within the benchmarking group, which consists of both a working group and a steering committee. The working group prepares information for the benchmark analysis, and sub-groups of the working group should focus on a specific asset type. Throughout the process, the working group should be supported by the steering committee by providing feedback. The specification of the generic benchmarks is performed by the working method as presented in this research. This step-wise method, as presented in Figure 3, follows a sequence of steps, tolerating multiple iterations: brainstorm, define, check, collect, measure, compare, and analyse.

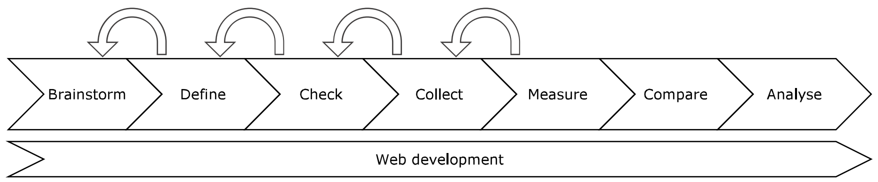


**Figure 3 Benchmark development process.** A step-wise method in development of benchmarks. *Source:* Authors' own elaboration

Asset managers are required to be closely involved in the process. The benchmarks are defined in a performance measurement template. This tool enables asset managers to assemble the required information in a structured manner, as is good practice in developing and using performance indicators (Rozner, 2013). The structured template contains among others, a hierarchical tree which entails decomposition of the measurement. To aim for an attitude directed towards a continuous striving for improvements the DMAIC approach is applied. Five interconnected phases cluster all elements of the template: Define, Measure, Analyse, Improve, and Control (Sokovic, Pavletic, & Kern Pipan, 2010). This approach also highlights the importance of a clear definition, *'if you cannot define it you cannot measure it'*. Neely et al. (1997) collected recommendations for defining performance measures, these suggestions are incorporated in the template.

The resulting framework for performance measurements ensures that measures are clearly defined and are based on an explicitly defined formula and data requirements. As a result, the benchmarking analysis provides in-depth understanding of all aspects involved. A dashboard enables asset managers to measure, monitor, and manage the developed benchmarks. The processing function of the dashboard can be depicted in an IDEF0 diagram, which leads to a structured graphical presentation of an activity (Akasah, Amirudin, & Alias, 2017). Throughout the benchmark development process particular attention is paid to the requirements of the dashboard. The approach of software development advocates adaptive project planning and iterative benchmark development. The so-called agile software development is an approach under which requirements and solutions evolve through the collaborative effort of self-organising and cross-functional teams (Collier, 2012). These characteristics are reflected in the benchmark development process, which enables continuous improvement of the benchmarks. In Table 1 all steps of the process are presented, and check marks indicate who should execute the process step and which tools are required. This comprehensive overview provides asset managers a guide which offers instructions during model development.

**Table 1** Tools and participants required to develop benchmarks.

| **Process** | | | *Brainstorm* | *Define* | *Check* | *Collect* | *Measure* | *Compare* | *Analyse* |
|---|---|---|---|---|---|---|---|---|---|
| **Tool** | Manual | | ✓ | ✓ | | | | | |
| | Performance measurement template | Empty | | ✓ | | | | | |
| | | Filled in | | | ✓ | ✓ | ✓ | | |
| | Properties file | | | | | ✓ | | | |
| | Data template | Empty | | | | ✓ | | | |
| | | Filled in | | | | | ✓ | | |
| | Web application | | | | | | ✓ | ✓ | ✓ |
| **Participants** | Working Group | Generic | ✓ | | ✓ | | | | |
| | | Asset specific | | ✓ | | ✓ | ✓ | ✓ | ✓ |
| | Steering Committee | | | | ✓ | | | | |

Previous applications of benchmarking are listed in the literature review and pitfalls are identified. In order to overcome these pitfalls, the preliminary design of the model provides solutions:

- *Pitfall 1:* delineation of the scope, and a clear focus on 'managing assets', ensures that relevant benchmarks are developed.
- *Pitfall 2:* close attention is paid to explanatory factors and contextual variables of the benchmark. An intensive consultation of asset managers throughout the design phases ensures that the obtained benchmarks results are linked to the underlying activities.
- *Pitfall 3:* the benchmarking model provides asset managers a guide for benchmark development in a collaborative way. The structured process and supporting tools supports the asset managers and ensures that asset managers are closely and actively involved throughout the process.
- *Pitfall 4:* the benchmarking model suggest an in-depth study of a small number of benchmarks by means of a case study. Next to this, the organisational structure of the benchmarking group provides a clear division of roles, of which particular members have a steering role and keep the other members on track towards genuine development of benchmarks.

## Case study and findings

This section describes the case study of asset management within the respective ports, identifies benchmarks, discusses the benchmarking process, and presents the obtained benchmark results. These results will be further discussed in the evaluation phase of this research.

### Case study background

The model is tested by means of a case study consisting of two distinct asset types, the road and quay wall assets, as set out in Table 2. For 2018 test data is collected, and incomplete data sets are supplemented with test data. For the other years sample data is generated, i.e. fictitiously data. The case study method closely examines the data within the specific context (Zainal, 2007). The asset managers which are involved in the demonstration represent the respective ports, namely the Port of Rotterdam (PoR), North Sea Port (NSP), Port of Hamburg (PoH), and Port of Gothenburg (PoG)[1]. The initiative of benchmarking stems from the collaboration between the four ports. Both on an port and asset level generic benchmarks are defined in the model design. A more thorough report is provided of the asset benchmarks, as the benchmarks on port level serve as context variables for these benchmarks. The benchmarks on asset level require a specification based on the characteristics of the regarding asset type. As the asset managers are responsible for either the port roads or quay walls in the harbour area, there is decided to work on a Proof of Concept which contains these asset under management.

**Table 2** Case study sampling.

| | **Case 1** | **Case 2** |
|---|---|---|
| *Asset type* | Road | Quay wall |
| *Port* | PoR, NSP, PoH | PoR, NSP, PoH, PoG |
| *Benchmark* | Maintenance Costs, Condition, Availability | Maintenance Costs, Condition, Availability |
| *Year* | 2018, and fictitiously 2015-2017 | 2018, and fictitiously 2015-2017 |

The specification of the model compromises asset terminology, figures, and benchmarks. Information on these topics is obtained through a collaborative and iterative process, by means of literature review and expert consultation. The benchmarking process pays attention to the collaborative approach of the method, and points out the challenges that came across. The process is at least as important since benefits arose from collaborative process as the value lies in the dialogue before, during, and after the benchmark.

### Specification of the benchmarking model

Particular attention is paid to the quay wall terminology, figures, and maintenance costs benchmark in order to demonstrate how the model is applied in practice. During the case study there is decided to eliminate the availability benchmark from the analysis. Given time and resource constraints, asset managers did not succeed to finalise this benchmark.

#### *Asset terminology*

Table 3 encompasses the asset terminology of the quay wall asset. In order to measure the performance in the same units the unit of measurement is defined in the asset terminology, where all road measures are standardised to square meter and quay walls the metric (running) meter is chosen as unit. In doing so, assets with comparable characteristics are presented in the benchmark overview. Since the unit of measurement of quay walls is meter, which represents the length, there is decided that the height to be characteristic on which the assets are clustered in order to define a classification.

#### *Asset figures*

The asset figures provide information on the portfolio's of the benchmarking partners, this information creates understanding to whom one is benchmarking against and depicts some key characteristics of the portfolio. This information is presented in the benchmark overview of each asset type. Characteristics that are brought to

[1]As Port of Gothenburg does not own road assets, the asset managers solely work on the quay wall benchmarks

**Table 3** Quay wall terminology

| Term | Definition |
|---|---|
| *Quay wall* | Earth-retaining structure at which ships can berth (De Gijt & Broeken, 2013). |
| *Quay wall classification* | Quay wall assets are classified based on construction height. The construction height is the height from the lowest low water line (LLWL) up to the construction depth. The assets are classified in four classes based on construction height ranges: $x \leq 5$, $5 < x \leq 10$, $10 < x \leq 15$, and $x \geq 15$ meter. |
| *Quay wall type* | Quay walls fulfil varied functions, and construction methods therefore also vary. Based on the construction method, four basic quay walls can be distinguished: gravity walls, sheet pile walls, structure with relieving platform, and open berth quays. |
| *Sheet type* | Construction sheets are part of the vertical construction of the quay wall. Categorisation is based on type and material of the construction: concrete, concrete sheet pile, steel combined wall, steel sheet pile, and wooden sheet pile. |
| *Construction year* | Year of construction refers to the year in which the construction of the quay was completed. For quays this is the year they started to use the asset. |
| *Unit of measurement* | Per (running) meter ($m$). The size of the asset is expressed in meters, which represents the length of the quay asset. Consequently, the performance measures are data obtained by measuring against this metric. |

attention are, among others, utilisation of assets, economies of scale, and obsolescence of the asset portfolio. In Figure 4 is depicted how asset figures as defined for the quay wall asset are presented in the dashboard. In addition, the geographical location of the ports is included as it indicates the environmental conditions of the assets.

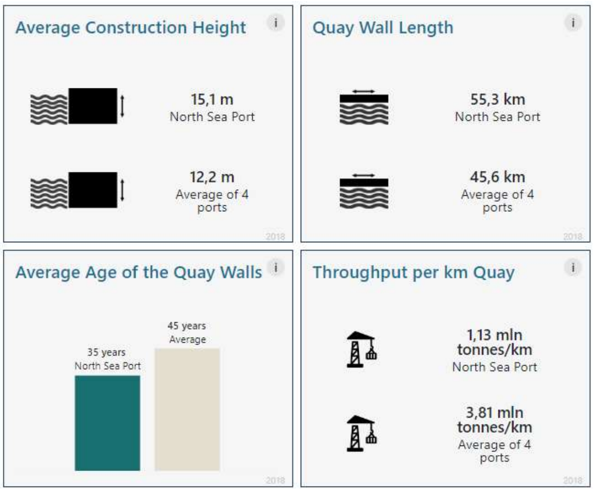


**Figure 4 Quay wall figures.** The visualisation as presented in the dashboard.

*Asset benchmarks*

The asset benchmarks cover the key information of this research, as these measurements provide information on the performance. Based on asset specific characteristics the theoretical definitions are adjusted in order to define the asset benchmarks, and accordingly the benchmarks are presented in the dashboard.

In the case of maintenance costs firstly the theoretical definition is discussed, which concerns the 'Define' part of the DMAIC approach. This benchmark is brought forward, because a major part of the activities involved with asset management are related to maintenance. The position of the benchmark within the framework is as follows: the benchmark concerns a costs ('focus') measure, which is an input ('processes') indicator. Within the port control model it can be positioned as expenses of asset management. The maintenance strategy substantiates which maintenance sources are available and used to manage ('control') the assets. Maintenance within asset management enables the optimal life cycle management of physical assets, by taking care of the integrity for the major part of the life.

The asset's unit of measurement is used as a standard for measurement of the same quantity. Any other quantity of that kind can be expressed as a multiple of the unit of measurement. For this example, when meter is the unit corresponding to quay wall assets, then its costs would be measured by a known currency per meter. The costs related to maintenance activities are delineated to the following activities: corrective maintenance, preventive maintenance, and inspections (IAM, 2015). The distinction between preventive and corrective maintenance can be clarified by stating that asset managers execute preventive maintenance before a failure has occurred. The task can be aimed at preventing a failure, minimising the consequence of the failure, or assessing the risk of the failure occurring. A failure means a breakdown or inability to use the asset, in this situation the asset does not meet its requirements. Besides, the functional failure is the loss of the intended functionality. On the other hand, asset managers can perform corrective maintenance, which asset managers conduct after the failure has occurred. Maintenance costs as stand-alone measurement indicates the yearly costs spent on maintenance, and how these costs evolve over time. In addition the allocation of costs over the different maintenance types provides information on the maintenance strategy. With regard to the data analysis there is decided to use a pie chart, substantiated with the accompanying maintenance methods and frequencies.

In order to define and measure benchmarks in a structured way, a hierarchical tree is included in the performance measurement template. A break down of the benchmark can be found in Figure 5, where the length refers to the unit of measurement. Moreover, a list of filters should be included which allows for customised benchmark analysis. For example asset specific characteristics, such as asset type and construction year, or environmental conditions, such as climate and soil type.

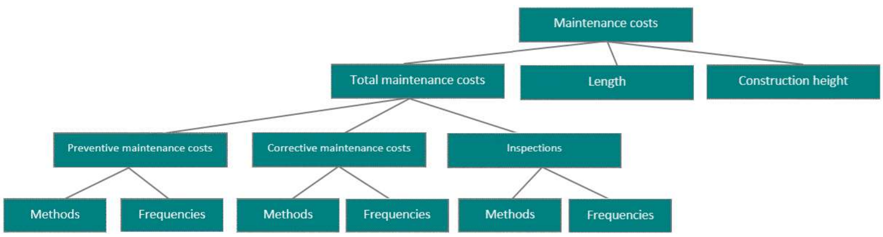


**Figure 5 Hierarchical view of maintenance costs.** The quay wall asset case.

Furthermore, a mathematical formula is provided in order quantify the benchmark, subsequently the identification of the data requirements. The key formula of the benchmark, as depicted in Equation 1, is a weighted average formula. The average costs are derived by multiplying the costs per meter by its weight, which is defined by the length of a single asset divided by the total length of all assets observed. The summation of these values divided by the total weight of all assets is the average as presented in the dashboard.

$$Average\ maintenance\ costs = \sum_{i=1}^{n} \left( \frac{preventive\ maintenance\ costs_i + corrective\ maintenance\ costs_i + inspection\ costs_i}{length_i} \right) * \left( \frac{length_i}{\sum_{i=1}^{n} length_i} \right) \quad (1)$$

### Benchmarking process

Throughout the process of benchmark development, multiple iterations have taken place. The proposed method can be seen as a cyclical process, since all steps can be performed iteratively, as instant feedback turns teaching moments into concrete adjustments. The close involvement of asset managers has its drawbacks, as it proved to be challenges to unify the different perspectives. Points of discussion can be clustered by the following subjects: lack of uniform definitions and their interpretations, issues following from the challenges of an international collaboration, restrictions in resources, and the operational perspective of the asset managers which tempted to go into too much detail. Some notable examples are outlined in this chapter.

Throughout the process it became clear that unambiguous definitions are not to be taken for granted. However, uniformity in definitions and interpretation of these definitions is essential for securing that information is maintained on appropriate quality levels. For example, there was a disagreement on maintenance types, since a few asset managers stated that corrective maintenance is in place when the asset is almost out of function. A more precise definition stated that corrective maintenance is carried out after the failure, whereas preventive maintenance is carried out before a failure has occurred.

Due to restrictions in time it was not possible to include all desired information. Asset managers indicated the importance of the asset utilisation, as this factor has a significant impact on the degradation of the asset. Following from the consultation of experts in the field port's network and planning, and adhering the time constraints, there is decided that it was unfeasible to add this information to the analysis.

The collaborative and international nature of the project has entailed many challenges. The diverse perspectives of the asset managers are explored in the form of group discussions, and it was often challenging to align the different opinions. By sharing thoughts and following the iterative process in the end the asset managers managed to come to an agreement. Decision rules are introduced to deal with the dynamics of group decision-making (Kaner, 2007): in the event of disagreement definitions in literature were decisive, the majority vote helped in decisions on practical matters, and lastly the steering committee has the final vote regarding major decisions. The time constraints set by the goal of Proof of Concept have put strain on the decision-making. The decision rules were a mechanism to make sure a decision was made, and have therefore speed up the process. Moreover, the organisational structure with clear division of roles facilitates the systematic and targeted approach.

### Presentation of benchmark results

Once the required information is defined by specifying the model, this information is processed by the dashboard tool to perform the benchmark analysis. This data processing is shown schematically in the IDEF0 of Figure 6.

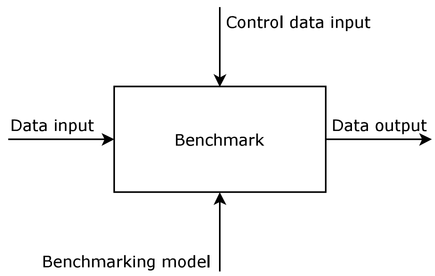


**Figure 6 IDEF0 diagram.** Benchmark analysis facilitated by the dashboard.

Test data is generated to observe whether the model stores and displays the data properly. Although used data is not representative, the theoretical relations are discussed in order to create understanding of how the results can be interpreted. The obtained performance measures can be compared, and therefore the question remains of how to interpret these results. Following the requirements of the model, the benchmark results should provide asset managers insights into performance improvement. Moreover, the model should be straightforward in order to grasp the essence quickly.

Examples of the benchmark's dashboard overviews, as presented in the platform, can be found in the Appendix . Figure 8 shows how the information of the quay wall is presented in the asset benchmark overview. For the example of maintenance costs a more in-depth benchmark analysis is presented in Figure 9[2]. These analysis can be customised according to the desires of the system's user. To perform the analysis, asset managers collected data ('data input'). The data requirements follow from specification of the model in which all required information is listed. For the maintenance costs benchmark the mathematical expression is depicted in Equation 1. The graphics in the dashboard display the performances of ports relative to their peers ('data output'). In the dashboard example of maintenance costs can be seen that for maintenance within Port 2 has incurred significantly higher expenses compared to Port 1. A more profound analysis of this measure is done by comparing maintenance strategies. Port 1 has a more preventive maintenance strategy. Whereas Port 2 has a significant higher share in corrective activities, which may imply a deliberate run-to-failure strategy. With these insights various actions can be considered in order to improve the performance ('control data input'), such

[2]Note: due to confidentially reasons the port names are blinded (e.g. Port 1, Port 2)

as accepting a lower condition level at lower costs (i.e. cost reduction), or a shift towards a more preventive strategy (i.e. change maintenance strategy). Besides, the context should be considered, since factors such as asset characteristics may cause higher costs. An example is the case of ageing assets. When it appears that ageing asset are relatively expensive, replacement of assets on a more frequent basis could be envisaged. The actions as mentioned above or examples of how asset managers could interpret, and act on the obtained benchmark results.

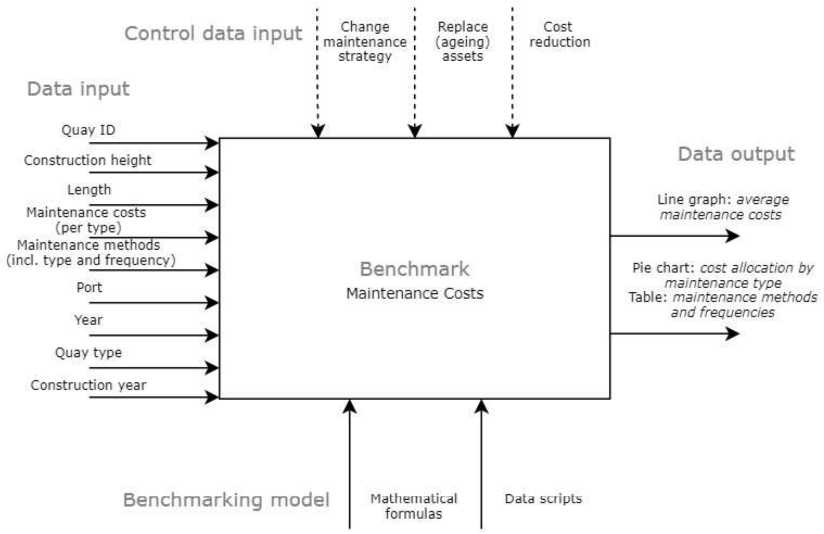


**Figure 7 IDEF0 for the maintenance costs.** The quay wall asset case.

## Evaluation

The validity of the model is explored through both validation and verification: assessment on predefined requirements and design, expert interviews, and evaluation of the process. This is done by and evaluation of the results following from the case study and empirical research.

First, the model is assessed on the predefined requirements and design, which state what is needed to accomplish the predetermined goal. A successful Proof of Concept proved the model is capable to provide guidance in both what to measure and how to measure. The model guides the asset managers in both the selection (*what to measure*) and specification of the benchmarks (*how to measure*). By following the steps of the working method, asset managers are able to develop a benchmarking model. Having made this observations, it can be stated that the design challenges of the research are addressed. Moreover, the model achieved the necessary degree of compliance with the design requirements.

Second, the model is reviewed by both by 'internal' experts, the asset managers which participated in the case study, and 'external' experts. Prior to the evaluation, these external experts were not involved in the benchmarking project, and thereby they provided expert and objective assessment. This expert panel forms a representative group composed of asset managers, asset owners, and other experts in the research area. According to both expert groups the model provides a suitable method for collaborative benchmarking. Information on performance was obtained through an in-depth analysis, using both quantitative and qualitative data. This information is presented in an easily analysable and comprehensible form. As a result, the dashboard gives interesting insights into the operations, which is perceived as refreshing by the asset managers. The model is not yet suitable to provide accurate insights into performance, since the results are dependent on multiple characteristics which are not included in the Proof of Concept. This last point also pertain to one of the study's limitations. This study being a case study within a specific context, the findings might not be generalisable to other contexts. Further research could address this limitation, as further development of established benchmarks and adding new benchmarks is desirable to receive all benefits. With regard to the existing benchmarks, the need for a more profound analysis by adding contextual variables and valid data is given priority. However, the insights gained from the benchmarking process and results are considered to be valuable. The benchmarking process supported the asset managers throughout the process, by providing a structured approach which managed to overcome, or in some cases reduce the impact of issues following the, the pitfalls. The benchmarks results are indicators of their relative performance, which stimulated ports to have a critical look at their current operations. To conclude, the model is sufficient for basic analyses and is perceived as added value by the (prospective) users of the system.

## Discussion

Having discussed the implications of the case study findings for practice, some remarks are in order regarding the implications for research and the limitations of the study.

The review of existing literature shows that this study is the first to explore in depth the possibilities for comparing port's performance on aspects of asset management. In doing so, this contributes several new insights to existing knowledge, with useful implications for academic research as well as practices with regard to port's asset management. In line with the two design challenges formulated in the introduction, this study set out to understand the criteria of proper benchmarks following the needs of the asset managers. Moreover, this paper imposes a benchmarking method in order to assist asset managers in the development of benchmarks in a collaborative way. Multiple challenges were identified and aligned with the characteristics of the model design. The need to address this issues is illustrated by examples of challenges that came across in the real-life context sketched out in the case study. Regarding various areas, a general conclusion is that a more profound study is required to achieve the full benefits of the benchmark results. The study findings highlight the importance of close involvement of the benchmark partners as the value lies in the dialogue before, during, and after the benchmark. This statement pertains to the benchmarking process, which is an important strength of the model design, as asset managers were continuously involved to verify the validity of the model.

The restrictions and time and resources play an important role in the decisions made with regard to the scope, and therefore only a small exercise is conducting in testing the model. The case study considers two asset types and succeeded to define two distinct benchmarks for each type. The findings from this study might therefore not be directly generalisable to other cases. Follow-up research is recommended to determine whether other asset types and benchmarks, for example the availability benchmark which is not included in the benchmark analysis, can be developed. However, the benchmarking model and its process proved to be effective in providing a structured guideline. The theoretical underpinnings of the model, i.e. the conceptual framework and processes, facilitate a structured approach on benchmarking. Moreover, the theoretical relations as presented in the dashboard seem promising, as asset managers are able to link the results of the benchmark analysis to their asset management strategy.

Another limitation of the study is that, due to restrictions in time, it did not lend itself well for quantification. The study's case partly used test data and therefore the obtained results should be interpreted with caution. Therefore it is not possible to draw conclusions from the relative performance. In case more ports are incorporated in the analysis, depicting the minimum and maximum value of the benchmark results can be interesting. An outlier can affect the average of a data set by skewing the results so that the mean is no longer representative for the data set. Moreover, it is recommended to include statistical analyses in further research. For example a standard deviation, as this is a measure of the spread of scores within a data set. The standard deviation could be introduced in order check whether the average is representative. If all numbers all close to the average a low standard deviation is observed. Further research can be geared towards this analysis consisting of larger amounts of data, and by incorporating statistical methods.

## Conclusions

The study's findings illustrate the complexity of obtaining a benchmarking model which is relevant for operational purpose. In order to align both theory and practice, a benchmarking framework by integrating findings from literature review and expert consultation. The resulting model lays a solid foundation for international benchmarking, using grounded theory. The set of criteria that indicates the asset management performance is reflected in the guiding principles. Benchmarks for asset management performance are positioned within three theoretical frameworks, that cover the following aspects of asset management: the processes of asset managers, control of asset managers, and the focus of asset managers. In order to measure the performance a model is designed to provide asset managers a guideline for the specification of this benchmarking model.

This study is an integrated approach of four streams in literature: benchmarking, performance measurement, asset management, and ports. Besides the unique combination of these topics, the benchmarking model is novel for the following reasons:

- *Operational perspective:* the perspective of the user of the system, the asset managers, left a significant mark in the model design. The model framework ensures that benchmarks reflect the performance of 'managing assets' in ports.
- *In-depth benchmarking analysis:* previous benchmarking models generally focus on single measurements, where this research provided a model for in-depth analysis of benchmark. Close attention is paid to explanatory factors and contextual variables.

- *Collaborative design:* as limited research is available, the benchmarking model is obtained through consulting asset managers. As a result, the model is retrieved in collaboration with experts by adapting existing theories. Because of the international nature of this study, asset managers have agreed on international standards for benchmarking.

The *benchmarking process* facilitates a collaborative design for the development of benchmarks. As a result, asset managers share knowledge before, during, and after the benchmark analysis.

The *benchmarking model* provides a standardised approach on the definition of benchmarks. In doing so, a replicable and standardised method is provided. The model is scalable als various benchmarks for different asset types can be created. The model is based on theoretical frameworks and methods, which have been adapted through intensive consultation of asset managers, the end users of the system. As a result, the perspective of the asset managers is considered throughout the design process. Next to the performance measurement, both the underlying activities and its context are included in the benchmark analysis. The resulting model supports asset managers in developing benchmark to obtain insights into performance improvement.

This research has several limitations which suggests some avenues for future research. The first limitation is the lack of data and the reliability of the available data. In addition, there was limited time and therefore only a small exercise is conducted in testing the model. As a result, opportunities for further research lie within the inclusions of more context variables in the analysis of the current benchmarks. These variables may explain the benchmark results and provide a more profound analysis. Next to this, this model considers a small selection of asset types, benchmarks, and ports. Further development of the model can be realised by introducing other asset types, developing other benchmarks, and attracting different benchmark partners. In the long run, it may be of interest to link the benchmark results of various departments, both within the overarching asset management department as within the entire organisation of the ports. In this manner the relations between organisation's strategic, tactical, and operational level can be outlined. This research focuses only on a small part of the port control model. The port control model is a class of abstracts systems, each consisting of a controlled part, an environment and a controller. This control model especially directs attention to the dual control-relationships between an organisation and its environment (De Leeuw, 1982). However, when considering additional subsystems and relations, more (asset management) departments should be involved in the benchmarking process. Besides the fact that in this case other theories should be selected, the benchmarking process will become more challenging and complex.

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**Confidentiality**
Due to confidentiality agreements, this report contains modifications in the contents and part of the information is excluded.

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## Appendix

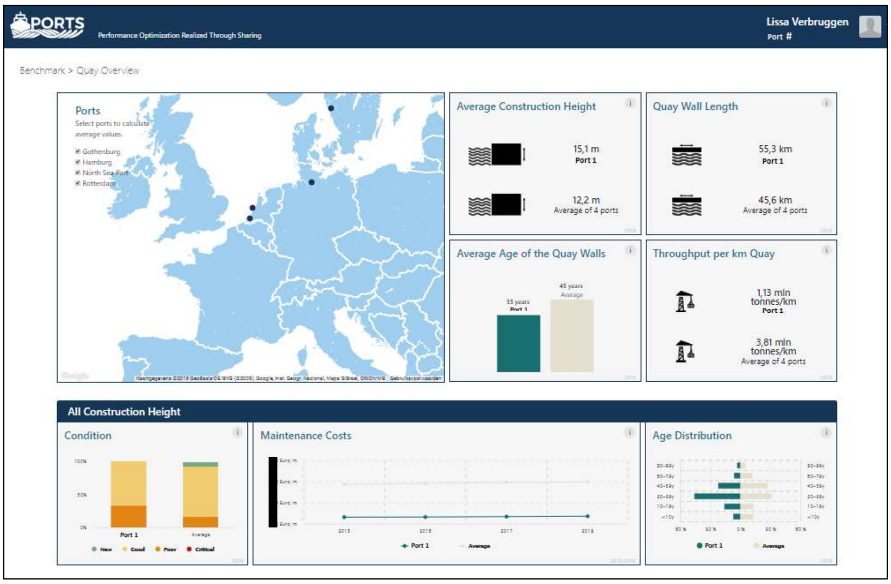



**Figure 8 Overview of the asset benchmarks in the dashboard.** The quay wall asset case.

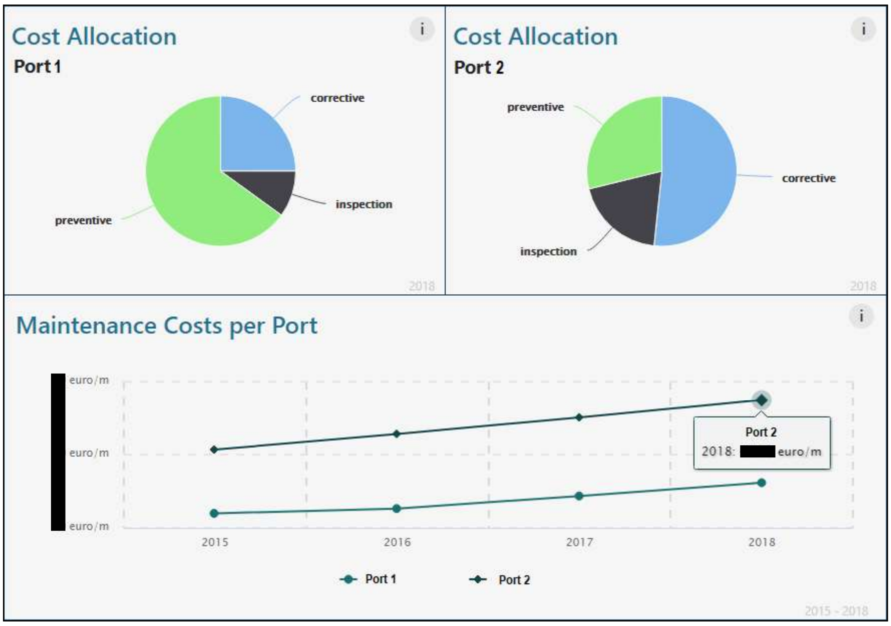



**Figure 9 In-depth analysis of the maintenance costs in the dashboard.** The quay wall asset case.

# B

# Asset Terminology

As ports hold different definitions and standards it was necessary to define international standards on asset information. These agreements are laid down in the asset terminology. This terminology is a guideline for proper collection of asset information for the purpose of international benchmarks.

## B.1. Road Terminology

**Road:** line of communication (travelled way) open to public traffic, built for road motor vehicles to travel along, using a stabilised base (hard surface) other than rails or air strips. Considering the cross section of the road. Only the *top layer* of the construction is selected. The superstructure of the roads, and not the foundation and soil. This is particularly important when considering the condition and maintenance costs of the road. Figure B.1 shows examples of road constructions, the layers that are marked red are considered as elements of the road asset type. In addition, not all parts of the road in vertical direction are taken into account. The part of the road that is analysed is the carriageway (or *roadway*), which is the part of the road intended for movement of road motor vehicles, exclusive of shoulders and auxiliary lanes (Figure B.2). Parts of the road intended for road vehicles which are not self-propelled or for parking of the vehicles are not included. In short, it considers it considers the width of the pavement way on which vehicles travel (EUROSTAT, ITF, & UNECE, 2009). Figure B.3, presents the cross section in which the roadway is specified.

**Road asset classification:** classification based on the material type. Road surface material has been classified into three common types: asphalt, concrete and (block) pavement. Comparing assets per material type contributes to a proper comparison:

1. *Asphalt:* specifically asphalt concrete. Asphalt is also known as bitumen, a sticky, black, and highly viscous liquid or semi-solid form of petroleum. Depending of the temperature at which it is applied, asphalt can be categorised as cold mix, warm mix, or hot mix. An advantage of this material is that the roadways include relatively low noise and cost compared with other paving methods, and perceived ease of repair. Disadvantages include less durability and the tendency to become slick and soft in hot weather.
2. *Pavement:* block pavement of concrete pavers/blocks. Block is a similar term referring to a rectangular unit composed of similar materials. An example of a disadvantage are the relatively high costs compared to other material types.
3. *Concrete:* surface is created using a concrete mix of cement, coarse aggregate, sand, and water. Three common types can be distinguished: jointed plain, jointed reinforced, and continuously reinforced. The differ in the jointing system used to control crack development. Concrete pavements are typically stronger and more durable than asphalt roadways. A notable disadvantage is that they can have higher initial costs.

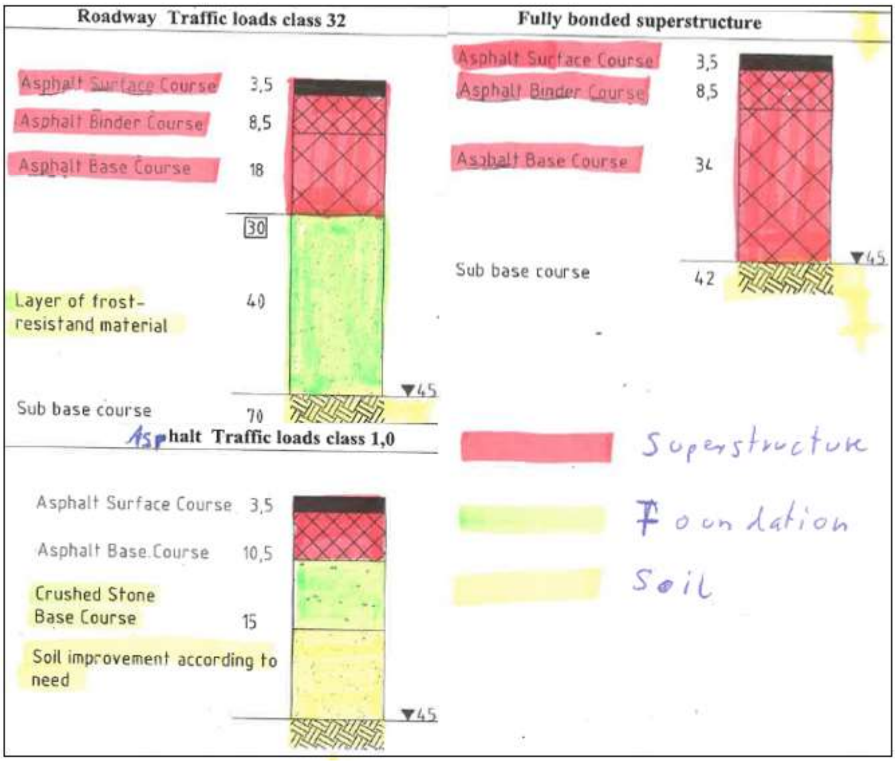



Figure B.1: Layers of the road construction

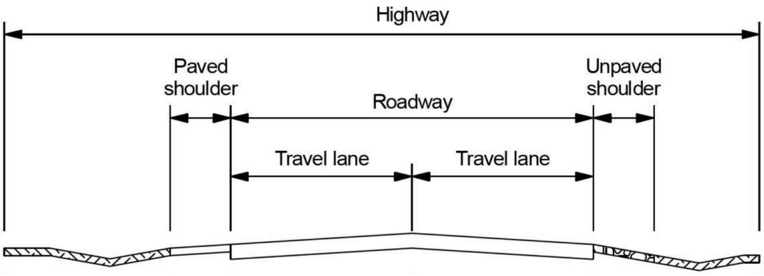



Figure B.2: Roadway and shoulders (Shanteau, 2013)

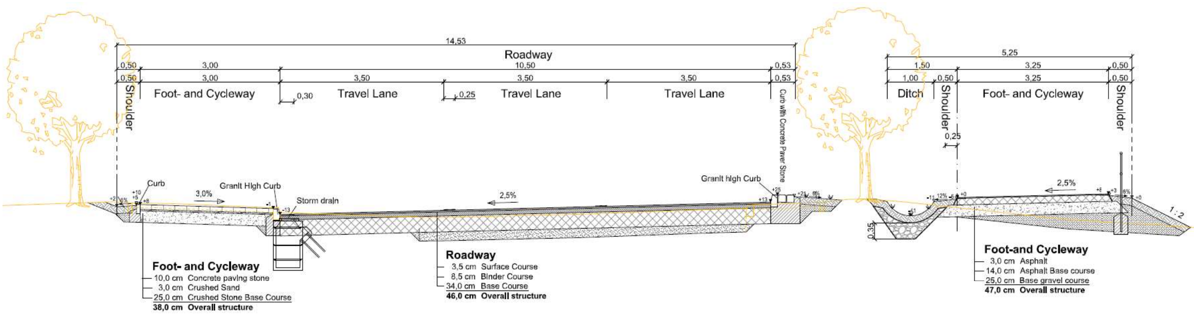



Figure B.3: Cross section: roadway

**Soil type:** the top layer of the earth surface, the natural underground. One of the physical factors that has influence on the degeneration of the asset is the soil type. The rate of erosion is determined by several factors, including soil type. Each kind of soil type different characteristics. Different types of damage and degrees of damage will appear. Three types of materials are distinguished: sand, peat, and clay.

**Construction year:** year of construction refers to the year in which the construction works were completed, and from the year in which the road is ready for use. For roads the year of foundation construction.

**Unit of measurement:** per square meter ($m^2$). The size of the asset is in square meters. Besides, all performance measures will measured against this metric.

## B.2. Quay Wall Terminology

**Quay wall:** earth-retaining structure at which ships can berth (De Gijt & Broeken, 2013).

**Quay wall asset classification:** the assets are clustered following the defined construction height ranges. The construction height is the height from the lowest low water line (LLWL) up to the construction depth. The construction height is shown schematically in figure B.4. As the unit of measurement for quay walls is the length in (running) meters, asset managers decided that asset classification should be based on the asset's construction height. For example the maintenance costs per meter will differ following the difference in construction height. Construction height ranges in meter:

- $x \leq 5$
- $5 < x \leq 10$
- $10 < x \leq 15$
- $x \geq 15$

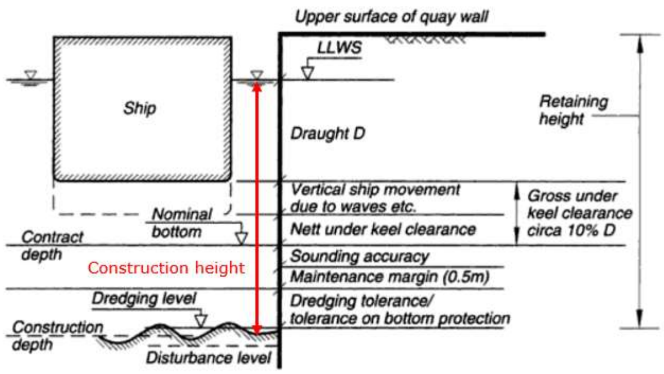



Figure B.4: Construction height

**Quay wall type:** to fulfil the varied functions of quay walls different construction methods have arisen over the years. Based on the construction method, four basic quay wall types are distinguished (De Gijt & Broeken, 2013):

1. *Gravity walls (Gravity Wall):* retaining function is obtained by the own weight of the structure, sometimes including the weight of the soil lying above the structure. Examples include the L-wall, block wall, caisson wall, cellular wall, and reinforced earth construction.

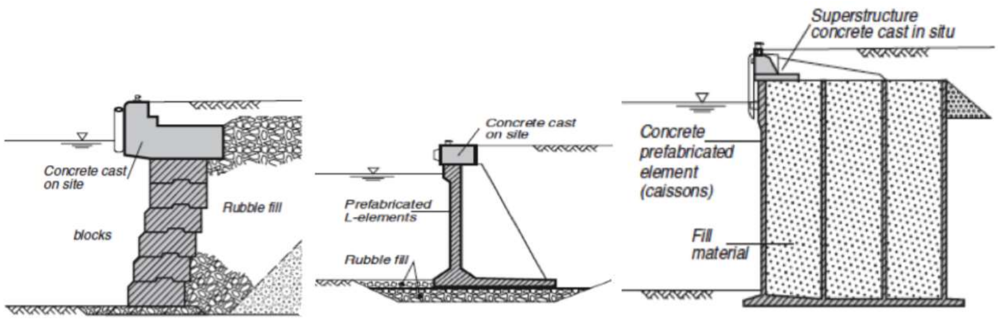



Figure B.5: Gravity wall structures: block wall, L-wall, and caisson wall (De Gijt & Broeken, 2013)

2. *Sheet pile walls (Sheet Pile):* soil retaining function is obtained from the soil pressure, combined with the anchoring system, and from resistance of the wall against bending moments and transverse forces. Examples include anchored sheet piles, combined walls, diaphragm walls, and cofferdam.

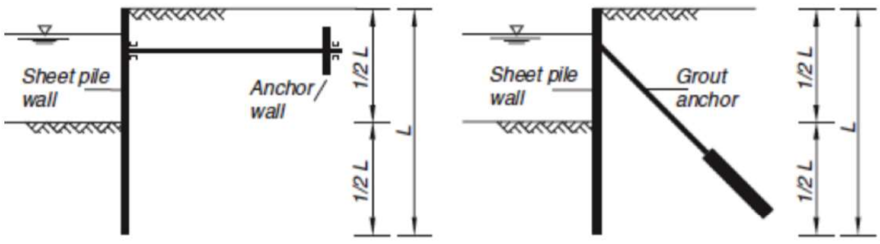



Figure B.6: Sheet pile wall structures: anchored sheet piles (De Gijt & Broeken, 2013)

3. *Structure with relieving platforms (Sheet Pile with Relieving Platform):* in fact also a sheet pile wall. The forces on the underlying retaining wall and the tensile forces in the foundation are highly reduced by the relieving platform. Two sub-types can be distinguished, being structures with a high and a deep relieving platform.

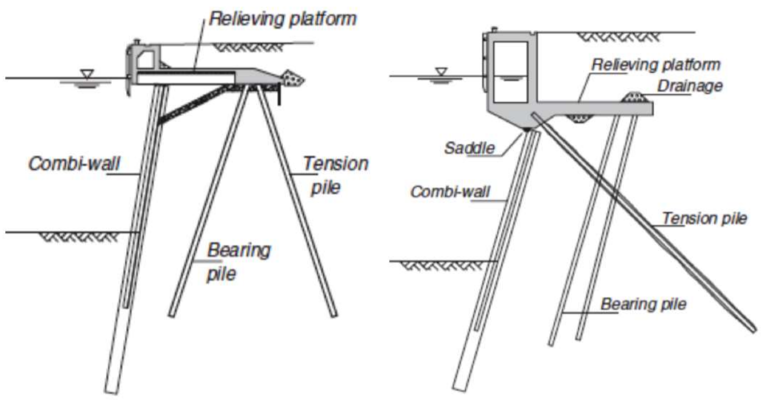



Figure B.7: Structure with relieving platforms: high and deep relieving platform (De Gijt & Broeken, 2013)

4. *Open berth quays (Open Berth Quay):* jetty-like structures consisting of a deck on piles that extends over a slope.

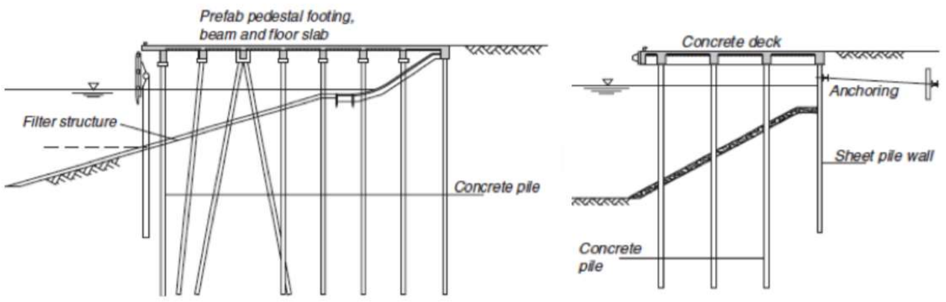



Figure B.8: Open berth quays: without and with retaining wall (De Gijt & Broeken, 2013)

**Sheet type:** sheet pile systems of the quay walls are categorised in five different types. These types define the construction sheet types. The construction sheets are part of the vertical construction of the quay wall. The categorisation is based on the type and material of the construction (De Gijt & Broeken, 2013):

1. *Concrete:* or diaphragm wall, is a reinforced concrete wall that is made on site, where the quay wall is to be constructed.
2. *Concrete sheet pile:* single sheet piling, sheet pile wall made of concrete (flat profile or U-profile).
3. *Steel combined wall:* combined sheet piling, combined wall consists of heavy primary elements deeply embedded in the subsoil at a set distance from each other.
4. *Steel sheet pile:* single sheet piling, sheet pile wall made of steel (U-profile, H-profile, or Z-profile).
5. *Wooden sheet pile:* single sheet piling, sheet pile wall made of wood (flat profile). Only used for small structures.

**Construction year:** year of construction refers to the year in which the construction of the quay was completed, and was ready for use. For quays this is the year they started to use the asset.

**Unit of measurement:** per (running) meter ($m$). The size of the asset is in meters. All performance measures will measured against this metric. The height of the assets is covered by the classification of the asset.

# C

# Performance Measurement Selection

## C.1. Results from Previous Attempts

A group of asset managers, as mentioned in Section 2.1.1, worked on a benchmarking model. The variables listed by this group are taken into considering. Note: brainstorm sessions without the predetermined list have taken place, to ensure a fresh start without being biased.

Predecessors of the current benchmarking group for this research, defined and categorised a list of variables which they called KPIs. This list can be found in the table below. Each indicator is stated whether it is a Performance (P), Costs (C), or Risk (R) KPI.

Table C.1: List of KPIs for benchmarking: performance, costs, and risk measures

| Assets | Type | Asset Management | Type | Asset Management System | Type |
|---|---|---|---|---|---|
| Condition | R | Mean time of repair | P | AMS cost/total replacement value deviation | C |
| Availability | P | Number of complaints | R | AMS satisfaction | P |
| Performance | P | Disruption time | P | Internal treatment time | P |
| Customer appreciation | P | Residual/standard lifetime | C | Number of inspections in time / inventory up-to-date | R |
| OPEX | C | Annual OPEX/CAPEX (e.g. 1,5%) deviation | C | Management reporting | P |
| Downtime | R | Compliance | R | Availability information | P |
| Remained lifetime | P | Mean time between failure | P | Timing/Planning to full AMS | P |
| Residual asset value/replacement value | C | Reliability | P | Deviation of predicted budget | P |
| Percentage of assets in criticality index | P | Number of incidents, accidents | R | | |
| Safety factor | R | Availability when needed | P | | |
| Time in use when available | P | Percentage risk analysis available | R | | |
| Yield (e.g. ton/k€ replacement value) | P | Cost effectivity | C | | |
| | | Curative/predictive maintenance | C | | |
| | | Number of high/unacceptable risks | R | | |

## C.2. Brainstorm Sessions - General

To understand the area of research and the needs of the asset managers, multiple brainstorm sessions have taken place. During this sessions the results from previous attempts and existing benchmarks from literature were discussed. The scope of this research is smaller than last time. Therefore only the KPIs in the asset column (or asset management) column of Table C.1 are interesting.

In the first place many approaches on the generation of performance measurements have are discussed. The hierarchical approach, Multiple Measurements Approach, and the Single Measurement Approach are discussed in the following sections. All lessons learned are taken into account for the development of frames in Chapter 2, and in Chapter 3, a more practical approach.

### C.2.1. Hierarchical Approach

The basic principles of asset management and performance measurement are identical (Steudle et al., 2012). Performance-based asset management applies the principles of performance measurement to the management of (physical) assets. The hierarchical view of the objectives and performance indicators represents the line of sight. In Figure C.1 this hierarchy is presented, the organisational objectives, asset management objectives, asset management activities, and performance indicators (Arthur et al., 2016).

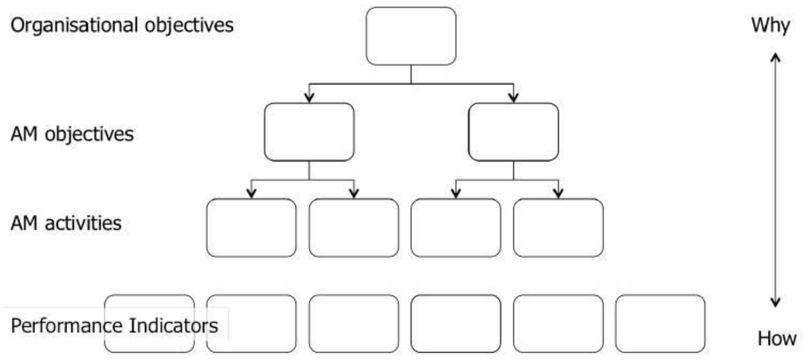



Figure C.1: Asset management as hierarchical performance measurement (Arthur et al., 2016)

For the purpose of asset management, efficiency needs to be achieved, while balancing performance, costs and risk. The main motive for asset managers to join the benchmarking group, is that they want to learn from other asset managers and increase their efficiency. Efficiency may be broken down into costs, performance, and risk. For each term various performance indicators can be defined. The structured approach of defining what to measure, can be subdivided into two different approaches. The top-down approach ensures all aspects of asset management are involved. The bottom-up approach, is a brainstorm of the BAM (Benchmarking Asset Management) group, which consists of asset managers that come up with interesting measurements. This concept is presented in Figure C.2.

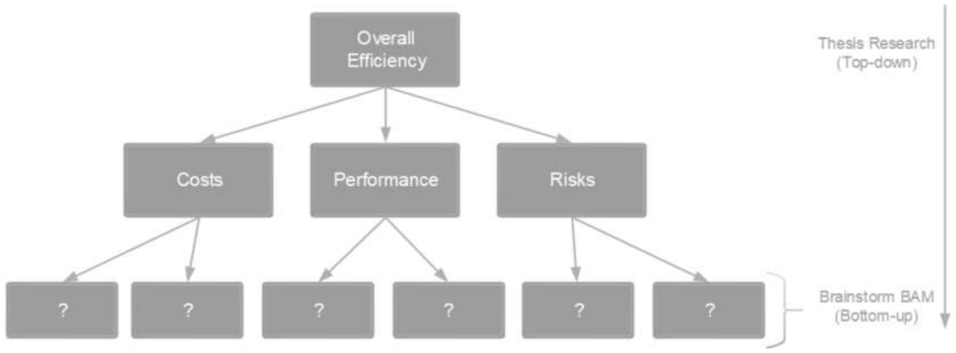



Figure C.2: Structured approach for defining measurements

Measurements such as maintenance costs and port calls are the results of brainstorm sessions with asset managers. Subsequently, predefined relationships are identified. The selected input-output variables, should also differ in category (costs, performance, and risk). An example of the combination of single measurements is presented in Figure C.3.

The example presented in Figure C.3 shows the idea of the analysis of multiple measurements. For both maintenance costs and port calls the measurements should be standardised, for example per meter. By defining quantifying the measurements per unit of measurement they can be analysed and compared. The hierarchical approach on its own turned out to be not that effective and helpful. The requirement for defining relations and seeking for measurements for the three predefined categories resulted in strange and less use-full measurements. Next this it was difficult to pick measurements and compose pairs, as they often are ambiguous. An interesting conclusion however is the importance of relations among measurements, and that it is important not to forget about: performance, costs, and risk.

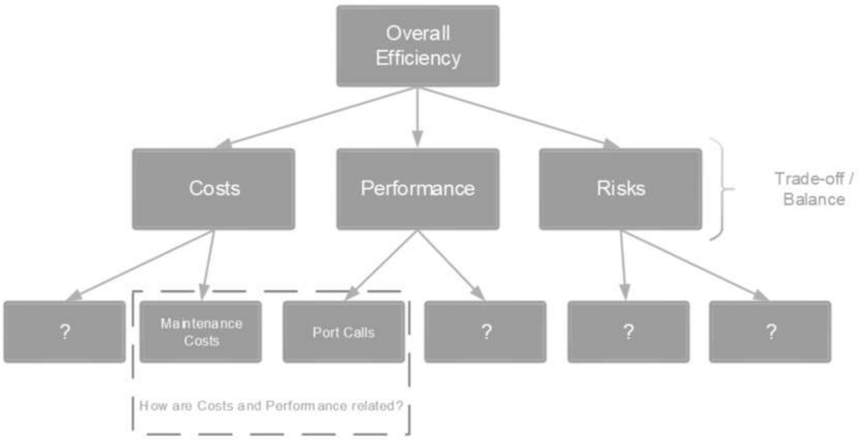



Figure C.3: Performance measurements and the asset management trade-off balance

### C.2.2. Multiple Measurements Approach

Asset management strategy and measurements can be analysed in different manners. Asset managers stated that they are interested in the effect of their strategy on multiple measurements. The starting point of this approach was the discussions on some questions that were submitted to the asset managers:

- *What* do you need?
- On what *level of detail* do you want to have information on the information you need?
- *Why* do you need it?
- What is the *added value* of the proposed measurement?

Following this questions the maintenance costs, and the break down of the various cost types, was defined. Two alternatives (A and B) where constructed and the measurements in relation to this alternatives were discussed. One of the alternatives was a preventive strategy and the other a corrective strategy. Following these strategies, among others, the condition, costs, asset characteristics, and occupancy rate of the asset were listed. The result of this approach is presented in Figure C.4, a photo of a whiteboard.

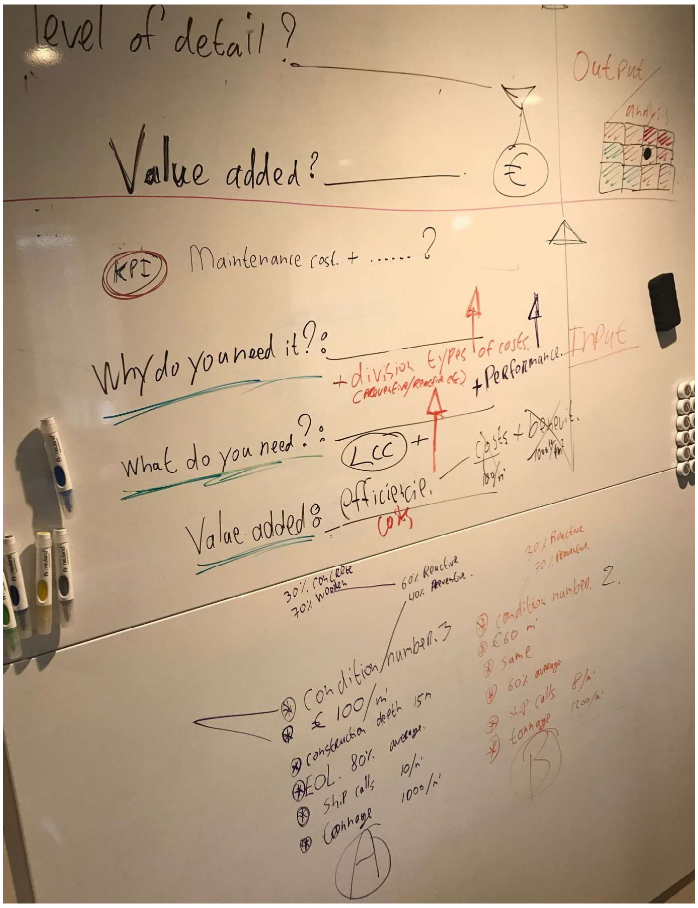



Figure C.4: Construction of alternatives for maintenance costs

The evaluation of this approach has provided useful insight of what is of importance for asset managers. The relations among variables, or influencing factors, are necessary for the understanding of a single measurement. The following approach focusing on the development of single measurements, and creating context for a more detailed and valuable analysis.

### C.2.3. Single Measurement Approach

The brainstorm sessions for the previous approaches created much confusion. The complexity of asset management emerged clearly. Moreover, the number of measurement was too large, focusing on a single measurement in the first place may be the solution. The starting point was to brainstorm on measurements that would give interesting insight both as stand-alone measurement and as benchmark.

For the quay wall and road asset type a first selection is made on performance measurements. The selection was discussed with the web development company to explore the possibilities for a dashboard. These selection is presented in a Mock-Up dashboard. The benchmarks defined in the case study will be presented in a improved version of the mock-up dashboard, the final dashboard is called 'Proof of Concept'. The selection, for the mock-up, following the single measurement approach is as follows:

- Asset EOL range: percentage of the assets within the theoretical end of lifetime (EOL) range
- Maintenance costs: costs for asset maintenance
- Cost control: maintenance costs relative to replacement value of the assets

Lessons learned: consistency in measurements would help to make full use of the advantages that a divers team of asset managers is able to give feedback on the developed benchmarks. Furthermore, some additional concepts and theories need to be collected to ensure that valuable and measurable measurements are created.

Furthermore, it was concluded that the measurements should be controlled by asset managers. Alone-standing measurements on a lower level are preferred. The data and information required for the measurements was not always in the reach of the asset managers. In addition, the measurements should be operational, for example cost control is a typical strategic measure.

Asset managers find *condition* one of the most important performance measurements, as many activities are involved with managing this condition. Furthermore, the *maintenance costs* is highly related with this measurement. The measurement maintenance costs lends itself for a more detailed analysis as a break down of the costs and activities of these costs show how asset managers maintain their assets. Another measurement, is *availability*, which is also a performance variable. The availability is of high importance for the outcome. The accessibility of the ports has a significance influence on the port's attractiveness.

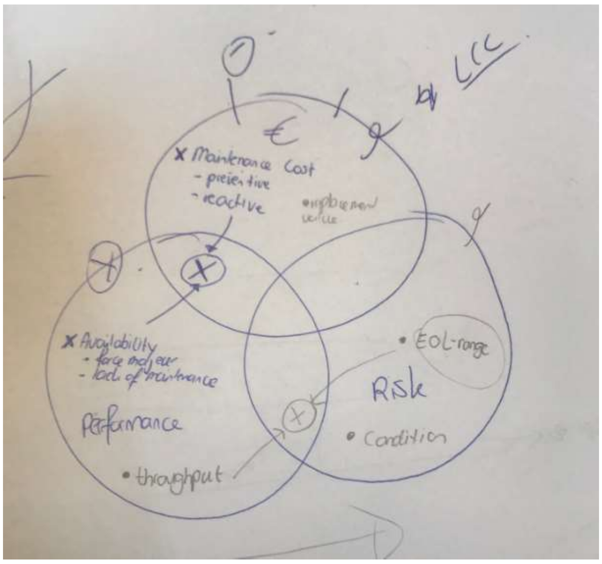



Figure C.5: Single measurements and related measurements

# D

# Participants of the Benchmarking Group

## D.1. Organisational Structure of the Benchmarking Project

The organisational structure of the benchmarking group provides asset managers a division of roles between the working group and steering committee. For the purpose of this research two asset types are included:

1. Asset type 1: Road
2. Asset type 2: Quay Wall

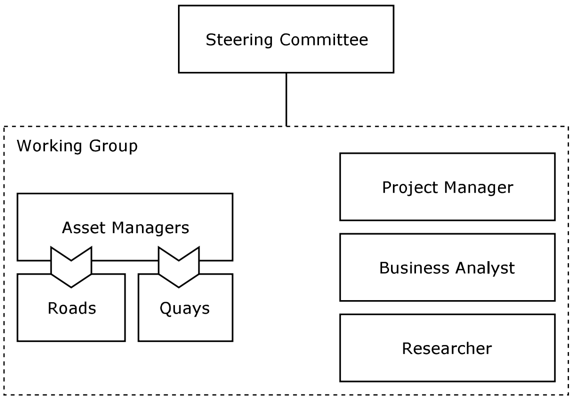



Figure D.1: Organisational structure of the benchmarking project

## D.2. Working Group

Multiple brainstorm sessions have taken place with a group of *quay wall asset managers*. Note all members of the quay wall group are also part of the working group.

Table D.1: Interviewees asset management quay walls

| | **Function** | **Port** |
|---|---|---|
| 1. | Asset Manager Quay Walls and Embankments | Port of Hamburg |
| 2. | Asset Manager Constructions | Port of Rotterdam |
| 3. | Manager Civil Works, Infrastructure | Port of Gothenburg |
| 4. | Junior Project Manager, Infrastructure | Port of Gothenburg |
| 5. | Asset Manager | North Sea Port |
| 6. | Information Analyst | North Sea Port |

Multiple brainstorm sessions have taken place with a group of *road asset managers*. Note all members of the road group are also part of the working group.

Table D.2: Interviewees asset management roads

| | Function | Port |
|---|---|---|
| 1. | Asset Manager Roads | Port of Hamburg |
| 2. | Head of Asset Management Roads | Port of Hamburg |
| 3. | Asset Manager Infrastructure | Port of Rotterdam |
| 4. | Asset Manager | North Sea Port |
| 5. | Information Analyst | North Sea Port |

## D.3. Steering Committee

The steering committee is responsible for monitoring the quality of the project as it develops. They have provided the advice about changes to the project as it develops. Together with the participants of the working group proposals on benchmarks are established. The steering committee, which are also experts on asset management, operations, and the maritime industry, have given feedback on what was developed. This 'external validation', was an important method to check whether the result of countless discussions was sensible and reasonable. The did not work on the development of the benchmarks themselves, and had an exclusively advisory role in all this.

Table D.3: Members Steering Committee

| | Function | Port |
|---|---|---|
| 1. | CTO | Port of Hamburg |
| 2. | Manager Maintenance & Operations | Port of Hamburg |
| 3. | Asset Manager Infrastructure | Port of Rotterdam |
| 4. | Asset Manager Port Infrastructure | Port of Rotterdam |
| 5. | Vice President Infrastructure | Port of Gothenburg |
| 6. | Senior Technical Advisor | Port of Gothenburg |
| 7. | Director Infrastructure | North Sea Port |
| 8. | Head of Asset Management | North Sea Port |

# E
# Performance Measurement Template - Initial Version

Towards the final version of a performance measurement template many iterations have taken place. The template was discussed prior to the demonstration. During the demonstration phase, in which die benchmarks for the Proof of Concept were defined, also some changes are made. In this initial version (Figure E.1) did not fulfil all requirements for a clear defined performance measurement, since it doesn't include:

- All aspects of asset management
- All information needed for analysis (measure and compare) and dashboard development
- Sufficient detail on the benchmark

These aspects are explored with expert interviews, testing, and literature review. The result is a more comprehensive and user-friendly template as presented in Appendix G.

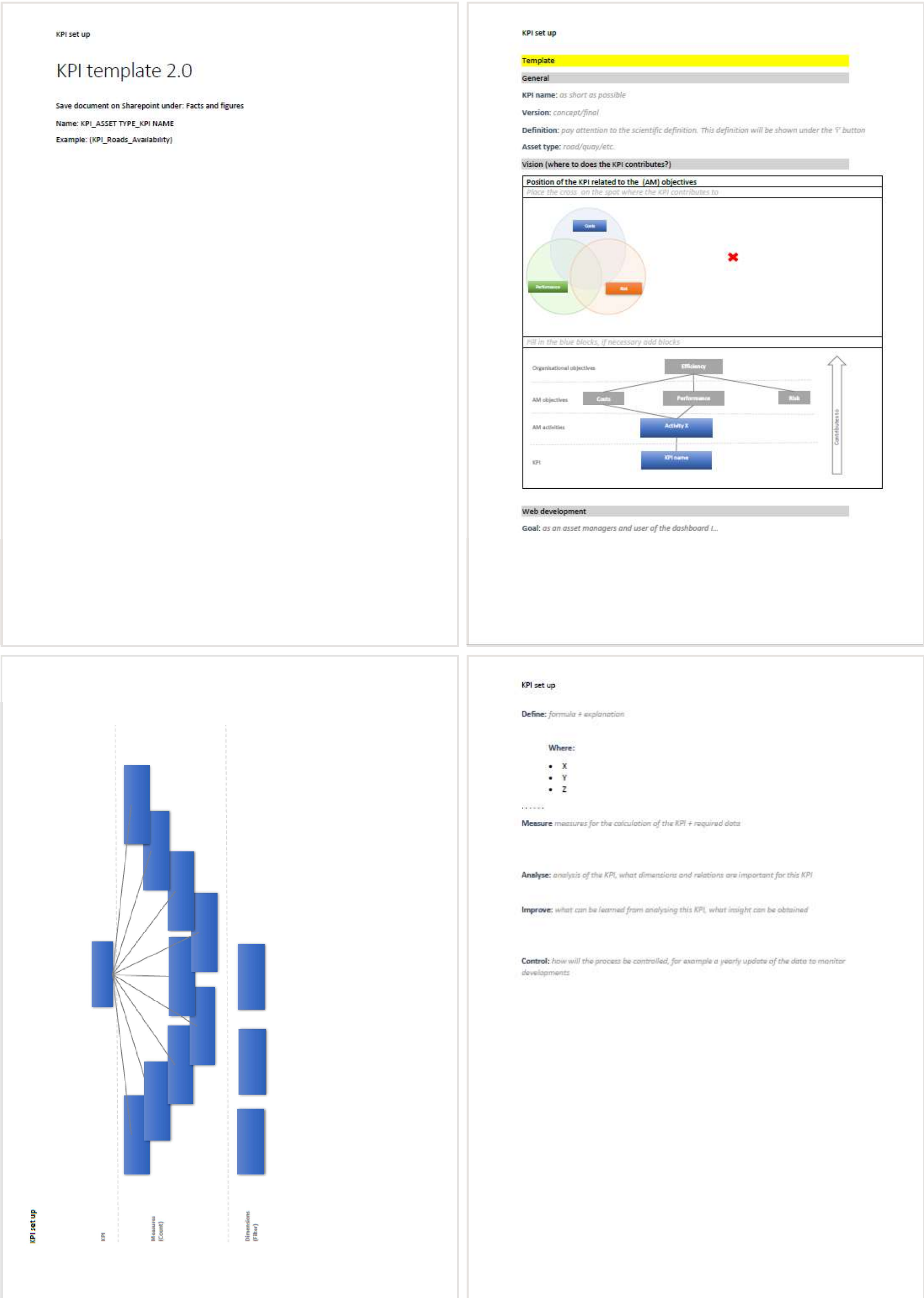



Figure E.1: First draft performance measurement template

# F

# Elements of the Final Performance Measurement Template

All information required for the asset benchmarks is defined in this template. In the template some parts are labelled with a rectangle containing </>, this symbol highlights what information is relevant for the web developers (Figure F.1). The symbol can be found in the final template presented of Appendix G. Together with the web developers a platform is built. The template is divided into the five elements of an improvement cycle: Define, Measure, Analyse, Improve, and Control (Sokovic et al., 2010). By filling out the template in some cases a question can be answerd. These questions are included as well.

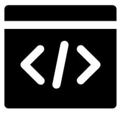


Figure F.1: Icon web development

► **Define**

The following questions is addressed in the 'Define' part of the template: *What do we measure?*

<u>General Information</u>

- Benchmark name: as short as possible. Title of the measure should be clear and concise. Self-explanatory and not include functionally specific jargon (Neely et al., 1997).
- Version: concept/final. It should be clear whether the template is finalised.
- Definition: description of based on theory (starting point) and practice (finalise). Add a short definition of the benchmark on which all asset managers agreed. Prior to any decision, in case necessary a discussion has taken place. For ambiguous definitions the following rule applies: majority rules. This rule applies to all steps in the benchmarking process reflected in the template.
- Asset type: road/quay wall/etc. The template is designed in such way that it standardised the benchmarks, but it is also flexible as it is a suitable tool for each asset or benchmark type.

<u>Guiding Principles: Theoretical Constructs to Position the Benchmark</u>
The guiding principles presented in Section 2.3.3 can be found in this part of the template. The guiding principles help understanding understanding what we measure and how it is related to the aspects of asset management. It is also a check whether the identified benchmarks are appropriate. This part of the template aligns the practical tool with theory.

- Focus of Asset Managers: triangle of performance, costs, and risks: relation to asset management objectives (IAM, 2015). Position of the benchmark in relation to asset management objectives. In a figure of three overlapping circles (performance, costs, and risk) a cross should be placed at the right spot. Question: *What do we measure?*

- Processes of Asset Managers: performance measurement framework: processes of managing assets (Pollitt & Bouckaert, 2011). Position of the benchmark in processes involved when managing assets. In the template a performance measurement framework for managing assets (the process) is presented. In this figure the input, output, and/or influencing factors should be marked in case the benchmark measured this part of the framework.
  Question: *How do we measure?*
- Control of Asset Managers: hierarchical structure of the organisations and the position of asset management, asset managers and assets (De Leeuw, 1994). Relations quantities should be controlled by the asset manager, or in co-operation (Neely et al., 1997). The port control model is presented in this research. Considering the scope of the research some elements are faded. The other elements are numbered. In the template should be described which numbers apply to the benchmark.
  Question: *If we Analyse this, are we able to improve? How can we control this quantity?*

Hierarchical Construct of the Benchmark
Question: *What level of detail is useful?*
A break down of the benchmark presented in a hierarchical tree. Define variables (measurements) on lower level(s). This variables are required to quantify the benchmark, and to collect the required data. Dimensions and filters are useful, as it enables asset managers to compare 'apples with apples'. Relations can be defined to add graphs that are interesting for detailed analysis. The different levels:

- Benchmark name
- Measurements: decompose the benchmark. Define variables/measurements required to quantify the benchmark. Different levels are identified, each providing information for different graphs or other visualisations. Relevant for the asset overview and benchmark overview in the dashboard. The first level of the benchmark break down provides the information for the benchmark graph in the asset overview.
- Dimensions/filters: enabling asset clustering. Selection based on characteristics of the assets of importance. In this manner the analysis is customised and this contributes to a fair comparison. The dimensions are the filters in the dashboard. Relevant for the benchmark overview (detailed overview of the benchmark) in the dashboard.
- Relations: what relations with other benchmarks or figures are interesting for analysis. Benchmarks can be analysed in relation to other benchmarks or variables and some additional visualisations can be added. Relevant information for the benchmark overview in the dashboard.

Goal
Question: *Why do we measure?, What is the added value?*

- Purpose: rationale of the measurement, it should enable asset managers to monitor and stimulate improvement. Performance measurements should relate to specific goals. The measurement should be relevant for asset managers (Neely et al., 1997).

**▸ Measure**

The following questions is addressed in the 'Measure' part of the template: *How do we measure?*

Mathematical Formula

- Main formula – benchmark overview: mathematical formula and explanation of calculations behind the graph in the benchmark overview. Add a simple example below the formula, and an Excel file with a more detailed calculation using real data.
- Formula – after clicking on benchmark: additional formulas for graphs presented in the detailed overview of the benchmark. Add a simple example below the formula, and an Excel file with a more detailed calculation using real data

International Comparison

- Cross-port: in case there are differences between ports that are of importance for the benchmark they should be written down. Check whether each port measures the required data in the same way. In case not add appendix with explanation and scaling. Explain how benchmarking group handles with the differences and make share all ports agreed upon this solution to ensure data quality.

- Cross-country: same idea as on port-level. Differences between ports should be written down. The appendix provides sufficient space for further explanations. An example of a difference between ports, in case the are located in different countries, is the unit of measurement. For example the currencies for costs units. Standardisation can offer a solution, align all variables by standardising to units or scaling.

Data Collection Frequency

- Frequency: all ports should annually collect the data required for the benchmark. In this manner the performance can be recorded and reported, which allows asset managers to monitor the development of the benchmark. Some variables will not change each year, but it remains important to revise the data. The frequency of recording and reporting the performance is a function of the importance of the measure and data availability (Neely et al., 1997).

Required Data

- Data table: variable names (counts) which can be found in the 'hierarchical construct of the benchmark' presented in the template, field name should match with the column names in the shape file or Excel sheet, definition obtained from properties file. The table in the template consists of three columns: data, field name, definition. The data requirements should provide sufficient information on what data asset managers have to collect.

**▸ Analyse**

Dashboard enables asset managers to monitor the benchmarks.

- Dashboard: possibility to make suggestions or the dashboard development. Initial plan for visualisation to inform users, usually some sort of graph or chart that demonstrates the overall direction or level of performance over some period of time (or for one year) in a comparative way. Examples of how the results should be presented in the dashboard can be annexed.

**▸ Improve**

This part of the improvement cycle is the responsibility of each port and its asset managers individually. Improvement options and actions should be defined. The 'goal', which is also defined in the template, of the benchmark development explains what information can be derived from this benchmark.

- Useful insights: explain why the analysis of this benchmark contributes to continuous improvement. Has to be in line with the 'goal'. Identify how reasons for poor or good performance that can be subtracted from the dashboard. Also add limitations, as many results can be context specific. Furthermore, insights for improvement require further research.

**▸ Control**

Sustaining gain. The benchmarks should be monitored over the years as this enables asset managers to monitor performance and this will contribute to continuous improvement.

- Data: each port has to deliver the required data (see 'data requirements' and 'data collection frequency'). Data checks will take place both automatic and manual. Shape files shall be given the preference over Excel files, as it is highly compressed, portable, and less prone to errors.

# G
# Performance Measurement Template - Final Version

Empty performance measurement template, part of toolkit for asset managers to develop performance measurements for the benchmarking model. This template is used to define the benchmarks. This template is filled out for the case study in Chapter 4. In this chapter the template is completed by defining maintenance costs and condition, for both the quay wall and road asset.

# Performance Measurement Template

## Define

### General Information

**Benchmark name:** *as short as possible*

**Version:** *concept/final*

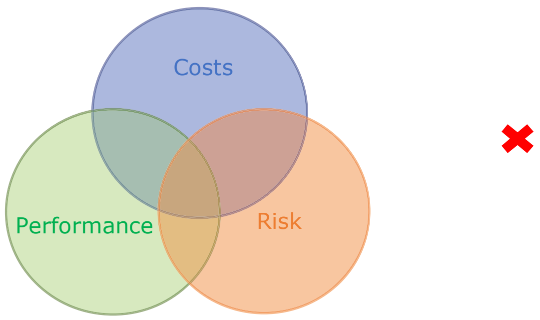
**Definition:** *description of benchmark based on theory (starting point) and practice (finalise)*

**Asset type:** *road/quay wall/etc.*

### Guiding Principles: Theoretical Constructs to Position the Benchmark .

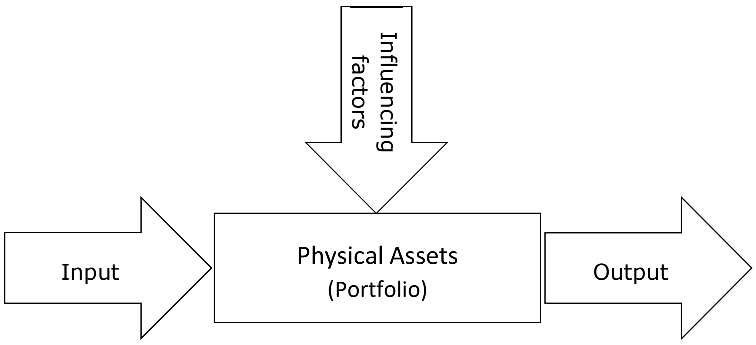
**Focus of Asset Managers:** position of the benchmark in relation to Asset Management objectives. The triangle of performance, costs and risk.

*Place the cross on the spot to show what the benchmark measures*




**Processes of Asset Managers:** position of the benchmark in processes involved when managing assets. Performance measurement framework.

*Mark the boxes grey to show what type of variable is measured*

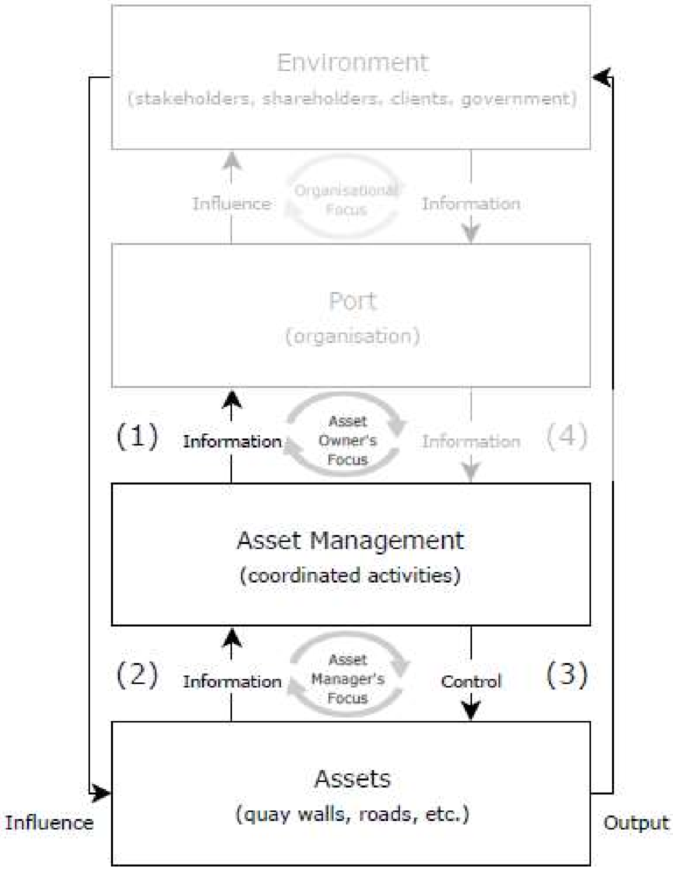



Note: examples can be found in Appendix I

benchmark set up – *asset type – benchmark name*

**Control of Asset Managers:** hierarchical structure of the organisations and the position of asset management, asset managers and assets. Relations quantities should be controlled by the asset manager, or in co-operation.

*Discuss port control model, and decide what number is applicable and why*




Select at least one of the numbers: (1), (2), (3) or (4)

**Number:** *(1), (2), (3), (4)*

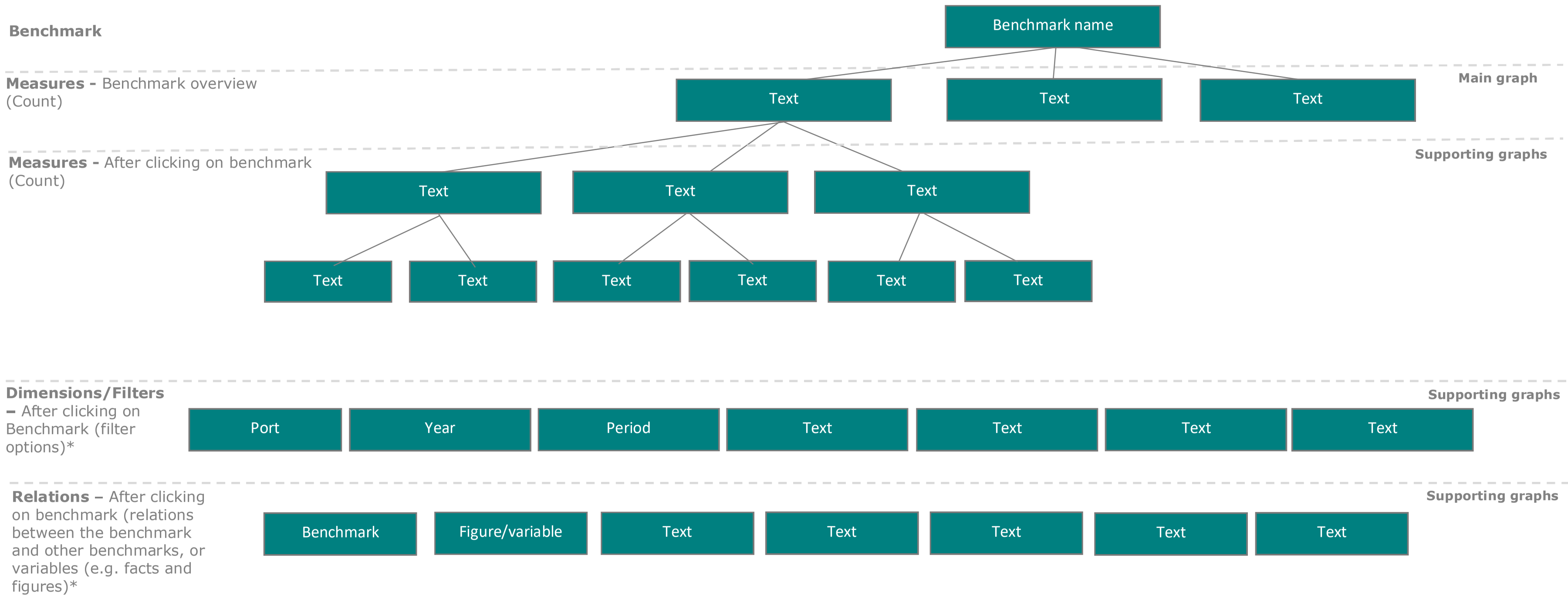
Explain why it is applicable to the benchmark

**Explanation:** *justification of the selected option, and in case one of the examples is applicable also mention this.*

Note: examples can be found in Appendix II

## Hierarchical Construct of the Benchmark

**Hierarchical tree to measure and analyse:** hierarchical decomposition of the benchmark into variables on a lower level. This variables are required to quantify the benchmark, and identify necessary data. Identify dimensions and filters, for customised analysis to ensure a fair comparison ('like-for-like'). Identify relations to present additional graphs for detailed analysis.




*In the general overview with all Performance Measures/Benchmarks a distinction is made based on the asset type. Example: quay walls; construction height, roads; material (top layer) benchmark set up – *asset type – benchmark name*

## Goal .

**Purpose:** *describe the rationale of the measurement, it should enable asset managers to monitor and stimulate improvement. Performance measurements should relate to specific goals. The measurements should be relevant for asset managers, as they aim for continuous improvement.*

# Measure

## Mathematical Formula .

**Main formula – benchmark overview:**

Type equation here.

*Simple example calculation*

*Appendix #: example in Excel sheet using real asset data*.

**Formula – after clicking on benchmark:**

Type equation here.

*Simple example calculation*

*Appendix #: example in Excel sheet using real asset data.*

## International Comparison .

**Cross-port:** *write down arrangements in case applicable. Does every port measure the required data in the same way? In case not add appendix with explanation and scaling. Explain how benchmarking group handles with the differences and make share all ports agreed upon this solution to ensure data quality. More information: Appendix #*

**Cross-country:** *same idea as on port-level. Identify difference in case necessary. Check if every unit measured in the same units (example: currencies for cost units). More information: Appendix #.*

## Data Collection Frequency .

**Frequency:** all ports should collect data required for the benchmark annually. In this manner the performance can be recorded and reported, which allows asset managers to monitor the development of the benchmark.

## Required Data .

**Data table:** variable names (counts) which can be found in the 'hierarchal construct of the benchmark' presented in the template, field name should match with the column names in the shape file or Excel sheet, definition obtained from properties file. Shape or Excel must contain the following data:

| **Data** | **Field name** | **Definition** |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *… ID* | *…* | *Asset ID of the Quay Wall/Road* |
| *… type* | *…* | *Quay Wall/Road type as defined* |
| | | |
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| | | |

Note: the information can be found in the properties file, in which all data characteristics (fieldname, fieldname shapefile and explanations can be found)

## Analyse

**Dashboard:** *possibility to make suggestions or the dashboard development. Initial plan for visualisation to inform users, usually some sort of graph or chart that demonstrates the overall direction or level of performance over some period of time (or for one year) in a comparative way. Examples of how the results should be presented in the dashboard. More information: Appendix #*

## Improve

**Useful insights:** *explain why the analysis of this benchmark contributes to continuous improvement. Has to be in line with the 'goal'. Identify how reasons for poor or good performance that can be subtracted from the dashboard. Also add limitations, as many results can be context specific. Next to this many improvement options required further research.*

Note: improvement and actions are the responsibility of each port and the asset managers individually. The goals explains what information can be derived from this benchmark.

## Control

**Data:** each port has to deliver the required data (see 'data requirements' and 'data collection frequency'). Data checks will take place both automatic and manual. Shape files shall be given the preference over Excel files, as it is highly compressed, portable, and less prone to errors.

# Appendices

## Appendix I .

**Processes of Asset Managers – Examples**

As asset managers have to manage their asset, they deliver input to the assets which results in a certain output of the assets. These input and outputs can be measured:

| | *Define* | *Measure* | *Asset** |
|---|---|---|---|
| *Input* | Preventive maintenance | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | Corrective maintenance | Methods (description) | G |
| | | Costs (€/year) | G |
| | Inspections | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | etc. | | |
| *Output* | Availability of the asset | % Available (%) | G |
| | Condition of the asset | Rating | G |
| | etc. | | |
| *Influencing factors* | Climate conditions | Temperature (°C) | G |
| | Salinity of the water | Gram/parts (ppt) | Q |
| | Demand | Throughput (tonnes/year) | G |
| | | Intensity (veh/h) | R |
| | | Port Calls (#/year) | Q |
| | Requirements | Budget (€/year) | G |
| | | Port vision (#,% or description) | G |
| | | Rules & Regulations (description) | G |
| | Age of assets | EOL range | G |
| | etc. | | |

**Quay wall (Q), Road (R), Generic (G)*
*Note: additional variables can be determined in the column Define*

*Mark the cells in case they examples are relevant for this benchmark.*

## Appendix II .

**Control of Asset Managers – Examples**

Controlled/influenced by the asset manager?

*(1) Information*
Maintenance costs

- Preventive maintenance costs
- Corrective maintenance costs
- Inspection costs (+testing and monitoring)

*(2) Information*
Performance of assets

- Availability
- Condition (visual or constructive)
- Risks

*(3) Control*
Maintenance activities

- Preventive maintenance: methods/activities, frequencies
- Corrective maintenance: methods/activities
- Inspections: methods/activities, frequencies

Not (direct) controlled/influenced by asset manager?
(4) *Information*
Requirements

- Budget
- Port vision: goals (environmental, etc.)
- Rules and regulations (international, national and port specific)

## Appendix # .

Text

# H Benchmark Overview in Dashboard

For each asset type an overview of all benchmarks and other figures is presented in the dashboard. The following information in presented in the asset benchmark overview.

- *Geographical location ports:* map in which the locations of the participating ports are shown.
- *Figures:* some general facts and figures, information on the ports their asset portfolios, to understand to whom you are comparing against.
- *Asset benchmarks:* performance measurements for all classification, and each classifications separately.

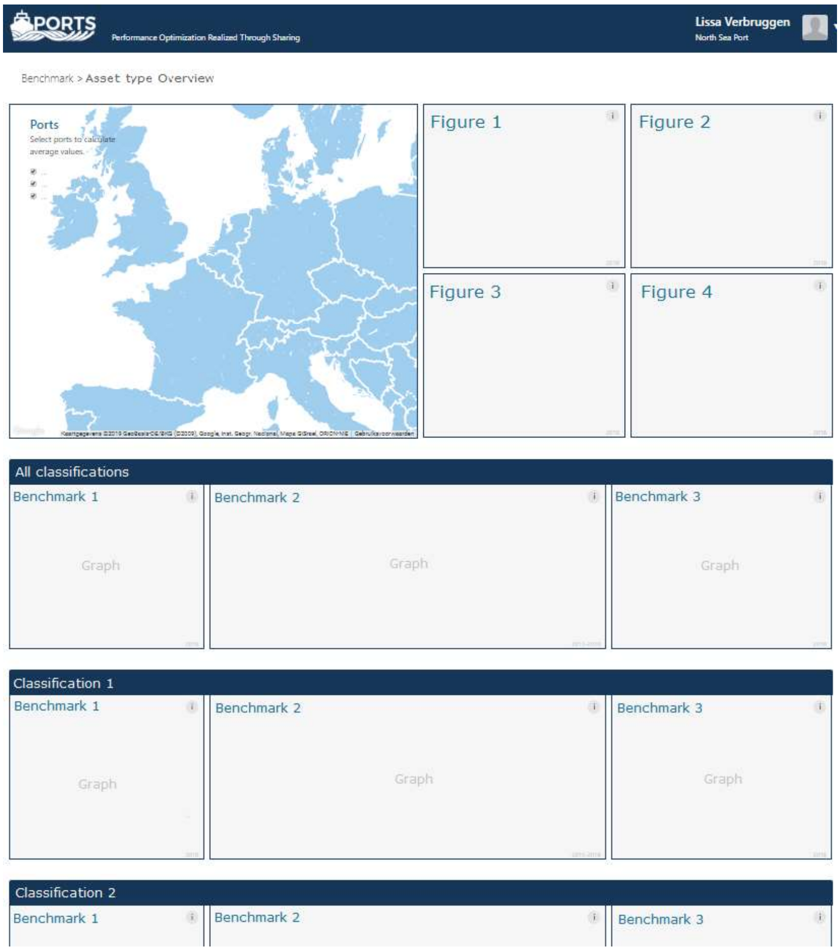



Figure H.1: Empty benchmark overview in dashboard

# I

# Data

Several data are used for this research. The data sets are supplied by the four participating ports: Port of Rotterdam, North Sea Port, Port of Hamburg, and Port of Gothenburg. The data is collected in a standardised formats, shape file or Excel sheet. The required data is listed for both the port and asset benchmarks. For ports the required data is fixed, and for the benchmarks it depends on the asset and benchmark type. This information can be found in the performance measurement templates as presented in appendices. For data processing data lists are generated with scripts written in SQL. In this manner the required data for each dashboard overview is generated, and can quickly be obtained. The data is processed by the benchmarking model and the results are presented in graphs.

## I.1. Data Collection

### I.1.1. Port data

The port data set contains data for port benchmarks. The data is retrieved from public accessible sources, such as annual reports. All data has been reviewed by the ports. In case data was missing data is obtained from internal sources, the port's database. As not all ports had published the facts and figures for 2018 the data was obtained from various sources, and the test data is manipulated. The data (as presented in Table 4.2) can therefore not be seen as real data. Multiple annual reports and other document are used to provide an indication.

### I.1.2. Asset data

The asset data is obtained for the asset figures and benchmarks. The data is obtained from databases with information on either quay wall or road assets. Due to time constraints not all ports were able to provide real data. Therefore mock-up data has been generated in collaboration with the asset managers. Each port partly managed to supply real data for 2018. The other years are generated by using random percentages.

Table I.1: Asset data generation for multiple years

| **Port** | **Benchmark** | **2015** | **2016** | **2017** | **2018** |
|---|---|---|---|---|---|
| *North Sea Port* | *Condition* | -2% | -5% | -10% | Fixed |
| | *Maintenance Costs* | -2% | -5% | -5% | Fixed |
| *Port of Hamburg* | *Condition* | -5% | -5% | -5% | Fixed |
| | *Maintenance Costs* | -5% | -5% | -5% | Fixed |
| *Port of Rotterdam* | *Condition* | -5% | -5% | -5% | Fixed |
| | *Maintenance Costs* | -2% | -2% | -2% | Fixed |
| *Port of Gothenburg* | *Condition* | -2% | -2% | -5% | Fixed |
| | *Maintenance Costs* | -2% | -2% | -2% | Fixed |

## I.2. Data Analysis

For data analysis in the dashboard the collected data has been structured and processed. Data sources are combined and structured, and the mathematical expressions are written down in a script to process the data.

### I.2.1. Data Preparing

The data collected on both port and asset level needs to be prepared for further analysis. As the data needs to be presented in dashboards, scripts are written in collaboration with software developers. These scripts consists of multiple queries. A query is a request for data or information from data files. The scripts collect the right data from all files supplied by the ports. These scripts are written in SQL, which are developed to make sure that data can be quickly obtained from the different data files. First the data needs to be prepared, to structure the required data per dashboard overview. An example of such script can be found in Appendix N. Separate scripts are written for the port benchmark overview (1 script), each asset type overview (2 scripts), and for each asset benchmark overview (4 scripts). These scripts 'generate' the required data sets.

### I.2.2. Data Processing

The data is generated in such way that it is prepared for data processing. Following the performance measurement templates of the benchmarks, the data needs to be processed. Benchmarks are expressed in mathematical formulas, and suggestions for visualisations of the benchmarks were outlined. Again for each overview a separate script has been written. Moreover, a general script is written for the customisation of the asset benchmarks. This script allows customisation of the benchmark analysis. This script can be found in Appendix N.5. These scripts call or 'get' the required graphs. All scripts are standardised, therefore scripts for other ports, assets, or benchmarks can be easily obtained.

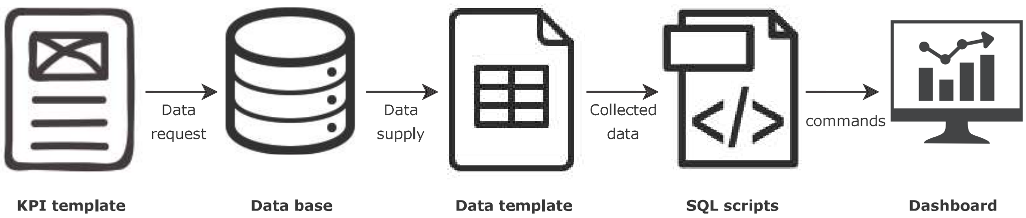



Figure I.1: From data requirements to dashboard visualisations

# J
# Case Study: Road, Maintenance Costs

In this Appendix for the asset ’road’ the benchmark ’maintenance costs’ is specified by filling out the performance measurement template which can be found in Appendix G.

# Performance Measurement Template

## Define

### General Information .

**Benchmark name:** *Maintenance costs*

**Version:** *final*

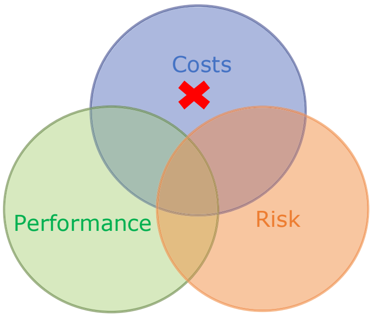
**Definition:** *average maintenance costs per m$^2$ road. The development of the maintenance cost (€/m$^2$ execution costs of the work onsite – labor of the contractor, materials and inspection costs) spend on the roads (top layers) over several years (y). The total maintenance costs are defined as the sum of:*
*Preventive maintenance costs: maintenance what is done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.*
*Corrective maintenance costs: maintenance executed after a failure has occurred (basically reinstating equipment functionality). To be clear, corrective maintenance can be the result of a deliberate run-to-failure strategy.*
*Inspection costs: costs for performing inspections. Information about the current state of assets is derived from inspection results.*
*- The cost allocation, methods and frequencies can be found by clicking on the benchmark*

**Asset type:** *road*

### Guiding Principles: Theoretical Constructs to Position the Benchmark .

**Focus of Asset Managers:** position of the benchmark in relation to Asset Management objectives. The triangle of performance, costs and risk.

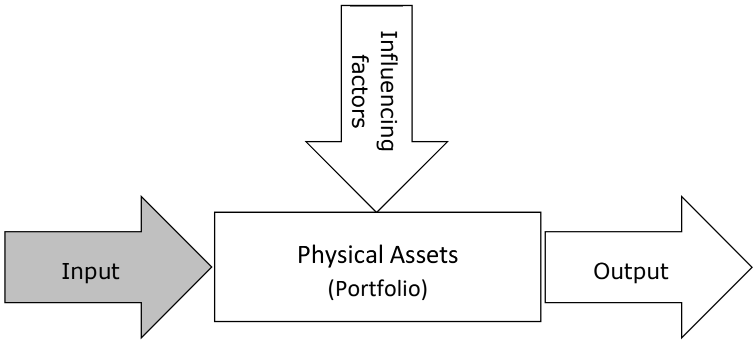
*Place the cross on the spot to show what the benchmark measures*



benchmark set up – *road – maintenance costs*

**Processes of Asset Managers:** position of the benchmark in processes involved when managing assets. Performance measurement framework.

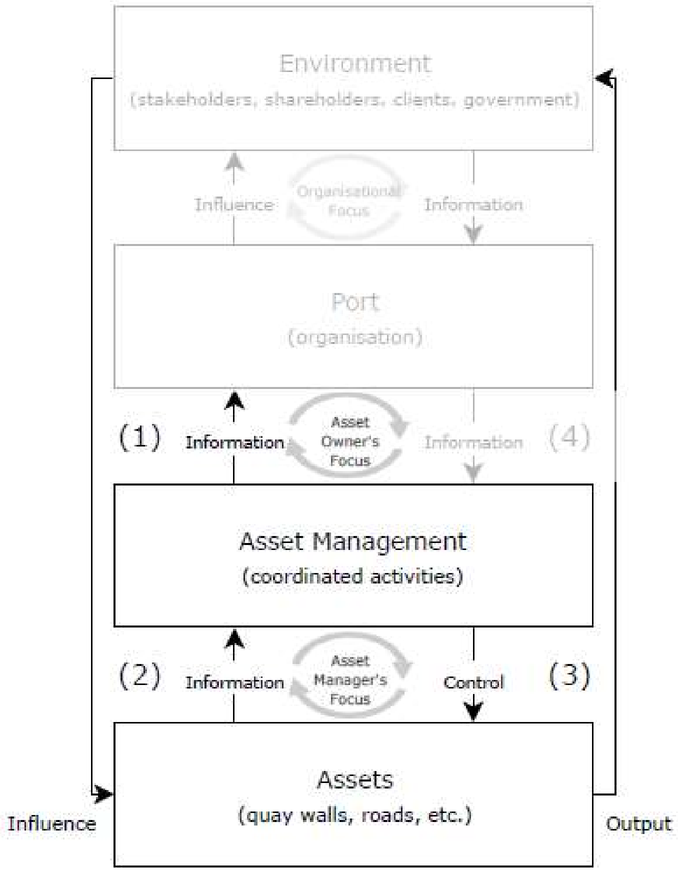
*Mark the boxes grey to show what type of variable is measured*




Note: examples can be found in Appendix I

**Control of Asset Managers:** hierarchical structure of the organisations and the position of asset management, asset managers and assets. Relations quantities should be controlled by the asset manager, or in co-operation.

*Discuss port control model, and decide what number is applicable and why*




Select at least one of the numbers: (1), (2), (3) or (4)

**Number:** *(1), (3)*

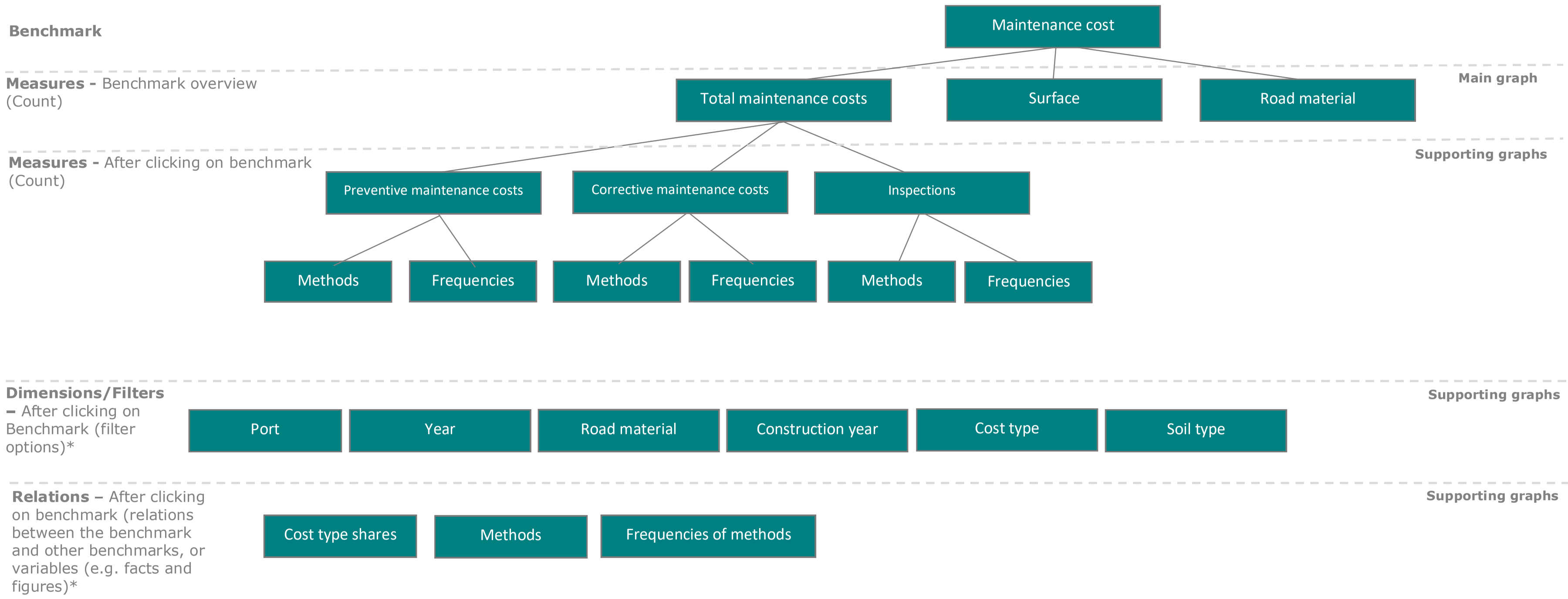
Explain why it is applicable to the benchmark

**Explanation:** *(1) maintenance costs; (3) maintenance activities: methods/concept/activities and the frequencies. The costs are costs a share of the total costs of the port as organisation and the budget. Budget constraints will follow from strategic decisions (4). Asset managers focus on managing assets. They can control their assets by performing maintenance. Information of interest for asset managers are certain maintenance (part of maintenance costs) and the frequencies on a yearly basis.*

Note: examples can be found in Appendix II

## Hierarchical Construct of the Benchmark

**Hierarchical tree to measure and analyse:** hierarchical decomposition of the benchmark into variables on a lower level. This variables are required to quantify the benchmark, and identify necessary data. Identify dimensions and filters, for customised analysis to ensure a fair comparison ('like-for-like'). Identify relations to present additional graphs for detailed analysis.




*In the general overview with all Performance Measures/Benchmarks a distinction is made based on the asset type. Example: quay walls; construction height, roads; material (top layer)

PORTS

## Goal

**Purpose:** *as user (asset managers) of the benchmarking model I can compare the maintenance costs per surface (m2) so I can see what costs which port has per road type (material) and what ratio between the different type of maintenance costs are: preventive maintenance, corrective maintenance and inspections. This allows ports to compare their maintenance costs on roads with other ports and seek for improvements in order to create an optimal maintenance concept. Next to the costs, and the shares on the different types of costs, as a user I also want to know which type of maintenance activities (methods) are performed per maintenance type. For example what methods (or type of activities) are involved when performing inspections (e.g. conserve/preserve, mill and inlay, cold asphalt, repavement etc.). Next to this I want to know the frequency of the activities performed in order to execute maintenance (either for preventive, corrective and inspections).*

# Measure

## Mathematical Formula

**Main formula – benchmark overview:**

$$average\ maintenance\ costs =$$

$$\sum_{i=1}^{n}\left(\frac{preventive\ maintenane\ costs_i + corrective\ maintenance\ costs_i + inspection\ cost_i}{surface_i}\right) * \left(\frac{surface_i}{\sum_{i=1}^{n} surface_i}\right)$$

With $i$ = road ID, $n$ = total number of road IDs (of a certain range)

Explanation new formula:

1. Cost per unit (surface)
   For each asset calculate the maintenance costs per square meter, being the sum of the three cost types divided by the surface: $\frac{preventive\ maintenance\ costs_i + corrective\ maintenance\ costs_i + inspection\ cost_i}{surface_i}$
2. Weight
   This costs per unit (surface) need to be multiplied by a weight, being the surface of that asset divided by the total surface of all road assets: $\frac{surface_i}{\sum_{i=1}^{n} surface_i}$
3. Average maintenance costs
   The sum of all assets gives the average costs of the asset portfolio (al roads included in the filters). This sum is the sum of all assets' costs per unit (surface) multiplied by the weight.

*Appendix III: example in Excel sheet using real asset data*.

**Formula – after clicking on benchmark:**

*For all maintenance types (preventive, corrective and inspection), define the type of activities to do/execute maintenance and the corresponding frequencies.*

*Table overview different type of maintenance:*

| ***Road material*** | ***Preventive maintenance methods*** | ***Corrective maintenance methods*** | ***Inspections*** |
|---|---|---|---|
| *Asphalt* | *Conserve/preserve (add a top layer/coating)* | *Crack filling* | *General visual inspection (global)* |
| | *Mill and inlay* | *Mill and inlay* | *Skid resistance measurements* |
| | *Reconstruction* | *Cold asphalt* | *Falling weight deflection measurements* |
| | | *Hot asphalt (hot box)* | *Safety inspection (daily inspection)* |
| *Concrete* | *Conserve/preserve (local repair)* | *Crack and gap fill/ corner recovery* | *General visual inspection (global)* |
| | *Plate replacement/mill/press* | *Plate replacement/mill/press* | *Skid resistance measurements* |
| | *Reconstruction* | | *Safety inspection (daily inspection)* |
| *Pavement* | *(partly) repavement* | *(partly) repavement* | *General visual inspection (global)* |
| | *Reconstruction* | | *Safety inspection (daily inspection)* |

*The frequencies can be found in the data files: excel sheets and shape files.*

## International Comparison

**Cross-port:** *ports have agreed upon the different maintenance methods. Maintenance methods are defined (see 'Mathematical Formula') in such a way that all ports should be able to allocate the methods to the methods defined in this template.*

**Cross-country:** *all ports should submit their costs in euro. For now only Port of Hamburg, North Sea Port and Port of Rotterdam join. Therefore the currency does not need to be converted. In case other ports join they should also make sure the costs are in euro.*

## Data Collection Frequency

**Frequency:** all ports should collect data required for the benchmark annually. In this manner the performance can be recorded and reported, which allows asset managers to monitor the development of the benchmark.

## Required Data

**Data table:** variable names (counts) which can be found in the 'hierarchal construct of the benchmark' presented in the template, field name should match with the column names in the shape file or Excel sheet, definition obtained from properties file. Shape or Excel must contain the following data:

| **Data** | **Field name** | **Definition** |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *Road ID* | *Road_ID* | *Asset ID of the road* |
| *Surface* | *Surface* | *Surface of the road ($m^2$)* |
| *Road material* | *Material_Type* | *Material type as defined: asphalt, concrete, (block) pavement* |
| *Construction Year* | *Constr_Yea* | *Year of construction of the foundation* |
| *Soil type* | *Soil* | *The natural underground: peat, clay, sand, gravel* |
| *Maintenance costs* | | *Sum of all costs of all types of maintenance (preventive, corrective, and inspections)*<br>*Note: other benchmark, enables to analyse the relation between maintenance cost (input) en condition (output)* |
| *Preventive costs* | *Prev_Main* | *Costs related to maintenance done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.* |
| *Preventive maintenance asphalt conserve/preserve (add a top layer/coating)* | *Prev_ Asph_Cons* | *Frequency of this preventive maintenance method* |
| *Preventive maintenance asphalt mill and inlay* | *Prev_ Asph_Mill* | *Frequency of the method Preventive maintenance asphalt mill and inlay* |
| *Preventive maintenance asphalt reconstruction* | *Prev_ Asph_Rec* | *Frequency of the method Preventive maintenance asphalt reconstruction* |

| | | |
|---|---|---|
| *Preventive maintenance concrete conserve/preserve (local repair)* | *Prev_ Con_Cons* | *Frequency of the method Preventive maintenance concrete conserve/preserve (local repair)* |
| *Preventive maintenance concrete plate replacement/mill/press* | *Prev_ Con_Repl* | *Frequency of the method Preventive maintenance concrete plate replacement/mill/press* |
| *Preventive maintenance concrete reconstruction* | *Prev_ Con_Rec* | *Frequency of the method Preventive maintenance concrete reconstruction* |
| *Preventive maintenance pavement (partly) repavement* | *Prev_ Pav_Repav* | *Frequency of the method Preventive maintenance pavement (partly) repavement* |
| *Corrective maintenance costs* | *Cor_Main* | *Costs related to maintenance executed after a failure has occurred (basically reinstating equipment functionality). To be clear, corrective maintenance can be the result of a deliberate run-to-failure strategy.* |
| *Corrective Maintenance asphalt crack filling* | *Cor_Asph_Crack* | *Frequency method, Corrective Maintenance asphalt crack filling* |
| *Corrective maintenance asphalt mill and inlay* | *Cor_Asph_Mill* | *Frequency method, Corrective maintenance asphalt mill and inlay* |
| *Corrective maintenance asphalt cold asphalt* | *Cor_Asph_Cold* | *Frequency of method, Corrective maintenance asphalt cold asphalt* |
| *Corrective maintenance asphalt hot asphalt (hot box* | *Cor_Asph_Hot* | *Frequency of method, Corrective maintenance asphalt hot asphalt (hot box)* |
| *Corrective maintenance concrete crack and gap fill/corner recovery* | *Cor_Con_Crack* | *Frequency of method, Corrective maintenance concrete crack and gap fill/corner recovery* |
| *Corrective maintenance plate replacement/mill/press* | *Cor_Con_Repl* | *Frequency of method, Corrective maintenance plate replacement/mill/press* |
| *Corrective maintenance pavement (partly) repavement* | *Cor_Pav_Repav* | *Frequency of method, Corrective maintenance of block pavement (partly) repavement* |
| *Inspection costs* | *Insp_Cost* | *Costs related to inspections* |
| *Inspections visual* | *Insp_Visual_Insp* | *Frequency of Inspections skid resistance measurements* |
| *Inspections skid resistance measurements* | *Insp_Skid_Insp* | *Frequency of Inspections falling weight deflection measurements* |
| *Inspections falling weight deflection measurements* | *Insp_Weight_Meas* | *Frequency of Inspection, Safety inspections (daily or general visual inspections)* |
| *Inspection, Safety inspections (daily or general visual inspections)* | *Insp_safety_Insp* | *Frequency of Inspections skid resistance measurements* |

Note: the information can be found in the properties file, in which all data characteristics (fieldname, fieldname shapefile and explanations can be found). Next to this all frequency are a number per year as al files are per year.

## Analyse

**Dashboard:** *maintenance costs can be analysed by comparing different ports, over different years, over different types of costs (preventive, corrective and inspections) and per material type. Next to this information about the shares of the different activities involved with a certain type of maintenance are displayed, and the corresponding frequencies of this type of maintenance activity. Examples/suggestions of how this benchmark could be presented are attached in the Appendix. More information: Appendix IV*

## Improve

**Useful insights:** *after analyses, ports can decide if there are optimisations possible in their maintenance execution. They can see how the maintenance costs are calculated and which type of activities are performed for the different types of maintenance, and even more detailed the user can also see what the frequencies of the different activities are. In this way the user has a complete and detailed overview of the costs and how maintenance is done. The 'goal' is in line with this contribution.*

Note: improvement and actions are the responsibility of each port and the asset managers individually. The goal explains what information can be derived from this benchmark.

## Control

**Data:** each port has to deliver the required data (see 'data requirements' and 'data collection frequency'). Data checks will take place both automatic and manual. Shape files shall be given the preference over Excel files, as it is highly compressed, portable, and less prone to errors.

# Appendices

## Appendix I .

**Processes of Asset Managers – Examples**

As asset managers have to manage their asset, they deliver input to the assets which results in a certain output of the assets. These input and outputs can be measured:

| | *Define* | *Measure* | *Asset** |
|---|---|---|---|
| *Input* | Preventive maintenance | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | Corrective maintenance | Methods (description) | G |
| | | Costs (€/year) | G |
| | Inspections | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | etc. | | |
| *Output* | Availability of the asset | % Available (%) | G |
| | Condition of the asset | Rating | G |
| | etc. | | |
| *Influencing factors* | Climate conditions | Temperature (°C) | G |
| | Salinity of the water | Gram/parts (ppt) | Q |
| | Demand | Throughput (tonnes/year) | G |
| | | Intensity (veh/h) | R |
| | | Port Calls (#/year) | Q |
| | Requirements | Budget (€/year) | G |
| | | Port vision (#,% or description) | G |
| | | Rules & Regulations (description) | G |
| | Age of assets | EOL range | G |
| | etc. | | |

**Quay wall (Q), Road (R), Generic (G)*
*Note: additional variables can be determined in the column Define*

*Mark the cells in case they examples are relevant for this benchmark.*

## Appendix II .

**Control of Asset Managers – Examples**

Controlled/influenced by the asset manager?

*(1) Information*
Maintenance costs

- Preventive maintenance costs
- Corrective maintenance costs
- Inspection costs (+testing and monitoring)

*(2) Information*
Performance of assets

- Availability
- Condition (visual or constructive)
- Risks

*(3) Control*
Maintenance activities

- Preventive maintenance: methods/activities, frequencies
- Corrective maintenance: methods/activities
- Inspections: methods/activities, frequencies

Not (direct) controlled/influenced by asset manager?
(4) *Information*
Requirements

- Budget
- Port vision: goals (environmental, etc.)
- Rules and regulations (international, national and port specific)

## Appendix III .

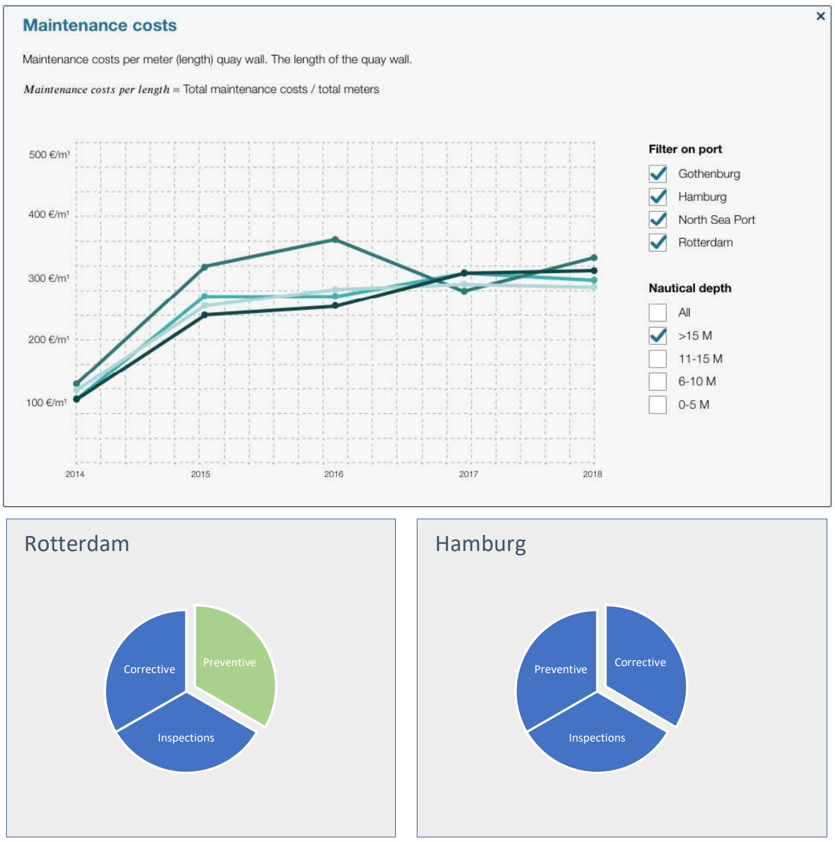
**Example Average Maintenance Costs using Real Data**

Excel sheet: *<not included due to confidentiality>*

## Appendix IV .

**Dashboard – Example Visualisation**

Idea of how to present the benchmark after clicking in the general overview in which all benchmarks for the Road asset presented:



benchmark set up – *road – maintenance costs*

By clicking on for example the red pie, you get an overview (in a new window) of all maintenance methods (activities) on corrective maintenance for Rotterdam, and next to that the columns of the selected ports:

**Preventive maintenance -Methods**

| Rotterdam | | Hamburg | |
|---|---|---|---|
| Activities (description) | Frequencies (#/…) | Activities (description) | Frequencies (#/…) |
| … | - | … | - |
| | | | |
| | | | |

**Corrective maintenance -Methods**

| Rotterdam | | Hamburg | |
|---|---|---|---|
| Activities (description) | Frequencies (#/…) | Activities (description) | Frequencies (#/…) |
| … | - | … | - |
| | | | |

*Note: All the dimension presented on page 4 should be a filter option, so a larger variety of filters (not only filter on port and material): ports, year, material, preventive maintenance costs, etc. In the example only port and nautical depth are filters (included the picture of quay wall, but off course nautical depth should be material for Road Performance Measures/Benchmarks)*

# K

# Case Study: Road, Condition

In this Appendix for the asset ’road’ the benchmark ’condition’ is specified by filling out the performance measurement template which can be found in Appendix G.

# Performance Measurement Template

## Define

### General Information

**Benchmark name:** *Condition*

**Version:** *final*

**Definition:** *condition of the road is the present state of the asset, for this benchmark it is related to the appearance (visual). The condition is determined by the degree of damage and deterioration, extracted from visual inspection.*

**Asset type:** *road*

### Guiding Principles: Theoretical Constructs to Position the Benchmark .

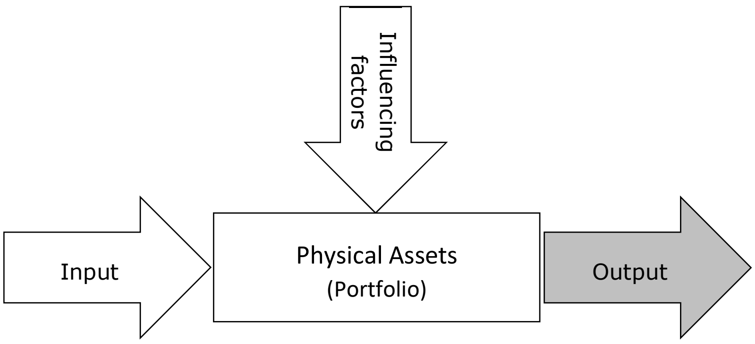
**Focus of Asset Managers:** position of the benchmark in relation to Asset Management objectives. The triangle of performance, costs and risk.

*Place the cross on the spot to show what the benchmark measures*


*Note: can also contribute to the risk level, road asset managers agreed upon performance*

**Processes of Asset Managers:** position of the benchmark in processes involved when managing assets. Performance measurement framework.

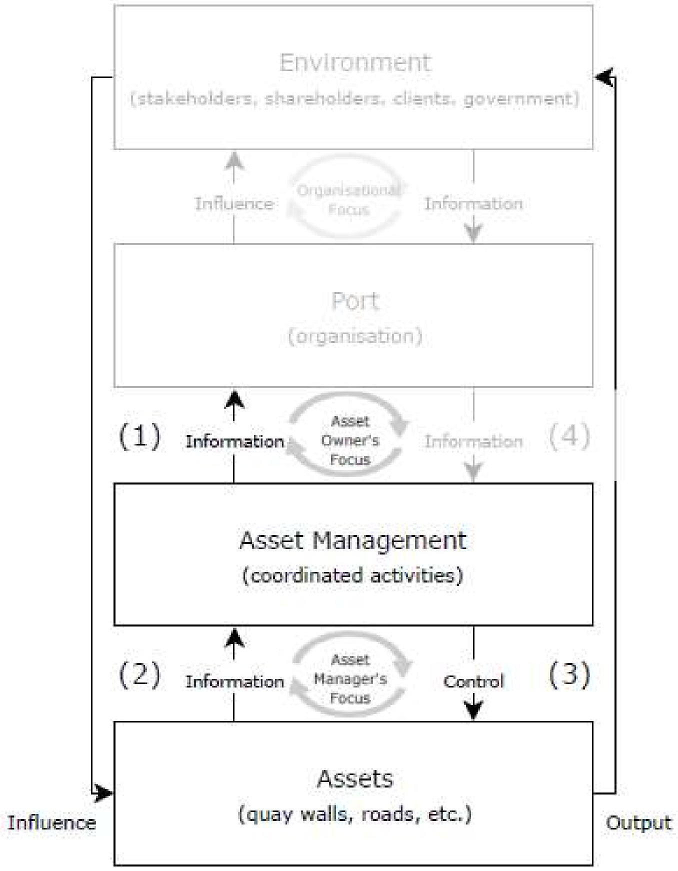
*Mark the boxes grey to show what type of variable is measured*




Note: examples can be found in Appendix I

**Control of Asset Managers:** hierarchical structure of the organisations and the position of asset management, asset managers and assets. Relations quantities should be controlled by the asset manager, or in co-operation.

*Discuss port control model, and decide what number is applicable and why*




Select at least one of the numbers: (1), (2), (3) or (4)

**Number:** *(2)*

Explain why it is applicable to the benchmark

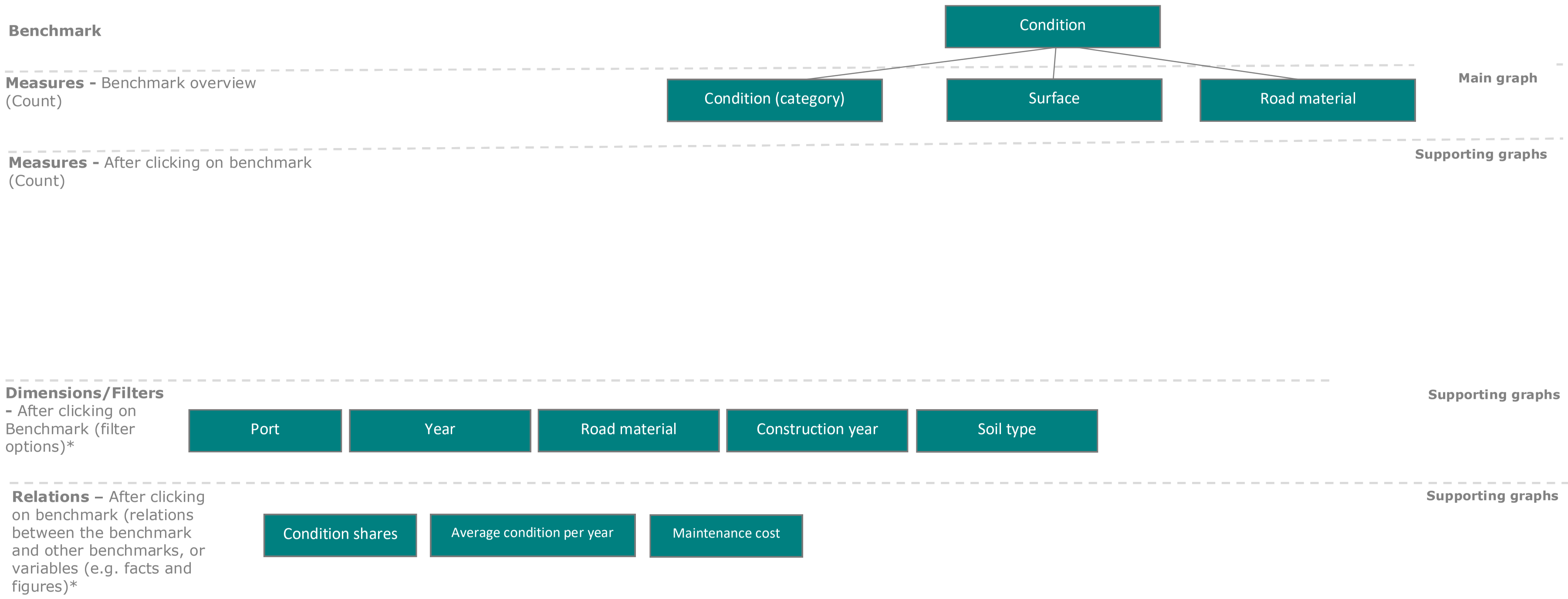
**Explanation:** *following from actions performed (control) or managed by the asset manager, the condition of the asset can be monitored by asset managers. The asset managers receive feedback, information (2), of the assets as they have a certain visual condition. The condition is important when it comes to the availability of the road. Next to this a bad condition can results in dangerous situations or high costs for preventive maintenance. It is the asset manager's responsibility to make sure the assets are in a certain condition if customers want to make use (drive on the road) the assets.*

Note: examples can be found in Appendix II

benchmark set up – *road – condition*

## Hierarchical Construct of the Benchmark

**Hierarchical tree to measure and analyse:** hierarchical decomposition of the benchmark into variables on a lower level. This variables are required to quantify the benchmark, and identify necessary data. Identify dimensions and filters, for customised analysis to ensure a fair comparison (‘like-for-like’). Identify relations to present additional graphs for detailed analysis.




*In the general overview with all Performance Measures/Benchmarks a distinction is made based on the asset type. Example: quay walls; construction height, roads; material (top layer)

PORTS

## Goal

**Purpose:** *as a BAM user I want to know what the condition of the assets is, by mapping/monitoring the condition the results can be used to make interpretations of other benchmarks such as maintenance costs. The condition of the assets say something about the output or performance of the asset managers.*

# Measure

## Mathematical Formula

**Main formula – benchmark overview:**

For every road ID you find the condition (green, yellow, orange, and red). After that you multiple it with the surface (this is a weight) of that road ID, and then you divide the total surface of all road IDs by the total surface. To define an average condition for a certain selection (made with filters) the colours should be linked to numbers: green (4), yellow (3), orange (2), red (1). Note: this is how we collect data. Numbers shouldn't be shown on the platform. The numbers are only for the data use and defining the average.
*Question:* what is the average colour (condition) of my assets?

$$(average)\ condition = \frac{\sum_{i=1}^{n} condition_i * road\ suface_i}{\sum_{i=1}^{n} road\ surface_i}$$

**Formula – after clicking on benchmark:**

For every category:

To define the shares in a certain condition, so how many square meters are in a certain condition. For every condition (there are four) you sum al the square metres in that condition rate/category.
*Question:* how many square meters are of a certain condition, defined in a percentage of the total number of square meters (=surface)?

$$Total\ square\ meters\ in\ each\ condition = \sum_{i=1}^{n} Road\ surface_i$$

$$Percentage\ of\ each\ condition = \frac{\sum_{i=1}^{n} Road\ surface_i}{Total\ surface} * 100\%$$

With $i$ = road ID, $n$ = total number of all (or for one condition range) road IDs

Where:

- $Condition_i$ = condition of road ID *i*
- $Road\ surface_i$ = surface in square metres of road ID *i*
- $Total\ road\ surface_i$ = sum of all road ID's. Total road surface.

The condition ranges between 4 and 1. The following definitions should be presented in the dashboard:

- New = green (4)
- Good = yellow (3)
- Poor = orange (2)
- Critical = red (1)

*Appendix IV: additional information on condition definitions*

*Simple example calculation:*

*Example 1* - calculation of the (average) condition of one port (A-D are all assets):

| Road ID | Condition | Surface ($m^2$) |
|---|---|---|
| A | 1 | 10 |
| B | 2 | 20 |
| C | 3 | 20 |
| D | 1 | 30 |

$$(average)\ condition = \frac{(1*10\ m^2)+(2*20\ m^2)+(3*20\ m^2)+(1*30\ m^2)}{80\ m^2} = 1.75$$

$$average\ condition\ is\ therefore\ 2$$

Note: 0,5 will be rounded to 1 and 0,45 will be rounded to 0

*Example 2* - calculation of the total square meters in each condition, example condition green (1):

$$Total\ square\ meters\ in\ condition_{green} = 10 + 30 = 40\ m^2$$

$$Percentage\ of\ each\ condition = \frac{40\ m^2}{80\ m^2} * 100\% = 50\%,$$

$$so\ 50\%\ of\ all\ assets\ (selected\ with\ the\ filters)\ have\ the\ green\ condition$$

**Dashboard – after clicking on benchmark:**

*More options to filter, and compare the condition of the assets:*

*- Per port for the selected year(s) (average of selected years of conditions of one year) presented in pie charts. Taking into account the weights (surface road/total length all roads)*

*- Development over the years (in the general overview the conditions shares are compared with the average of the selected ports)*

*- In relation to other benchmarks (e.g. the benchmark maintenance costs)*

*Appendix III: example in Excel sheet using real asset data.*

## International Comparison

**Cross-port:** *conditions is categorised in a different way for each port. For this reason conditions needs to be compared, and scaled in such a way that all ports can allocate their own condition to a generic condition. Ports have agreed upon four ranges. For each range (green, yellow, orange, red) both a definition and the standards ports use within their own company. More information: Appendix IV.*

**Cross-country:** *the conditions vary by port. Ports can use the same standards but still there are differences in interpretation on port-level. For this reason only the cross-port differences are relevant.*

## Data Collection Frequency

**Frequency:** all ports should collect data required for the benchmark annually. In this manner the performance can be recorded and reported, which allows asset managers to monitor the development of the benchmark.

## Required Data

**Data table:** variable names (counts) which can be found in the 'hierarchal construct of the benchmark' presented in the template, field name should match with the column names in the shape file or Excel sheet, definition obtained from properties file. Shape or Excel must contain the following data:

| Data | Field name | Definition |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *Road ID* | *Road_ID* | *Asset ID of the road* |
| *Road material* | *Material_Type* | *Material type as defined: asphalt, concrete, (block) pavement* |
| *Surface* | *Surface* | *Surface of the road ($m^2$)* |
| *Construction year* | *Constr_Yea* | *Year of construction of the foundation* |
| *Soil type* | *Soil* | *The natural underground: peat, clay, sand, gravel* |
| *Condition* | *Condition* | *Condition of the road of the road (condition categories in Appendix IV)* |
| *Maintenance costs* | | *Sum of all costs of all types of maintenance (preventive, corrective, and inspections)* *Note: other benchmark, enables to analyse the relation between maintenance cost (input) en condition (output)* |
| *Preventive costs* | *Prev_Main* | *Costs related to maintenance done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.* |
| *Corrective maintenance costs* | *Cor_Main* | *Costs related to maintenance executed after a failure has occurred (basically reinstating equipment functionality). To be clear, corrective maintenance can be the result of a deliberate run-to-failure strategy.* |
| *Inspection costs* | *Insp_Cost* | *Costs related to inspections* |

Note: the information can be found in the properties file, in which all data characteristics (fieldname, fieldname shapefile and explanations can be found)

benchmark set up – *road – condition*

## Analyse

**Dashboard:** *condition can be analysed by comparing different ports, over the years. The share of the total assets in a certain condition is presented in a pie-chart. Next to this the relation between maintenance costs and condition is presented, in this manner the input and output benchmarks are combined. Filters enable asset managers to compare assets with the same characteristics. For example the age of the asset can be interesting. It can be expected that ageing assets require a higher maintenance frequency. Of course characteristics like climate, budget of the port/department, usage (intensity or percentage heavy vehicles/load), are also of influence. More information: Appendix V.*

## Improve

**Useful insights:** *after analysing, port can decide if they want to improve their condition. Are the results in line with their strategy, objectives and the expected results considering the maintenance concept. The results obtained, costs or the relation between costs and condition, can be a trigger to adapt or revise their maintenance strategy. Next to this many improvement options required further research. This insights are also reflected in the 'goal' of this benchmark.*

Note: improvement and actions are the responsibility of each port and the asset managers individually. The goal explains what information can be derived from this benchmark.

## Control

**Data:** each port has to deliver the required data (see 'data requirements' and 'data collection frequency'). Data checks will take place both automatic and manual. Shape files shall be given the preference over Excel files, as it is highly compressed, portable, and less prone to errors.

# Appendices

## Appendix I .

**Processes of Asset Managers – Examples**

As asset managers have to manage their asset, they deliver input to the assets which results in a certain output of the assets. These input and outputs can be measured:

| | *Define* | *Measure* | *Asset** |
|---|---|---|---|
| *Input* | Preventive maintenance | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | Corrective maintenance | Methods (description) | G |
| | | Costs (€/year) | G |
| | Inspections | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | etc. | | |
| *Output* | Availability of the asset | % Available (%) | G |
| | Condition of the asset | Rating | G |
| | etc. | | |
| *Influencing factors* | Climate conditions | Temperature (°C) | G |
| | Salinity of the water | Gram/parts (ppt) | Q |
| | Demand | Throughput (tonnes/year) | G |
| | | Intensity (veh/h) | R |
| | | Port Calls (#/year) | Q |
| | Requirements | Budget (€/year) | G |
| | | Port vision (#,% or description) | G |
| | | Rules & Regulations (description) | G |
| | Age of assets | EOL range | G |
| | etc. | | |

**Quay wall (Q), Road (R), Generic (G)*
*Note: additional variables can be determined in the column Define*

*Mark the cells in case they examples are relevant for this benchmark.*

## Appendix II .

**Control of Asset Managers – Examples**

Controlled/influenced by the asset manager?

*(1) Information*
Maintenance costs

- Preventive maintenance costs
- Corrective maintenance costs
- Inspection costs (+testing and monitoring)

*(2) Information*
Performance of assets

- Availability
- Condition (visual or constructive)
- Risks

*(3) Control*
Maintenance activities

- Preventive maintenance: methods/activities, frequencies
- Corrective maintenance: methods/activities
- Inspections: methods/activities, frequencies

Not (direct) controlled/influenced by asset manager?
(4) *Information*
Requirements

- Budget
- Port vision: goals (environmental, etc.)
- Rules and regulations (international, national and port specific)

## Appendix III .

**Example Average Condition using Real Data**

Excel sheet: *<not included due to confidentiality>*

## Appendix IV .

**International Comparison – Cross-port**

Conditions ranges differ per port. Port of Hamburg, North Sea Port and Port of Rotterdam have agreed upon the definitions are presented in this appendix. Four categories are distinguished to quantify and measure the condition.

Condition: the performance of the asset is the ability to provide the required level of service to customers. It is the present state of a physical asset, usually referring to a structural integrity. It can also relate to the appearance. For this benchmark the results of visual inspection are taken into account (focus on appearance, also some structural measures are incorporated). All ports give their road ID's a condition based on standards. To scale these categories we have compared pictures of the different categories and the definitions. The resulting definitions and ratings for international benchmarks are presented in this appendix.

Standards used for the

- Germany:
  - German standards
- Belgium/Flanders: OCW MN 98/17
  - Opzoekingscentrum voor de Wegenbouw (OCW), measurement method MN 98/17
- Netherlands: CROW – Kwaliteitscatalogus openbare ruimte
  - CROW is a knowledge institute for infrastructure, public space, traffic and transport, and work and safety
  - Note: both Rotterdam and some areas of North Sea Port use the CROW standards.

| Hamburg (Germany) | NSP (Belgium) | Rotterdam/NSP (Netherlands) |
|---|---|---|
| 1 (blue): 1.00 – 1.49 | >= 0.8 (max 0.9) | A+ |
| 2 (green): 1.50 – 3.49 | [0.75 – 0.8] | A |
| 3 (yellow): 3.50 – 4.49 | [0.5 – 0.75] | B |
| 4 (red); 4.50 – 5.00 (change order, 1 is good) | [0.3 -0.5] | C |
| | < 0.3 | D |

General categories - From good to bad

| Category | Field (value of data) | Condition |
|---|---|---|
| Green | 4 | New |
| Yellow | 3 | Good (or fair) |
| Orange | 2 | Poor |
| Red | 1 | Critical |

More detailed description of the condition categories, including photos:

**4. Green**
*Description:* good (new), perfect condition [very good/new]
*Characteristics:* new or ideal condition, very good condition, no cracks/patches/potholes or other damages. Same for deterioration. The condition of the road surface is inconspicuous.
Formation of cracks: none
Out of flatness: no raveling/rutting

| Green (new) | | |
|---|---|---|
| **Picture** | | **Degree of damage/detoriation** |
|  |  | No/little transverse unevenness |
|  |  | No/little |
|  |  | No/little |
|  |  | |
|  |  | |

**3. Yellow**
*Description:* good/moderate condition [good/fair]
*Characteristics:* the road is in a good condition, surface is largely inconspicuous and shows no major damages or deterioration.
Formation of cracks: light
Out of flatness: light rutting/raveling

| Yellow (good) | |
|---|---|
| **Picture** | **Degree of damage/detoriation** |
|  | Limited transverse unevenness |
|  | Limited |
|  | Limited fraying |
|  | Limited |
|  | Limited |
|  | Limited |

**2. Orange**

*Description:* low/bad/poor condition [poor/bad]

*Characteristics:* condition of the road is conspicuous.

Formation of cracks: some/considerable/significant, exceeded level of warning

Out of flatness: some/considerable/significant rutting/raveling, exceeded level of warning

| Orange (poor) | |
|---|---|
| **Picture** | **Degree of damage/detoriation** |
|  | Moderate transverse unevenness |
|  | Moderate |
|  | Moderate fraying |
|  | Moderate |
|  | Moderate |
|  | Moderate |

**1. Red**
*Description:* unacceptable, very poor condition [very bad/critical]
*Characteristics:* condition of the road has reached a critical value. Various damages (cracks, potholes, etc.). Road surface needs repair.
Formation of cracks: many/critical
Out of flatness: many/critical rutting/raveling

| **Red (critical)** | |
|---|---|
| **Picture** | **Degree of damage/detoriation** |
|  | Many transverse unevenness |
|  | Many |
|  | Many frayings |
|  | Many |
|  | Many |
|  | Many |

*Note: in the definition not all type of damages may be included. Other damages that should also be taken into account when allocating conditions: non-continuities of the road surface, corrosion, dilatation joints, cracks/cracking etc.*

## Appendix V

### Dashboard – Example Visualisation

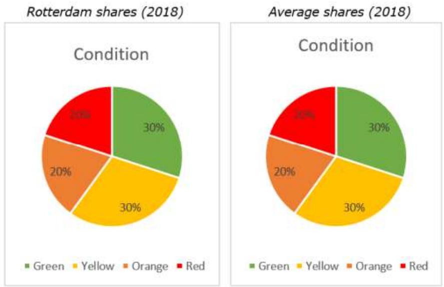
In the benchmark overview:

- Compare the condition shares of your port with the average conditions shares of all selected ports.

In the detailed overview some graphs should be presented:

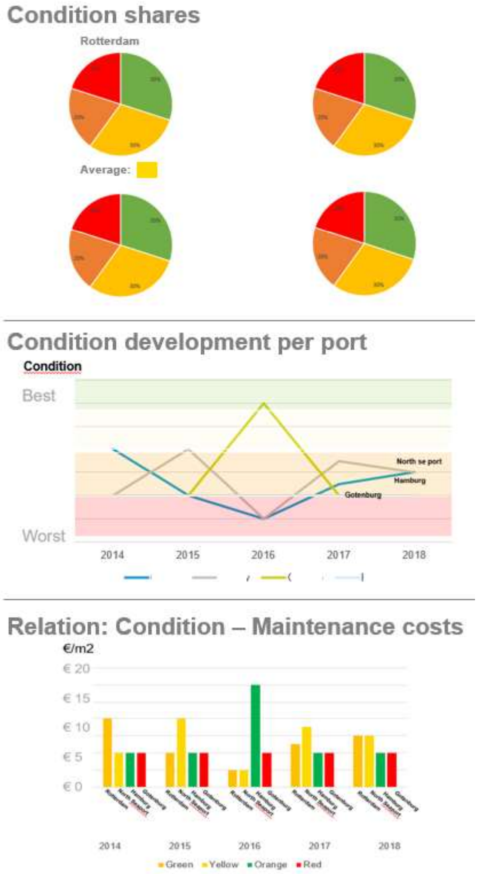
- Conditions shares, for each ports
- Condition development over the years, for each port
- Relation between two benchmarks: Maintenance Costs vs Condition

**Dashboard - Benchmark overview**




*Average condition Rotterdam: yellow (2,3)*
*Average condition: orange*

**Dashboard - Detailed page condition**



# L

# Case Study: Quay Wall, Maintenance Costs

In this Appendix for the asset ’quay wall’ the benchmark ’maintenance costs’ is specified by filling out the performance measurement template which can be found in Appendix G.

# Performance Measurement Template

## Define

### General Information

**Benchmark name:** *Maintenance Costs*

**Version:** *final*

**Definition:** *average maintenance costs per m quay wall. The development/evolution of the maintenance cost (€/m execution costs of the work onsite – labor of the contractor, materials and inspection costs) spend on the quay walls over several years (y). The total maintenance costs are defined as the sum of:*
*Preventive maintenance costs: maintenance what is done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.*
*Corrective maintenance costs: maintenance executed after a failure has occurred (basically reinstating equipment functionality). To be clear, corrective maintenance can be the result of a deliberate run-to-failure strategy.*
*Inspection costs: costs for performing inspections. Information about the current state of assets is derived from inspection results.*
*- The cost allocation, methods and frequencies can be found by clicking on the benchmark*

**Asset type:** *quay wall*

### Guiding Principles: Theoretical Constructs to Position the Benchmark .

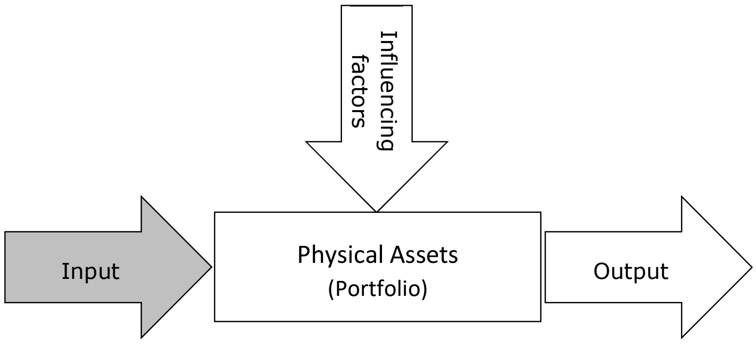
**Focus of Asset Managers:** position of the benchmark in relation to Asset Management objectives. The triangle of performance, costs and risk.

*Place the cross on the spot to show what the benchmark measures*

benchmark set up – *quay wall – maintenance costs*

**Processes of Asset Managers:** position of the benchmark in processes involved when managing assets. Performance measurement framework.

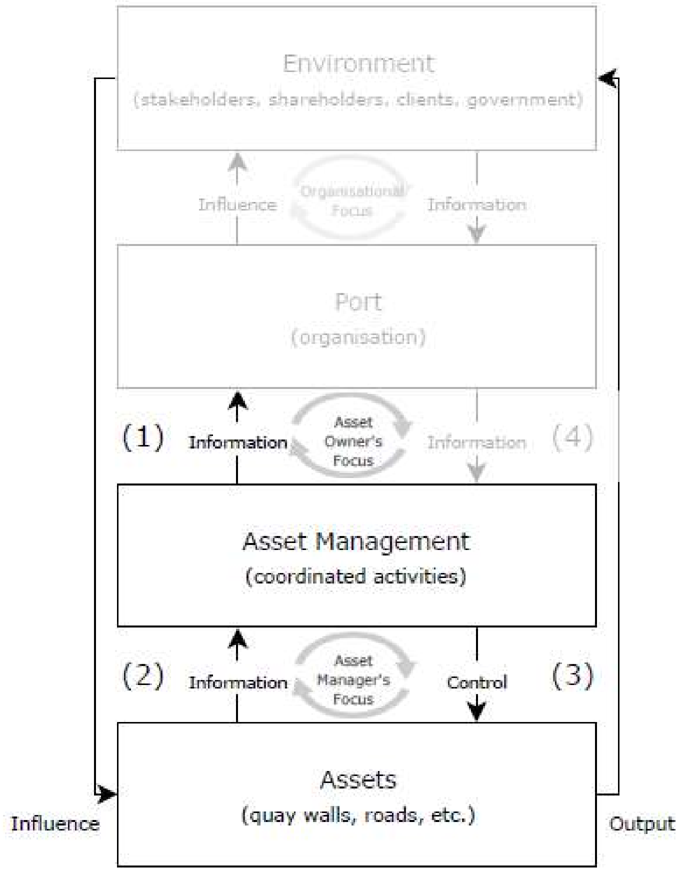
*Mark the boxes grey to show what type of variable is measured*




Note: examples can be found in Appendix I

**Control of Asset Managers:** hierarchical structure of the organisations and the position of asset management, asset managers and assets. Relations quantities should be controlled by the asset manager, or in co-operation.

*Discuss port control model, and decide what number is applicable and why*




Select at least one of the numbers: (1), (2), (3) or (4)

**Number:** *(1), (3)*

Explain why it is applicable to the benchmark

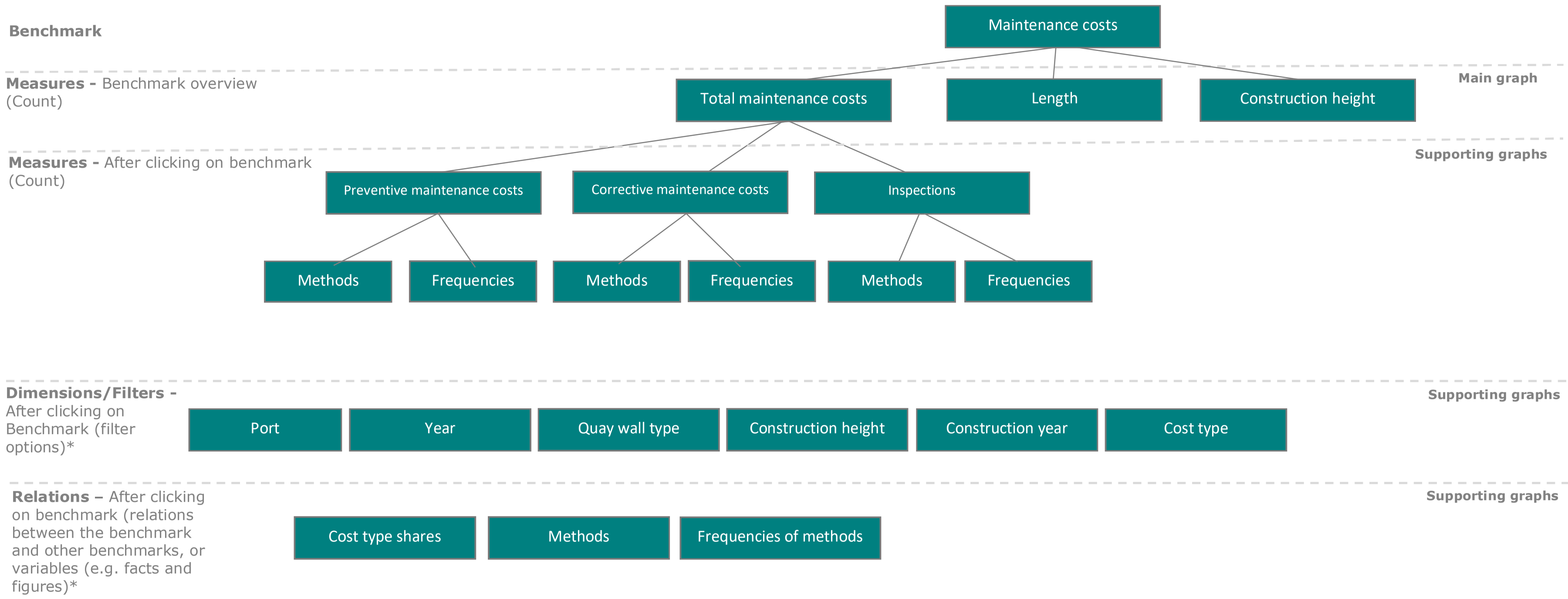
**Explanation:** *(1) maintenance costs; (3) maintenance activities: methods/concept/activities and the frequencies. The costs are costs a share of the total costs of the port as organisation and the budget. Budget constraints will follow from strategic decisions (4). Asset managers focus on managing assets. They can control their assets by performing maintenance. Information of interest for asset managers are certain maintenance (part of maintenance costs) and the frequencies on a yearly basis.*

Note: examples can be found in Appendix II

benchmark set up – *quay wall – maintenance costs*

## Hierarchical Construct of the Benchmark

**Hierarchical tree to measure and analyse:** hierarchical decomposition of the benchmark into variables on a lower level. This variables are required to quantify the benchmark, and identify necessary data. Identify dimensions and filters, for customised analysis to ensure a fair comparison ('like-for-like'). Identify relations to present additional graphs for detailed analysis.




*In the general overview with all Performance Measures/Benchmarks a distinction is made based on the asset type. Example: quay walls; construction height, roads; material (top layer)

## Goal

**Purpose:** *as a user (asset managers) of the benchmarking model I can compare the maintenance costs per length (m) so I can see what costs which port has per quay type and what ratio between the different type of maintenance costs are: preventive maintenance, corrective maintenance and inspections. This allows ports to compare their maintenance costs on quay walls with other ports and seek for improvements in order to create an optimal maintenance concept. Next to the costs, and the shares on the different types of costs, as a user I also want to know which type of maintenance activities (methods) are performed per maintenance type. For example what methods (or type of activities) are involved when performing inspections (e.g. diving inspection, corrosion measurements, visual inspections). Next to this I want to know the frequencies of the activities performed in order to execute maintenance (either for preventive, corrective and inspections).*

# Measure

## Mathematical Formula

**Main formula – benchmark overview:**

$$average\ maintenance\ costs =$$

$$\sum_{i=1}^{n}\left(\frac{preventive\ maintenane\ costs_i + corrective\ maintenance\ costs_i + inspection\ cost_i}{length_i}\right) * \left(\frac{length_i}{\sum_{i=1}^{n} lenght_i}\right)$$

*With $i$ = quay wall ID, $n$ = total number of quay wall IDs (of a certain range)*

*Explanation new formula:*

1. *Cost per unit (length)*
   *For each asset calculate the maintenance costs per meter, being the sum of the three cost types divided by the length:* $\frac{preventive\ maintenance\ costs_i + corrective\ maintenance\ costs_i + inspection\ cost_i}{length_i}$
2. *Weight*
   *This costs per unit (length) need to be multiplied by a weight, being the length of that asset divided by the total length of all quay wall assets:* $\frac{length_i}{\sum_{i=1}^{n} length_i}$
3. *Average maintenance costs*
   *The sum of all assets gives the average costs of the asset portfolio (all quays included in the filters). This sum is the sum of all assets' costs per unit (length) multiplied by the weight.*

   *Simple example:*
   *Grey cells are calculations, other cells is the data. The blue cell is the average cost, being the sum of that column.*

| Quay wall ID | Length$_i$ | Preventive costs$_i$ | Corrective costs$_i$ | Inspection cost$_i$ | Cost per unit | Weight | Cost per unit * Weight |
|---|---|---|---|---|---|---|---|
| 1 | 1000 | 10000 | 0 | 50 | 10.05 | 0.77 | 7.73 |
| 2 | 100 | 200 | 0 | 50 | 2.50 | 0.08 | 0.19 |
| 3 | 200 | 0 | 200 | 100 | 1.50 | 0.15 | 0.23 |
| sum | 1300 | | | | | | 8.15 |

*Note: the sum of the weight is in total 1. The weight depends on which assets are included in the filtering, so should change when the filter results in a smaller amount of assets.*

*Appendix IV: example in Excel sheet using real asset data.*

**Formula – after clicking on benchmark:**

*For all maintenance types (preventive, corrective and inspection), define the type of activities to do/execute maintenance and the corresponding frequencies.*

*Table overview different type of maintenance:*

| ***Maintenance type*** | ***Maintenance method*** |
|---|---|
| *Preventive maintenance* | *Hydrophobing concrete* |
| | *Coating sheet pile* |
| | *Flushing drainage* |
| | *Coating bollards* |
| | *Coating ladders* |
| | *Grease Quick Release Hooks* |
| | *Replacing dilatation joint* |
| | *Cathotic protection* |
| | *Replacing anodes* |
| | *Install erosion protection* |
| | *Replacing monitoring system* |
| *Corrective maintenance* | *Concrete repairs* |
| | *Replacing bollards* |
| | *Replacing fendering* |
| | *Replacing anchor* |
| | *Openings in sheet pile to reduce pressure* |
| | *Reinforce sheet pile* |
| | *Replacing erosion protection* |
| *Inspections* | *Visual inspections (above waterline)* |
| | *Diving inspections (visual)* |
| | *Thickness measurements* |
| | *Concrete chloride tests* |
| | *Concrete carbonation tests* |
| | *Concrete pressure test* |
| | *Sonar inspection* |
| | *Weight measurements anodes* |
| | *mV measurements anodes* |
| | *Monitoring systems* |

*The frequencies can be found in the data files: excel sheets and shape files. Frequencies are a number per year.*

## International Comparison

**Cross-port:** *ports have agreed upon the different maintenance methods. Maintenance methods are defined (see 'Mathematical Formula') in such a way that all ports should be able to allocate the methods to the methods defined in this template.*

**Cross-country:** *other currency. Therefore the costs in of Port of Gothenburg are divided by 10. More information: Appendix III*

## Data Collection Frequency

**Frequency:** all ports should collect data required for the benchmark annually. In this manner the performance can be recorded and reported, which allows asset managers to monitor the development of the benchmark.

## Required Data

**Data table:** variable names (counts) which can be found in the 'hierarchal construct of the benchmark' presented in the template, field name should match with the column names in the shape file or Excel sheet, definition obtained from properties file. Shape or Excel must contain the following data:

| **Data** | **Field name** | **Definition** |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *Quay ID* | *Quay_ID* | *Asset id of the quay* |
| *Quay type* | *Quaytype* | *Quay type as defined: Quay type as defined: Sheet pile, Sheetpile with relieving platform, Gravity wall, Open berth quay, Not applicable* |
| *Length* | *Length* | *Length of the quay wall (m)* |
| *Construction height* | *Const_Hght* | *Construction height of the quay wall* |
| *Construction year* | *Constr_Yea* | *Year of construction (year start using quay)* |
| *Maintenance cost* | | *Sum of all costs of all types of maintenance (preventive, corrective, and inspections)* |
| *Preventive costs* | *Prev_Main* | *Costs related to maintenance done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.* |
| *Hydrophobing concrete* | *pre_Coat_S* | *Hydrohobing, frequency of this preventive maintenance method* |
| *Coating sheet pile* | *pre_Flush_* | *Coating sheet pile, frequency of this preventive maintenance method* |
| *Flushing drainage* | *pre_Coat_B* | *Flusing drainage, frequency of this preventive maintenance method* |
| *Coating bollards* | *pre_Coat_L* | *Coating bollards, frequency of this preventive maintenance method* |
| *Coating ladders* | *pre_Grease* | *Coating ladders, frequency of this preventive maintenance method* |
| *Grease Quick Release Hooks* | *pre_Repla_* | *Grease quick release, frequency of this preventive maintenance method* |
| *Replacing dilatation joint* | *pre_Catho_* | *Replacing dilatation joint, frequency of this preventive maintenance method* |
| *Cathotic protection* | *pre_Repla1* | *Cathotic protection, frequency of this preventive maintenance method* |
| *Replacing anodes* | *pre_Insta_* | *Replacing anodes, frequency of this preventive maintenance method* |
| *Install erosion protection* | *pre_Repl_1* | *Install erosion protection, frequency of this preventive maintenance method* |

| | | |
|---|---|---|
| *Replacing monitoring system* | *Cor_Concr_* | *Replacing monitoring system, frequency of this preventive maintenance method* |
| *Hydrophobing concrete* | *Pre_Hydr_C* | *Hydrophobing concrete, frequency of this preventive maintenance method* |
| *Corrective maintenance costs* | *Cor_Main* | *Costs related to maintenance executed after a failure has occurred (basically reinstating equipment functionality). To be clear, corrective maintenance can be the result of a deliberate run-to-failure strategy.* |
| *Concrete repairs* | *Cor_Repla_* | *Concrete repairs, frequency of this corrective maintenance method* |
| *Replacing bollards* | *Cor_Repla1* | *Replacing bollards, frequency of this corrective maintenance method* |
| *Replacing fendering* | *Cor_Repl_1* | *Replacing fendering, frequency of this corrective maintenance method* |
| *Replacing anchor* | *Cor_Openi_* | *Replacing anchor, frequency of this corrective maintenance method* |
| *Openings in sheet pile to reduce pressure* | *Cor_Reinf_* | *Openings in sheet pile to reduce pressure, frequency of this corrective maintenance method* |
| *Reinforce sheet pile* | *Cor_Repl_2* | *Reinforce sheet pile, frequency of this corrective maintenance method* |
| *Replacing erosion protection* | *Insp_Visua* | *Replacing erosion protection, frequency of this corrective maintenance method* |
| *Replacing monitoring system* | *Cor_Concr_* | *Replacing monitoring system, frequency of this corrective maintenance method* |
| *Inspection costs* | *Insp_Cost* | *Costs related to inspections* |
| *Visual inspections (above waterline)* | *Insp_Visua* | *Visual inspections (above waterline), frequency of this inspection method* |
| *Diving inspections (visual)* | *Insp_Divin* | *Diving inspections (visual), frequency of this inspection method* |
| *Thickness measurements* | *Insp_Thick* | *Thickness measurements, frequency of this inspection method* |
| *Concrete chloride tests* | *Insp_Concr* | *Concrete chloride tests, frequency of this inspection method* |
| *Concrete carbonation tests* | *Insp_Con_1* | *Concrete carbonation tests, frequency of this inspection method* |
| *Concrete pressure test* | *Insp_Con_2* | *Concrete pressure test, frequency of this inspection method* |
| *Sonar inspection* | *Insp_Sonar* | *Sonar inspection, frequency of this inspection method* |
| *Weight measurements anodes* | *Insp_Weigh* | *Weight measurements anodes, frequency of this inspection method* |
| *mV measurements anodes* | *Insp_mV_Me* | *mV measurements anodes, frequency of this inspection method* |
| *Monitoring systems* | *Insp_Monit* | *Monitoring systems, frequency of this inspection method* |

Note: the information can be found in the properties file, in which all data characteristics (fieldname, fieldname shapefile and explanations can be found)

## Analyse

**Dashboard:** *maintenance costs can be analysed by comparing different ports, over different years, over different types of costs (preventive, corrective and inspections) and per construction height range. Next to this information about the shares of the different activities involved with a certain type of maintenance are displayed, and the corresponding frequencies of this type of maintenance activity. Examples of how the results could be presented in the dashboard can be found in the Appendix. More information: Appendix V*

## Improve

**Useful insights:** *after analyses, ports can decide if there are optimisations possible in their maintenance execution. They can see how the maintenance costs are calculated and which type of activities are performed for the different types of maintenance, and even more detailed the user can also see what the frequencies of the different activities are. In this way the user gets a complete and detailed overview of the costs and how maintenance is done. The 'goal' is in line with this contribution.*

Note: improvement and actions are the responsibility of each port and the asset managers individually. The goal explains what information can be derived from this benchmark.

## Control

**Data:** each port has to deliver the required data (see 'data requirements' and 'data collection frequency'). Data checks will take place both automatic and manual. Shape files shall be given the preference over Excel files, as it is highly compressed, portable, and less prone to errors.

# Appendices

## Appendix I

**Processes of Asset Managers – Examples**

As asset managers have to manage their asset, they deliver input to the assets which results in a certain output of the assets. These input and outputs can be measured:

| | *Define* | *Measure* | *Asset** |
|---|---|---|---|
| *Input* | Preventive maintenance | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | Corrective maintenance | Methods (description) | G |
| | | Costs (€/year) | G |
| | Inspections | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | etc. | | |
| *Output* | Availability of the asset | % Available (%) | G |
| | Condition of the asset | Rating | G |
| | etc. | | |
| *Influencing factors* | Climate conditions | Temperature (°C) | G |
| | Salinity of the water | Gram/parts (ppt) | Q |
| | Demand | Throughput (tonnes/year) | G |
| | | Intensity (veh/h) | R |
| | | Port Calls (#/year) | Q |
| | Requirements | Budget (€/year) | G |
| | | Port vision (#,% or description) | G |
| | | Rules & Regulations (description) | G |
| | Age of assets | EOL range | G |
| | etc. | | |

**Quay wall (Q), Road (R), Generic (G)*

*Note: additional variables can be determined in the column Define*

*Mark the cells in case they examples are relevant for this benchmark.*

## Appendix II

**Control of Asset Managers – Examples**

Controlled/influenced by the asset manager?

*(1) Information*

Maintenance costs

- Preventive maintenance costs
- Corrective maintenance costs
- Inspection costs (+testing and monitoring)

*(2) Information*

Performance of assets

- Availability
- Condition (visual or constructive)
- Risks

*(3) Control*
Maintenance activities

- Preventive maintenance: methods/activities, frequencies
- Corrective maintenance: methods/activities
- Inspections: methods/activities, frequencies

Not (direct) controlled/influenced by asset manager?
(4) *Information*
Requirements

- Budget
- Port vision: goals (environmental, etc.)
- Rules and regulations (international, national and port specific)

## Appendix III .

**International Comparison – Cross-country**

Port of Gothenburg

- Country: Sweden
- Currency: Swedish Krona

North Sea Port

- Country: Belgium, The Netherlands
- Currency: Euro

Port of Hamburg

- Country: Germany
- Currency: Euro

Port of Rotterdam

- Country: The Netherlands
- Currency: Euro


Assumption: Sweden has decided to divide all their costs by 10. In this way all ports can collect costs with the same unit (euro/m)

## Appendix IV .

**Example Average Maintenance Costs using Real Data**

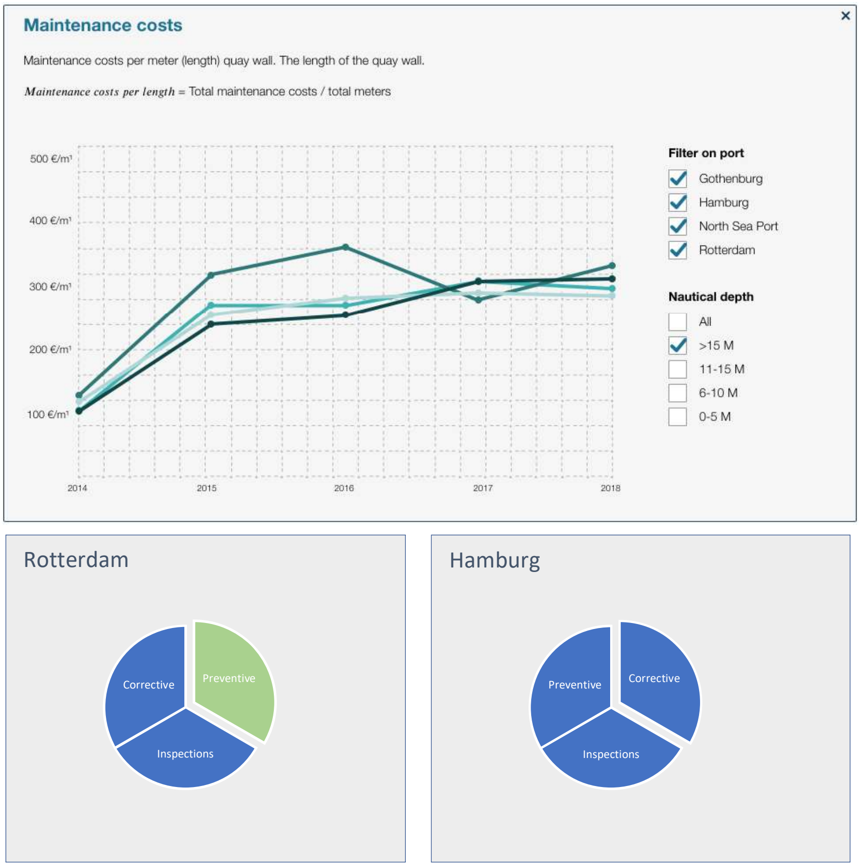
Excel sheet: *<not included due to confidentiality>*

# Appendix V

**Dashboard – Example Visualisation**

Idea of how to present the benchmark after clicking in the general overview in which all benchmarks for the Quay Wall asset presented:

Note: filters should be expanded: all dimensions presented in the 'hierarchical structure' should be a filter option, so a larger variety of filters (not only filter on port and nautical height)




By clicking on for example the red pie, you get an overview (in a new window) of all maintenance methods (activities) on corrective maintenance for Rotterdam, and next to that the columns of the selected ports:

**Preventive maintenance -Methods**

| Rotterdam | | Hamburg | |
|---|---|---|---|
| Activities (description) | Frequencies (#/…) | Activities (description) | Frequencies (#/…) |
| … | - | … | - |
| | | | |
| | | | |

**Corrective maintenance -Methods**

| Rotterdam | | Hamburg | |
|---|---|---|---|
| Activities (description) | Frequencies (#/…) | Activities (description) | Frequencies (#/…) |
| … | - | … | - |
| | | | |

# M

# Case Study: Quay Wall, Condition

In this Appendix for the asset 'road' the benchmark 'condition' is specified by filling out the performance measurement template which can be found in Appendix G.

benchmark set up – *quay wall – condition*

# Performance Measurement Template

## Define

### General Information

**Benchmark name:** *Condition*

**Version:** *final*

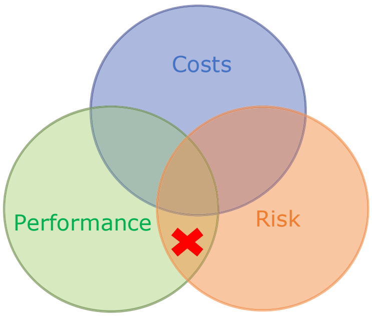
**Definition:** *condition of the quay wall is the present state of the asset, usually present state of a physical asset, usually referring to the structural integrity. It can also relate to appearance, therefore the visual condition (results of inspections) is also taken into account. The condition is determined by the degree of damage and deterioration, extracted from visual inspection or destructive or non-destructive testing.*

**Asset type:** *quay wall*

### Guiding Principles: Theoretical Constructs to Position the Benchmark .

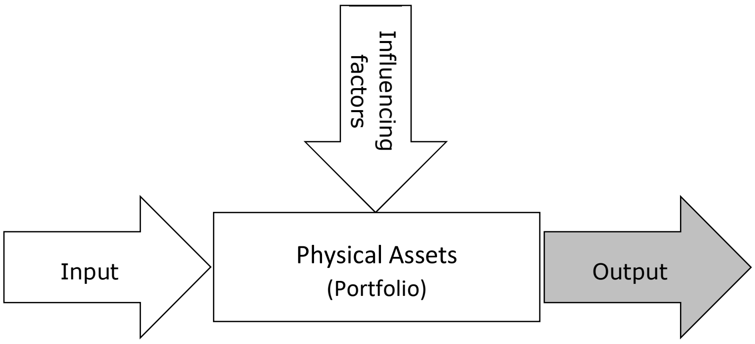
**Focus of Asset Managers:** position of the benchmark in relation to Asset Management objectives. The triangle of performance, costs and risk.

*Place the cross on the spot to show what the benchmark measures*




**Processes of Asset Managers:** position of the benchmark in processes involved when managing assets. Performance measurement framework.

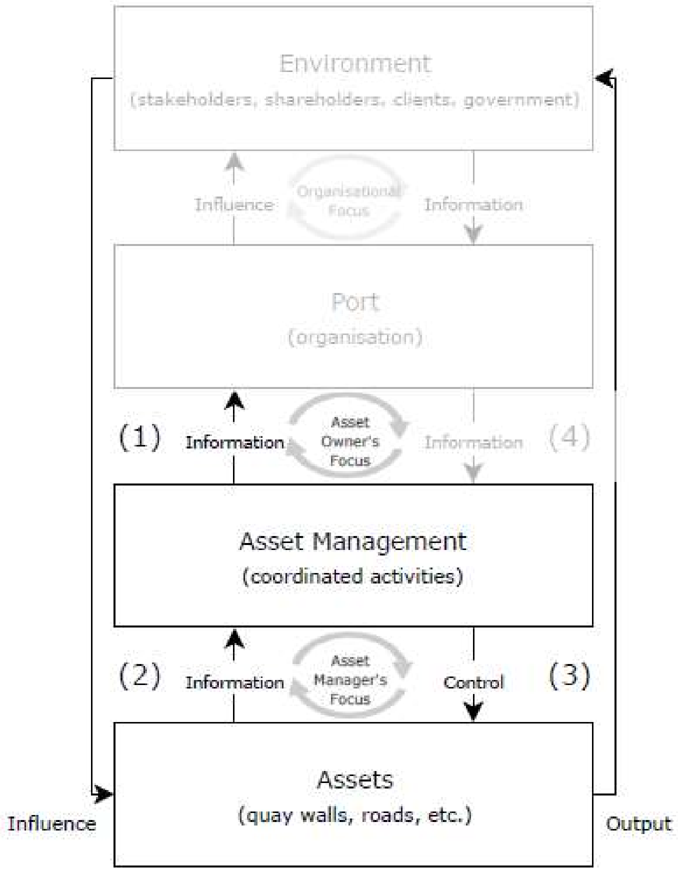
*Mark the boxes grey to show what type of variable is measured*




Note: examples can be found in Appendix I

**Control of Asset Managers:** hierarchical structure of the organisations and the position of asset management, asset managers and assets. Relations quantities should be controlled by the asset manager, or in co-operation.

*Discuss port control model, and decide what number is applicable and why*




Select at least one of the numbers: (1), (2), (3) or (4)

**Number:** *(2)*

Explain why it is applicable to the benchmark

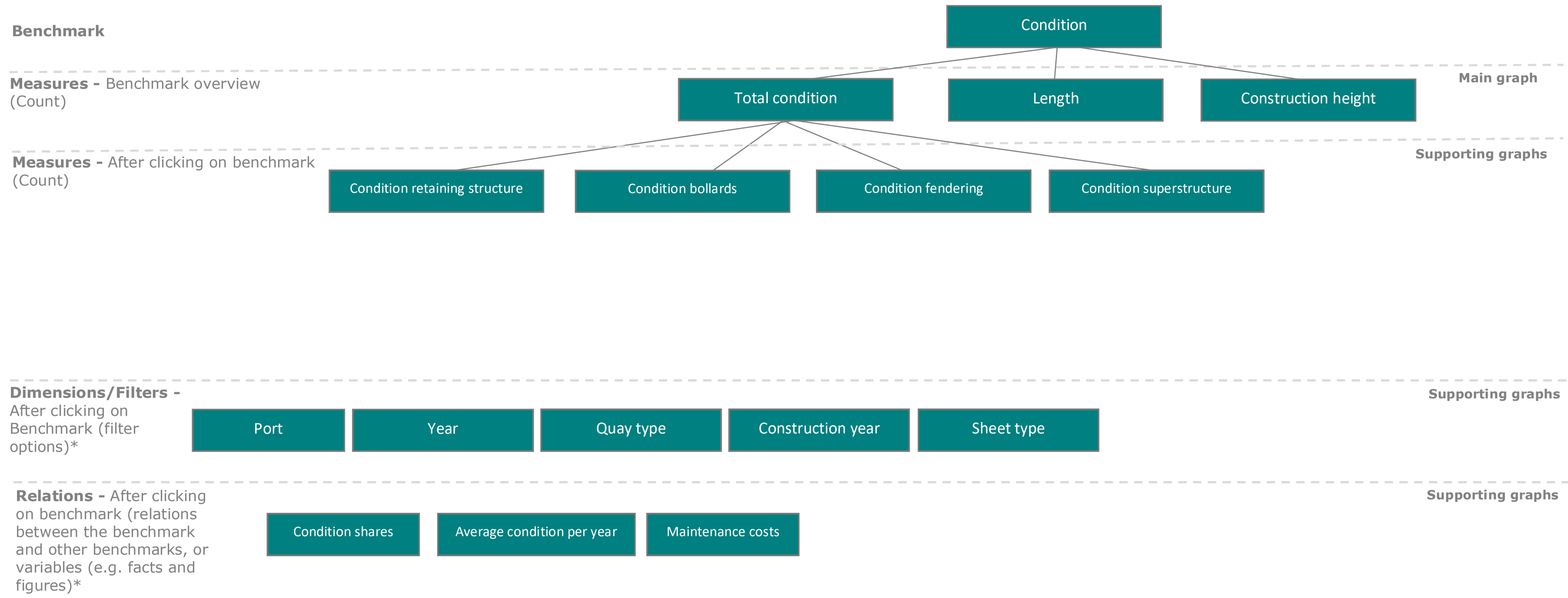
**Explanation:** *following from actions performed (control) or managed by the asset manager, the condition of the asset can be monitored by asset managers. The asset managers receive feedback, information (2), of the assets as they have a certain structural/visual condition. The responsibility to make sure the assets are in a certain condition if customers want to make use of the assets. Port calls/berth, transshipment of goods etc.*

Note: examples can be found in Appendix II

benchmark set up – *quay wall – condition*

## Hierarchical Construct of the Benchmark

**Hierarchical tree to measure and analyse:** hierarchical decomposition of the benchmark into variables on a lower level. This variables are required to quantify the benchmark, and identify necessary data. Identify dimensions and filters, for customised analysis to ensure a fair comparison ('like-for-like'). Identify relations to present additional graphs for detailed analysis.




*In the general overview with all Performance Measures/Benchmarks a distinction is made based on the asset type. Example: quay walls; construction height, roads; material (top layer)

PORTS

## Goal

**Purpose:** *As a user (asset manager) I want to know what the condition of the assets is, by mapping the condition the results can be used to make interpretations of other benchmarks and figures. Asset condition reflects the physical state of the asset, which may or may not affect its performance. The performance of the asset is the ability to provide the required level of service to customers. Level of risk is also an output, the condition of an asset also contributes to the risk level. The condition of the assets tells how assets are managed, a certain maintenance concept and strategy, next to this the results of how the input of the asset manager is translated into output. Limitations: many other factors are involved. For example: utilisation, weather conditions, salinity of the water etc.*

# Measure

## Mathematical Formula

**Main formula – benchmark overview:**

For every quay ID you find the condition (green, yellow, orange, and red). After that you multiple it with the length (this is a weight) of that quay ID, and then you divide the total length of all quay wall IDs by the total surface. To define an average condition for a certain selection (made with filters) the colours should be linked to numbers: green (4), yellow (3), orange (2), red (1). Note: this is how we collect data. Numbers shouldn't be shown on the platform. The numbers are only for the data use and defining the average. *Question:* what is the average colour (condition) of my assets?

$$(average)\ condition = \frac{\sum_{i=1}^{n} condition_i * length_i}{\sum_{i=1}^{n} length_i}$$

Add for quay walls:
The condition of one quay wall ID: first determine the condition with a formula for condition:

$$condition_i = weight_{retaining\ structure} * condition_{i,retaining\ structure} + weight_{bollards} * condition_{i,bollards} + weight_{fenders} * condition_{i,fenders} + weight_{superstructure} * condition_{i,superstructure}$$

Fixed values, with a total value of 1 (sum):

$$weight_{retaining\ structure} = 0{,}50$$

$$weight_{superstructure} = 0{,}25$$

$$weight_{bollards} = 0{,}15$$

$$weight_{fenders} = 0{,}10$$

**Formula – after clicking on benchmark:**

For every category:

To <u>define the shares in a certain condition</u>, so how many meters are in a certain condition. For every condition (there are four) you sum al the length in that condition rate/category. The results of these calculations are presented in pie charts.
*Question:* how many meter quay wall is of a certain condition, defined in a percentage of the total number of meters (=length/running meter)?

$$Total\ meters\ in\ each\ condition = \sum_{i=1}^{n} Length_i$$

$$Percentage\ of\ each\ condition = \frac{\sum_{i=1}^{n} Length_i}{Total\ length} * 100\%$$

With $i$ = quay wall ID, $n$ = total number of all (or for one condition range) quay wall IDs

Where:

- $Condition_i$ = condition of quay wall ID *i*
- $Length_i$ = length in metres of quay ID *i*
- $Total\ length_i$ = sum of all quay wall ID's. Total length.

The condition ranges between 4 and 1. The following definitions should be presented in the dashboard:

- New = green (4)
- Good = yellow (3)
- Poor = orange (2)
- Critical = red (1)

*Appendix IV: additional information on condition definitions*

*Simple example calculation*

Calculation of the (average) condition of one port (A-D are all quays).

| Quay ID | Part | Condition | Length (m) |
|---|---|---|---|
| A | | | 550 |
| | Superstructure | 1 | |
| | Retaining structure | 4 | |
| | Fendering | 3 | |
| | Bollards | 2 | |
| B | | | 700 |
| | Superstructure | 2 | |
| | Retaining structure | 4 | |
| | Fendering | 1 | |
| | Bollards | 2 | |
| C | | | 1250 |
| | Superstructure | 4 | |
| | Retaining structure | 4 | |
| | Fendering | 3 | |
| | Bollards | 2 | |
| D | | | 250 |
| | Superstructure | 1 | |
| | Retaining structure | 1 | |

| | | | |
|---|---|---|---|
| | Fendering | 4 | |
| | Bollards | 3 | |

$$Condition_A = 0.50 * 4 + 0.25 * 1 + 0.15 * 2 + 0.10 * 3 = 2.85 \rightarrow 3$$

$$Condition_B = 0.50 * 4 + 0.25 * 2 + 0,15 * 2 + 0,10 * 1 = 2.90 \rightarrow 3$$

$$Condition_C = 0.50 * 4 + 0.25 * 4 + 0.15 * 2 + 0.10 * 3 = 3.60 \rightarrow 4$$

$$Condition_D = 0.50 * 1 + 0.25 * 1 + 0.15 * 3 + 0.10 * 4 = 1.60 \rightarrow 2$$

*Note: 0,5 will be rounded to 1 and 0,45 will be rounded to 0*

$$(average)\ condition = \frac{(3 * 550m) + (3 * 700m) + (4 * 1250) + (2 * 250)}{2750m} = 3.36$$

**Dashboard – after clicking on benchmark:**

*More options to filter, and compare the condition of the assets:*

*- Per port for the selected year(s) (average of selected years of conditions of one year) presented in pie charts. Taking into account the weights (length quay wall/total length all quay walls)*

*- Development over the years (in the general overview the conditions shares are compared with the average of the selected ports)*

*- In relation to other benchmarks (e.g. the benchmark maintenance costs)*

*Appendix III: example in Excel sheet using real asset data*.

## International Comparison .

**Cross-port:** *conditions is categorised in a different way for each port. For this reason conditions needs to be compared, and scaled in such a way that all ports can allocate their own condition to a generic condition. Ports have agreed upon four ranges. For each element (retaining structure, bollards, fendering and superstructure) the conditions are discussed. For each range (green, yellow, orange, red) both a definition and pictures are added. More information: Appendix IV.*

**Cross-country:** *the conditions vary by port. Ports can use the same standards but still there are differences in interpretation on port-level. For this reason only the cross-port differences are relevant.*

## Data Collection Frequency .

**Frequency:** all ports should collect data required for the benchmark annually. In this manner the performance can be recorded and reported, which allows asset managers to monitor the development of the benchmark.

## Required Data .

**Data table:** variable names (counts) which can be found in the 'hierarchal construct of the benchmark' presented in the template, field name should match with the column names in the shape file or Excel sheet, definition obtained from properties file. Shape or Excel must contain the following data:

| **Data** | **Field name** | **Definition** |
|---|---|---|
| *Port* | *Port_Area* | *Port name* |
| *Year* | *BM_Year* | *Year* |
| *Quay ID* | *Quay_ID* | *Asset ID of the quay* |
| *Quay type* | *Quaytype* | *Quay type as defined: Sheet pile, Sheetpile with relieving platform, Gravity wall, Open berth quay,Not applicable* |
| *Length* | *Length* | *Length of the quay wall (m)* |
| *Construction height* | *Const_Hght* | *Construction height of the quay wall* |
| *Construction year* | *Constr_Yea* | *Year of construction (year start using quay)* |
| *Condition* | *Cond_Total* | *Condition of the quay wall. Weighted sum of all elements for which a condition is defined. Ranges: 4 (green), 3 (yellow), 2 (orange), 1 (red). Note: green is the perfect/new condition. In Appendix IV can be found more information on the categories* |
| *Condition retaining structure* | *Cond_Retai* | *Condition of the retaining structure.* |
| *Condition bollards* | *Cond_Bolla* | *Conditions of the bollards.* |
| *Condition superstructure* | *Condi_Super* | *Condition of the superstructure.* |
| *Condition fendering* | *Cond_Fende* | *Condition of the fendering.* |
| *Maintenance cost* | | *Sum of all costs of all types of maintenance (preventive, corrective, and inspections) Note: other benchmark, enables to analyse the relation between maintenance cost (input) en condition (output)* |
| *Preventive costs* | *Prev_Main* | *Costs related to maintenance done before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.* |

| | | |
|---|---|---|
| *Corrective maintenance costs* | *Cor_Main* | *Costs related to maintenance executed after a failure has occurred (basically reinstating equipment functionality). To be clear, corrective maintenance can be the result of a deliberate run-to-failure strategy.* |
| *Inspection costs* | *Insp_Cost* | *Costs related to inspections* |
| *Condition* | *Cond_Total* | *Condition of the quay wall. Weighted sum of all elements for which a condition is defined. Ranges: 4 (green), 3 (yellow), 2 (orange), 1 (red). Note: green is the perfect/new condition. In Appendix IV can be found more information on the categories* |
| *Sheet type* | *Constr_She* | *Type of the sheetpile. Type: Steel combiwall, Steel sheetpile, Concrete, Wooden sheetpile, Concrete sheetpile, Not applicable* |

Note: the information can be found in the properties file, in which all data characteristics (fieldname, fieldname shapefile and explanations can be found)

benchmark set up – *quay wall – condition*

## Analyse

**Dashboard:** *condition can be analysed by comparing different ports, over the years. The share of the total assets in a certain condition. Next to this the condition will be visualised in relation to maintenance costs. The age of the asset (construction year) is also of importance, it can be expected that older ages require more/frequent maintenance. In this way filters can ensure fair comparison, comparing 'apples with apples'. More information: Appendix V.*

## Improve

**Useful insights:** *after analysing, port can decide what they think about their condition. Is it in line with their strategy. In this way ports can measure and compare their performance in terms of condition. Based on the results, only the condition or the relation between cost and condition, can be a trigger to adapt their maintenance strategy. Ports can learn from each other in this way. This insights are also reflected in the 'goal' of this benchmark. Many improvement options require further research.*

Note: improvement and actions are the responsibility of each port and the asset managers individually. The goal explains what information can be derived from this benchmark.

## Control

**Data:** each port has to deliver the required data (see 'data requirements' and 'data collection frequency'). Data checks will take place both automatic and manual. Shape files shall be given the preference over Excel files, as it is highly compressed, portable, and less prone to errors.

# Appendices

## Appendix I .

**Processes of Asset Managers – Examples**

As asset managers have to manage their asset, they deliver input to the assets which results in a certain output of the assets. These input and outputs can be measured:

| | *Define* | *Measure* | *Asset** |
|---|---|---|---|
| *Input* | Preventive maintenance | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | Corrective maintenance | Methods (description) | G |
| | | Costs (€/year) | G |
| | Inspections | Methods (description) | G |
| | | Frequencies (#/year) | G |
| | | Costs (€/year) | G |
| | etc. | | |
| *Output* | Availability of the asset | % Available (%) | G |
| | Condition of the asset | Rating | G |
| | etc. | | |
| *Influencing factors* | Climate conditions | Temperature (°C) | G |
| | Salinity of the water | Gram/parts (ppt) | Q |
| | Demand | Throughput (tonnes/year) | G |
| | | Intensity (veh/h) | R |
| | | Port Calls (#/year) | Q |
| | Requirements | Budget (€/year) | G |
| | | Port vision (#,% or description) | G |
| | | Rules & Regulations (description) | G |
| | Age of assets | EOL range | G |
| | etc. | | |

**Quay wall (Q), Road (R), Generic (G)*
*Note: additional variables can be determined in the column Define*

*Mark the cells in case they examples are relevant for this benchmark.*

## Appendix II .

**Control of Asset Managers – Examples**

Controlled/influenced by the asset manager?

*(1) Information*
Maintenance costs

- Preventive maintenance costs
- Corrective maintenance costs
- Inspection costs (+testing and monitoring)

*(2) Information*
Performance of assets

- Availability
- Condition (visual or constructive)
- Risks

*(3) Control*
Maintenance activities

- Preventive maintenance: methods/activities, frequencies
- Corrective maintenance: methods/activities
- Inspections: methods/activities, frequencies

Not (direct) controlled/influenced by asset manager?
(4) *Information*
Requirements

- Budget
- Port vision: goals (environmental, etc.)
- Rules and regulations (international, national and port specific)

## Appendix III .

**Example Average Condition using Real Data**

Excel sheet: *<not included due to confidentiality>*

## Appendix IV .

**International Comparison – Cross-port**

Conditions ranges differ per port. As quay walls have different elements, for each of this element (or clustering of elements) a conditions is given. Port of Gothenburg, Port of Hamburg, North Sea Port and Port of Rotterdam have agreed upon the definitions as presented in this appendix. This agreement enables ports to compare asset conditions.

The condition of one quay wall (ID) can be defined by multiplying the conditions with the following weights:

Fixed values, with a total value of 1 (sum):

$$weight_{retaining\ structure} = 0{,}50$$

$$weight_{superstructure} = 0{,}25$$

$$weight_{bollards} = 0{,}15$$

$$weight_{fenders} = 0{,}10$$

**Condition - Retaining Structure**

$Condition_{retaining\ structure}$ :

| Score | Definition |
|---|---|
| 4 (New) | There are no or minor damages and no or little appearance of deterioration. |
| 3 (Good) | There are damages and/or considerable deterioration without influence on the functionality. |

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| | |
|---|---|
| 2 (Poor) | There are damages and/or deterioration with significant influence on the functionality but the safety factor remains above 1.0 |
| 1 (Critical) | The functionality is not given or/and the safety factor is below 1.0 |

**Condition - Bollards**

$\text{Condition}_{\text{bollards}}$ :

| Score | Definition |
|---|---|
| 4 (New) | There are no or minor damages and no or little appearance of deterioration regarding the coating, steel thickness and numbering. |

| | |
|---|---|
| 3 (Good) | There are damages and/or considerable deterioration regarding the coating, steel thickness and numbering. without influence on the functionality. |



| | |
|---|---|
| 2 (Poor) | There are damages and/or deterioration with significant influence on the functionality. For example; because of the reduced steel thickness, it is not possible to use the total bollard capacity (kN). |

benchmark set up – *quay wall – condition*

| | |
|---|---|
| 1 (Critical) | The functionality is not given |

**Condition - Fenders**

Condition$_{\text{fenders}}$ :

| Score | Definition |
|---|---|
| 4 (New) | There are no or minor damages and no or little appearance of deterioration. |


| | |
|---|---|
| 3 (Good) | There are damages and/or considerable deterioration without influence on the functionality. |

| | |
|---|---|
| 2 (Poor) | There are damages and/or deterioration with significant influence on the functionality |

| | |
|---|---|
| 1 (Critical) | The functionality is not given |

**Condition - Superstructure**

Condition$_{superstructure}$ :

| Score | Definition |
|---|---|
| 4 (New) | There are no or minor damages and no or little appearance of deterioration. |

benchmark set up – *quay wall – condition*

| | |
|---|---|
| 3 (Good) | There are damages and/or considerable deterioration without influence on the functionality. |

| | |
|---|---|
| 2 (Poor) | There are damages and/or deterioration regarding the steel rebars and concrete. For example; the steel rebars are visible and you can see the concrete pouring of the superstructure and/or there are significant cracks in the concrete |

| | |
|---|---|
| 1 (Critical) | The functionality is not given |

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# Appendix V

## Dashboard – Example Visualisation

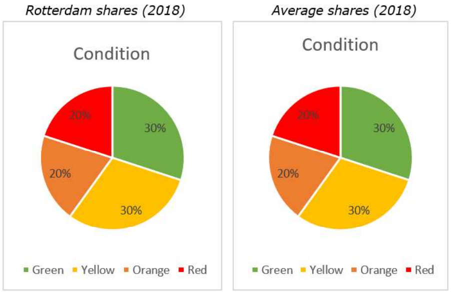
In the benchmark overview:

- Compare the condition shares of your port with the average conditions shares of all selected ports.

In the detailed overview some graphs should be presented:

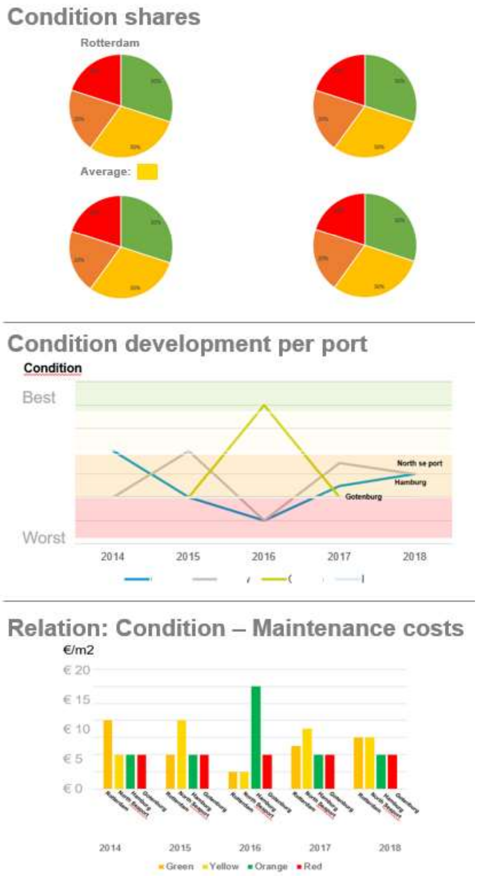
- Conditions shares, for each ports
- Condition development over the years, for each port
- Relation between two benchmarks: Maintenance Costs vs Condition

### Dashboard - Benchmark overview




*Average condition Rotterdam: yellow (2,3)*
*Average condition: orange*

### Dashboard - Detailed page condition



# N

# Dashboard Scripts

The scripts are written in SQL, developed to make sure quick and direct interactions between the different data sources in the database can take place.

All p_gen_* scripts ensure that all port or asset data can be quickly obtained per page (dashboard overview) or per graph. When executing scripts, this code will be used to quickly create the required overviews in the dashboard. The p_get_* scripts will be executed when a graph is being called. Before all p_get_* scripts are executed to create overviews, the filters for customised analysis will be applied via p_getReport script.

For each overview a script for data preparing (p_gen_*) and graph creating (p_get_*) is written. For customising (p_getReport) only one script is required. This script can be applied to every overview. The example presented in Section N.1 shows an example of a script for data preparation. This script generates the date required for the ports facts & figures overview.

Some SQL scrips can be found in this appendix to show how the visualisation in the dashboard are created:

- *Appendix N.1:* Data preparation for ports facts & figures page. Generate data lists for the port benchmarks.
- *Appendix N.2:* Draw graphs to visualise benchmark results on port level.
- *Appendix N.3:* Data preparation for asset benchmark. Generate data lists for asset benchmark: maintenance costs, quay wall.
- *Appendix N.4:* Draw graphs to visualise benchmark results on asset level: maintenance costs, quay wall.
- *Appendix N.5:* Include filter options to customise benchmarks at asset level.

## N.1. Generate Data - Ports Facts & Figures

```
CREATE PROCEDURE [rpt].[p_gen_ports_facts_figures]
AS
BEGIN
    SET NOCOUNT ON;

    DECLARE @curr_year INT;

    SET @curr_year = (SELECT MAX(asd_period)
                      FROM   app.t_asd_assetData);

    DELETE FROM rpt.t_rpt_report
    WHERE       rpt_rtt_code = 'ports_facts_figures';

        INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                                     , rpt_rtt_dataset
```

```
                              , rpt_filter1)
SELECT distinct 'ports_facts_figures'
      , 'default'
      , asd.asd_period
FROM   app.v_asd_port asd;

INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                              , rpt_rtt_dataset
                              , rpt_filter1
                              , rpt_filter2
                              , rpt_value1
                                                             , rpt_value2 )
SELECT 'ports_facts_figures'
      , 'vessels'
      , asd.asd_period
      , prt.prt_name
      , SUM(ISNULL(asd.asd_vessels_sea_going, 0))
      , SUM(ISNULL(asd.asd_vessels_inland, 0))
FROM   app.v_asd_port AS asd
INNER JOIN app.t_prt_port AS prt ON prt.prt_code = asd.asd_prt_code
GROUP BY prt.prt_name
        , asd.asd_period;


INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                              , rpt_rtt_dataset
                              , rpt_filter1
                              , rpt_filter2
                              , rpt_value1)
SELECT 'ports_facts_figures'
      , 'seaborne_throughput'
      , asd.asd_period
      , prt.prt_name
      , SUM(ISNULL(asd.asd_seaborne_throughput, 0))
FROM   app.v_asd_port AS asd
INNER JOIN app.t_prt_port AS prt ON prt.prt_code = asd.asd_prt_code
GROUP BY prt.prt_name
        , asd.asd_period;

INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                              , rpt_rtt_dataset
                              , rpt_filter1
                              , rpt_filter2
                              , rpt_value1)
SELECT 'ports_facts_figures'
      , 'added_value'
      , asd.asd_period
      , prt.prt_name
      , SUM(ISNULL(asd.asd_added_value, 0))
FROM   app.v_asd_port AS asd
INNER JOIN app.t_prt_port AS prt ON prt.prt_code = asd.asd_prt_code
GROUP BY prt.prt_name
        , asd.asd_period;
INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                              , rpt_rtt_dataset
                              , rpt_filter1
```

```
                                 , rpt_filter2
                                 , rpt_value1)
    SELECT 'ports_facts_figures'
         , 'businesses'
         , asd.asd_period
         , prt.prt_name
         , SUM(ISNULL(asd.asd_number_of_businesses, 0))
    FROM   app.v_asd_port AS asd
    INNER JOIN app.t_prt_port AS prt ON prt.prt_code = asd.asd_prt_code
    GROUP BY prt.prt_name
           , asd.asd_period;
    INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                                 , rpt_rtt_dataset
                                 , rpt_filter1
                                 , rpt_filter2
                                 , rpt_value1)
    SELECT 'ports_facts_figures'
         , 'employment'
         , asd.asd_period
         , prt.prt_name
         , SUM(ISNULL(asd.asd_employment, 0))
    FROM   app.v_asd_port AS asd
    INNER JOIN app.t_prt_port AS prt ON prt.prt_code = asd.asd_prt_code
    GROUP BY prt.prt_name
           , asd.asd_period;
    INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                                 , rpt_rtt_dataset
                                 , rpt_filter1
                                 , rpt_filter2
                                 , rpt_value1)
    SELECT 'ports_facts_figures'
         , 'port_area'
         , asd.asd_period
         , prt.prt_name
         , SUM(ISNULL(asd.asd_hectares_port_area, 0))
    FROM   app.v_asd_port AS asd
    INNER JOIN app.t_prt_port AS prt ON prt.prt_code = asd.asd_prt_code
    GROUP BY prt.prt_name
           , asd.asd_period;
END;
```

## N.2. Generate Dashboard Visualisations - Ports Facts & Figures

```
CREATE PROCEDURE [rpt].[p_get_ports_facts_figures]
  @chr_code VARCHAR(50)
, @chr_param1 VARCHAR(20)
, @chr_param2 VARCHAR(20)
, @rtt_code VARCHAR(50)
, @rtt_dataset VARCHAR(50)
, @rtt_sequence INT
, @t rpt.tt_rpt READONLY
AS
BEGIN
  SET NOCOUNT ON;

  IF(@chr_code = 'facts_figures_seaborne_throughput')
```

```
BEGIN
        SELECT rpt.rpt_filter2 AS rpt_filter1
             , rpt.rpt_value1
             , '' AS rpt_value5
        FROM   @t AS rpt
        WHERE  rpt.rpt_rtt_code = @rtt_code
                 AND rpt.rpt_rtt_dataset = @rtt_dataset;
END

ELSE IF(@chr_code = 'facts_figures_added_value')
BEGIN
        SELECT rpt.rpt_filter2 AS rpt_filter1
             , rpt.rpt_value1
             , '' AS rpt_value5
        FROM   @t AS rpt
        WHERE  rpt.rpt_rtt_code = @rtt_code
                 AND rpt.rpt_rtt_dataset = @rtt_dataset;
END

ELSE IF(@chr_code = 'facts_figures_number_of_businesses')
BEGIN
        SELECT rpt.rpt_filter2 AS rpt_filter1
             , rpt.rpt_value1
             , '' AS rpt_value5
        FROM   @t AS rpt
        WHERE  rpt.rpt_rtt_code = @rtt_code
                 AND rpt.rpt_rtt_dataset = @rtt_dataset;
END

ELSE IF(@chr_code = 'facts_figures_employment')
BEGIN
        SELECT rpt.rpt_filter2 AS rpt_filter1
             , rpt.rpt_value1
             , '' AS rpt_value5
        FROM   @t AS rpt
        WHERE  rpt.rpt_rtt_code = @rtt_code
                 AND rpt.rpt_rtt_dataset = @rtt_dataset;
END

ELSE IF(@chr_code = 'facts_figures_hectares_port_area')
BEGIN
        SELECT rpt.rpt_filter2 AS rpt_filter1
             , rpt.rpt_value1
             , '' AS rpt_value5
        FROM   @t AS rpt
        WHERE  rpt.rpt_rtt_code = @rtt_code
                 AND rpt.rpt_rtt_dataset = @rtt_dataset;;
END

ELSE IF(@chr_code = 'facts_figures_vessels')
BEGIN
        SELECT rpt.rpt_filter2 AS rpt_filter1
             , IIF(@chr_param1 = 'sea-going', rpt.rpt_value1, rpt.rpt_value2) AS rpt_
             , '' AS rpt_value5
        FROM   @t AS rpt
        WHERE  rpt.rpt_rtt_code = @rtt_code
```

```
                                        AND rpt.rpt_rtt_dataset = @rtt_dataset
  END
END;
GO
```

## N.3. Generate Data - Quay Wall Maintenance Costs

```
CREATE PROCEDURE [rpt].[p_gen_quay_maintenance]
AS
BEGIN
    SET NOCOUNT ON;

    DELETE FROM rpt.t_rpt_report
    WHERE       rpt_rtt_code = 'quay_maintenance';

    WITH
         cte_data
         AS (SELECT prt.prt_name
                  , asd.asd_period
                  , asd.asd_wall_type
                  , rng_depth.rng_name AS rng_name_depth
                  , rng_constr_year.rng_name AS rng_name_constr
                  , SUM(ISNULL(asd.asd_maint_insp, 0)) AS asd_maint_insp
                  , SUM(ISNULL(asd.asd_maint_corr, 0)) AS asd_maint_corr
                  , SUM(ISNULL(asd.asd_maint_prev, 0)) AS asd_maint_prev
                                  , SUM(ISNULL(asd.asd_length, 0)) AS asd_length
             FROM   app.v_asd_quay AS asd
                        INNER JOIN app.t_prt_port prt ON prt.prt_code = asd.asd_prt_code
                        INNER JOIN cnf.t_rng_range rng_constr_year
                               ON asd.asd_constr_year BETWEEN rng_constr_year.rng_start AND rng_const
                               AND rng_constr_year.rng_type_lsi = 'quay_constr_year'
                        INNER JOIN cnf.t_rng_range rng_depth
                        ON ABS(asd.asd_constr_depth) BETWEEN rng_depth.rng_start AND rng_depth.rng_en
                               and rng_depth.rng_type_lsi = 'quay_depth'
             GROUP BY prt.prt_name
                  , asd.asd_period
                  , asd.asd_wall_type
                  , rng_depth.rng_name
                  , rng_constr_year.rng_name)
         INSERT INTO rpt.t_rpt_report ( rpt_rtt_code
                                      , rpt_rtt_dataset
                                      , rpt_filter1
                                      , rpt_filter2
                                      , rpt_filter3
                                      , rpt_filter4
                                      , rpt_filter5
                                      , rpt_filter6
                                      , rpt_value1
                                      , rpt_value2 )
         SELECT 'quay_maintenance'
              , 'default'
              , cte.prt_name
              , cte.asd_period
              , ISNULL(cte.asd_wall_type, 'undefined')
              , cte.rng_name_depth
              , cte.rng_name_constr
```

```
            , lsi.lsi_code
            , IIF(lsi.lsi_code = 'inspection', cte.asd_maint_insp, IIF(lsi.lsi_code = 'correct
                    , cte.asd_length
        FROM   cte_data AS cte
        CROSS JOIN cnf.t_lsi_listItem AS lsi
        WHERE  lsi.lsi_group = 'maintenance_type';
END;
GO
```

## N.4. Generate Dashboard Visualisation - Quay Wall Maintenance Costs

```
CREATE PROCEDURE [rpt].[p_get_quay_maintenance]
  @chr_code VARCHAR(50)
, @chr_param1 VARCHAR(20)
, @chr_param2 VARCHAR(20)
, @rtt_code VARCHAR(50)
, @rtt_dataset VARCHAR(50)
, @rtt_sequence INT
, @t rpt.tt_rpt READONLY
AS
BEGIN
  SET NOCOUNT ON;

  DECLARE @i INT
              , @average REAL
        , @current_year INT = cnf.sf_getCurrentYear();

  IF (@chr_code = 'quay_maintenance_total')
  BEGIN
    SET @i = ( SELECT COUNT(1)
               FROM rpt.t_flt_filter AS flt
               WHERE flt.flt_rtt_seq = @rtt_sequence
                     AND flt_nr = 6
                     AND flt.flt_active = 1);

    SELECT tmp.rpt_filter1
         , tmp.rpt_filter2
         , ROUND((SUM(rpt_value1) / SUM(rpt_value2)) * @i, 2) AS rpt_value1
                 , 'euro/m' AS rpt_value5
    FROM @t AS tmp
    GROUP BY tmp.rpt_filter1
           , tmp.rpt_filter2
        ORDER BY tmp.rpt_filter2;
  END;

  ELSE IF (@chr_code = 'quay_maintenance_port')
  BEGIN
              WITH cte AS (
                      SELECT tmp.rpt_filter1
                                   , tmp.rpt_filter6 AS rpt_filter6
                                   , SUM(rpt_value1) / SUM(rpt_value2) AS rpt_value1
                                   , '%' AS rpt_value5
                      FROM @t AS tmp
                      WHERE tmp.rpt_filter1 = @chr_param1
                      GROUP BY tmp.rpt_filter1
                                                   , tmp.rpt_filter6
```

```
                )
                SELECT rpt_filter1
                                 , t1.maintenance_type AS rpt_filter6
                                 , rpt_value1
                                 , rpt_value5
                FROM cte
                CROSS APPLY(SELECT lsi_name FROM cnf.t_lsi_listItem where lsi_group = 'maintenance_typ
        END;
END;
GO
```

## N.5. Generate Customised Analysis with Filters

```
CREATE PROCEDURE [rpt].[p_getReport]
  @chr_code VARCHAR(50)
, @chr_param1 VARCHAR(20)
, @chr_param2 VARCHAR(20) = NULL
, @chr_description VARCHAR(MAX) = NULL OUTPUT
, @rtt_sequence INT
AS
BEGIN
  SET NOCOUNT ON;

  DECLARE @t rpt.tt_rpt
        , @i INT
        , @rtt_code VARCHAR(50)
        , @rtt_dataset VARCHAR(50)
        , @t1 DATETIME
        , @t2 DATETIME
        , @t_str VARCHAR(MAX)
                                , @average REAL
        , @current_year INT = cnf.sf_getCurrentYear()
                                , @sp_name VARCHAR(50);

  SET @t1 = GETUTCDATE();
  SET @t2 = GETUTCDATE();
  SET @t_str = @chr_code + '-' + ISNULL(@chr_param1, '') + ': ';

  SELECT @rtt_code = chr.chr_rtt_code
       , @rtt_dataset = chr.chr_rtt_dataset
       , @chr_description = chr.chr_description
    FROM rpt.t_chr_chart AS chr
    WHERE chr_code = @chr_code;

  WITH flt
  AS
   (SELECT flt_nr
         , flt_value
                 , flt_active
      FROM rpt.t_flt_filter AS flt
      WHERE flt.flt_rtt_seq = @rtt_sequence)
  INSERT INTO @t (rpt_rtt_code
                , rpt_rtt_dataset
                , rpt_filter1
                , rpt_filter2
                , rpt_filter3
```

```
                , rpt_filter4
                , rpt_filter5
                , rpt_filter6
                , rpt_value1
                , rpt_value2
                , rpt_value3
                , rpt_value4
                , rpt_value5
                , rpt_value6
                , rpt_value7
                , rpt_value8)
SELECT  rpt.rpt_rtt_code
      , rpt.rpt_rtt_dataset
      , rpt.rpt_filter1
      , rpt.rpt_filter2
      , rpt.rpt_filter3
```

# O

# Presentation of Results: Dashboard

## O.1. Benchmark Overview

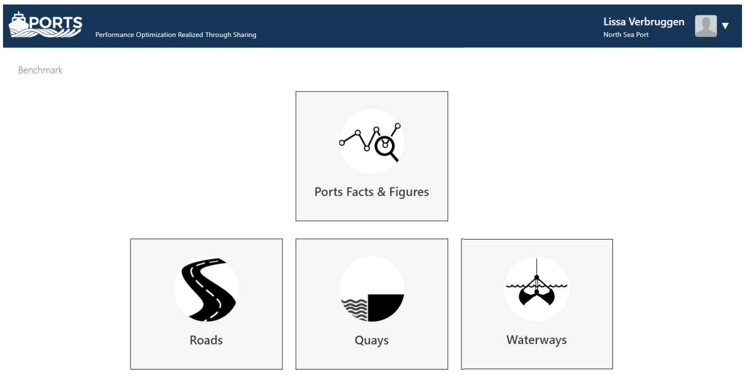



Figure O.1: Dashboard - Benchmark overview

## O.2. Benchmark Ports

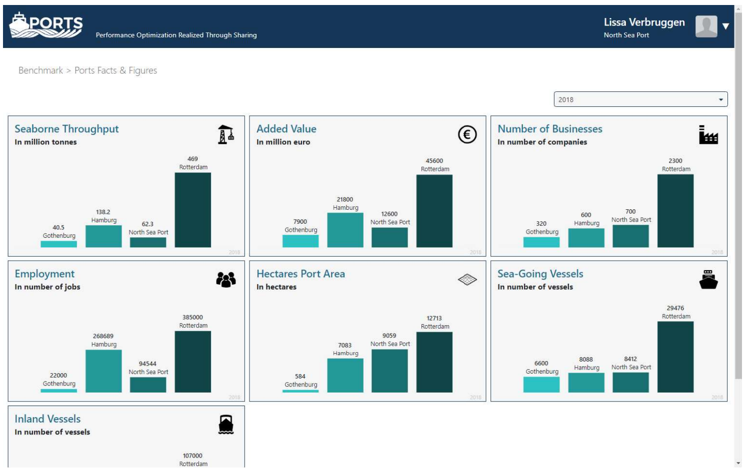



Figure O.2: Dashboard - Ports facts & figures

# O.3. Benchmark Roads

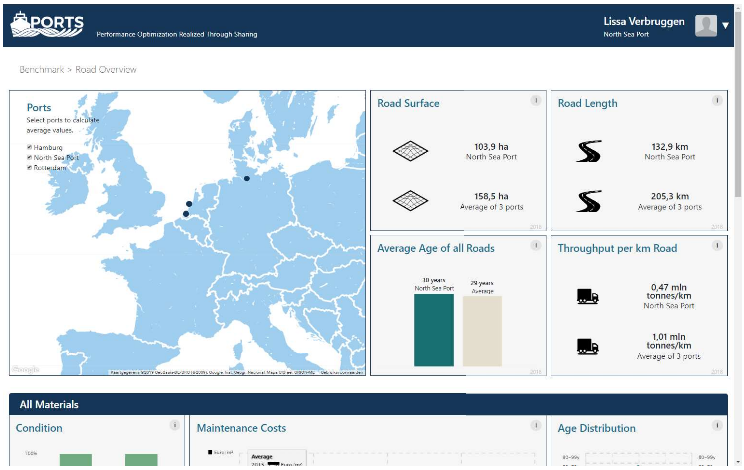



Figure O.3: Dashboard - Overview of the road benchmark (1)


Figure O.4: Dashboard - Overview of the road benchmark (2)

## O.3.1. Maintenance Costs

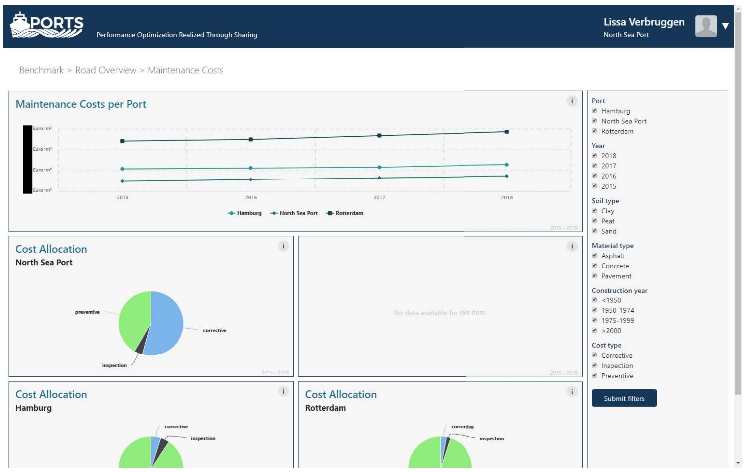



Figure O.5: Dashboard - Road maintenance costs (1)

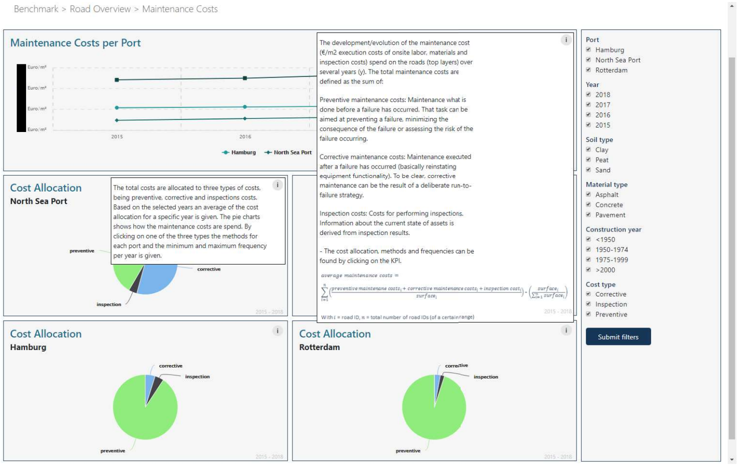



Figure O.6: Dashboard - Road maintenance costs (2)

## O.3.2. Condition

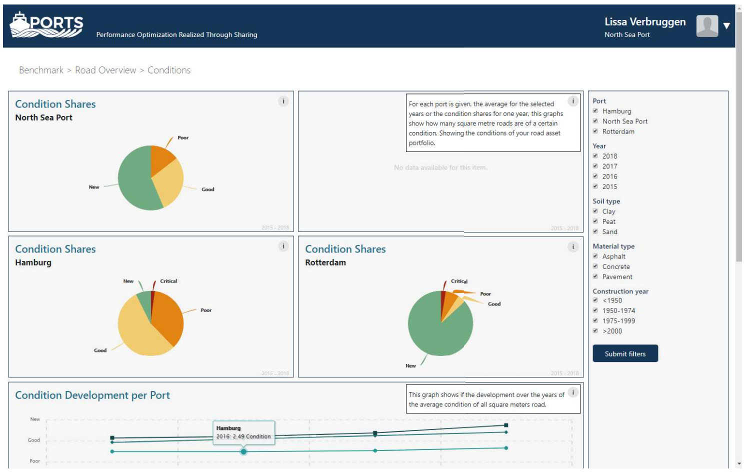



Figure O.7: Dashboard - Road condition (1)

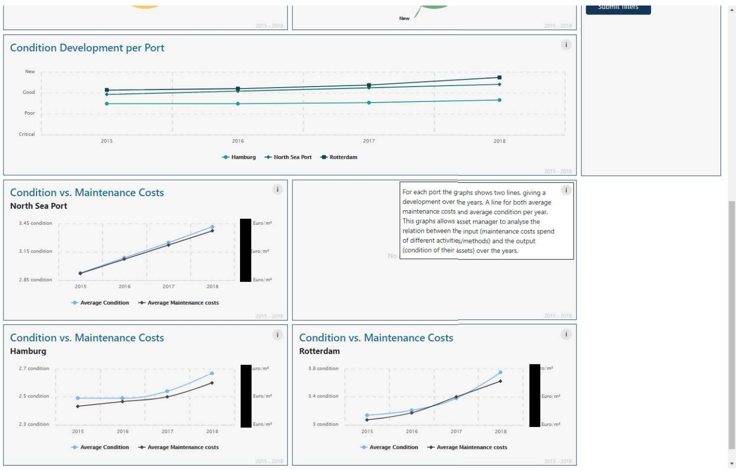



Figure O.8: Dashboard - Road condition (2)

# O.4. Benchmark Quay Walls

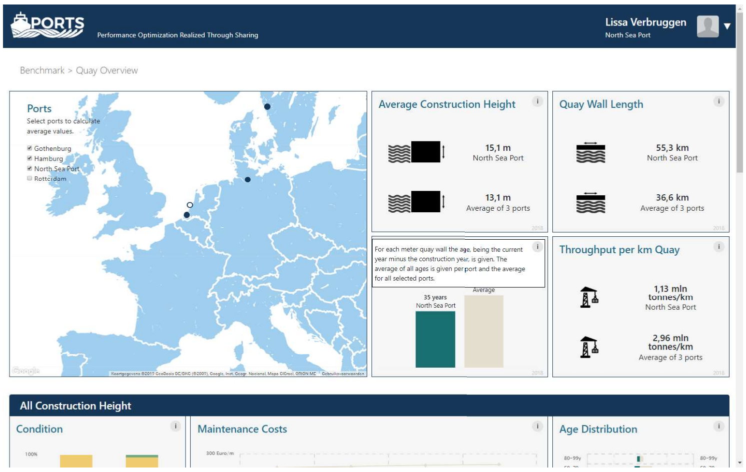



Figure O.9: Dashboard - Overview of the quay wall benchmark (1)

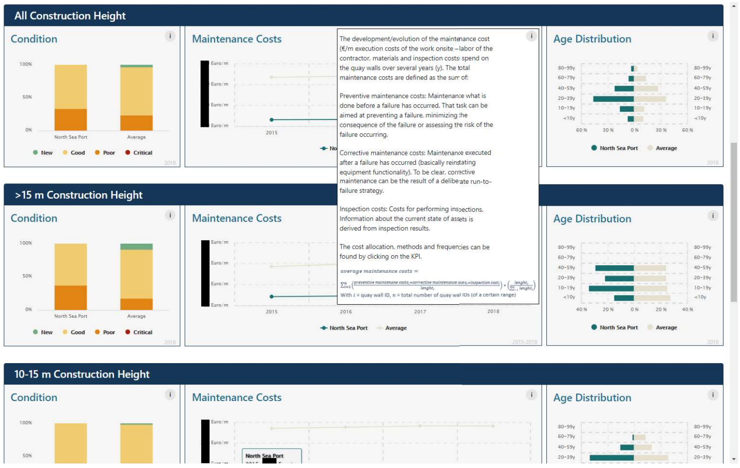



Figure O.10: Dashboard - Overview of the quay wall benchmark (2)

## O.4.1. Maintenance Costs

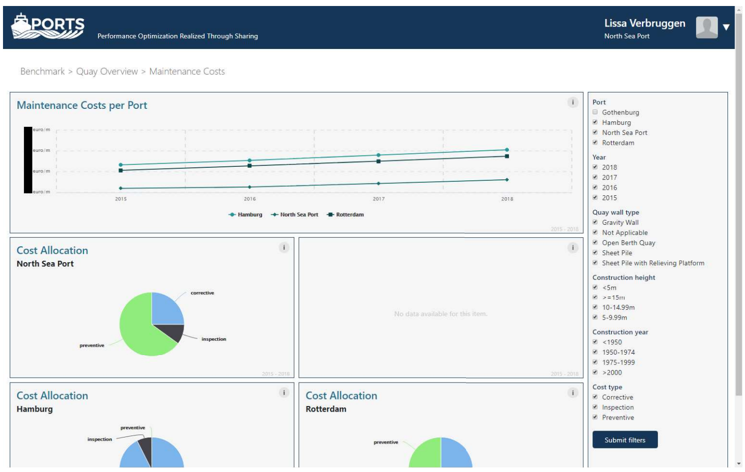



Figure O.11: Dashboard - Quay wall maintenance costs (1)

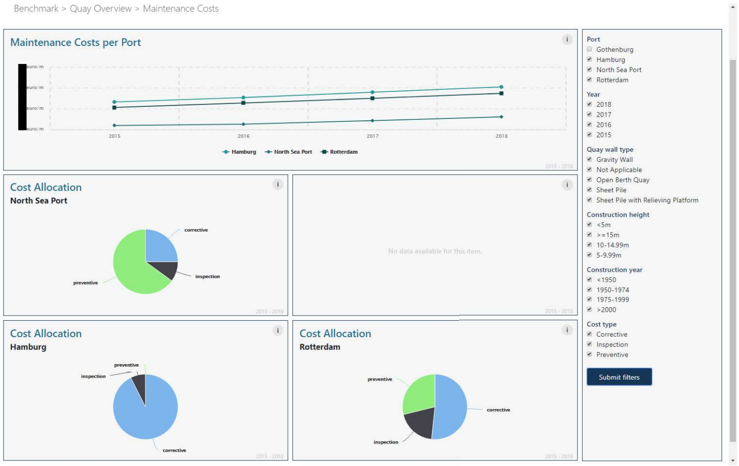



Figure O.12: Dashboard - Quay wall maintenance costs (2)

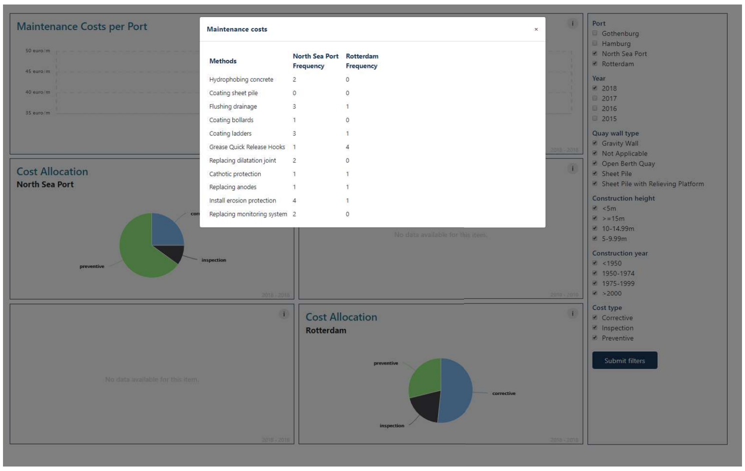



Figure O.13: Dashboard - Quay wall preventive maintenance methods and frequencies

## O.4.2. Condition

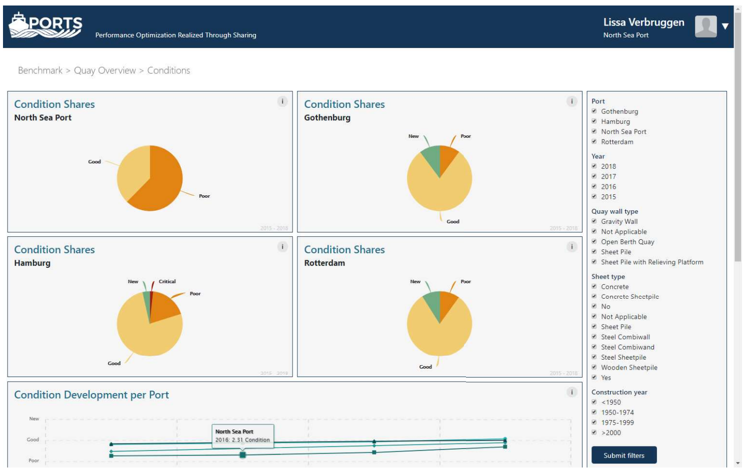



Figure O.14: Dashboard - Quay wall condition (1)

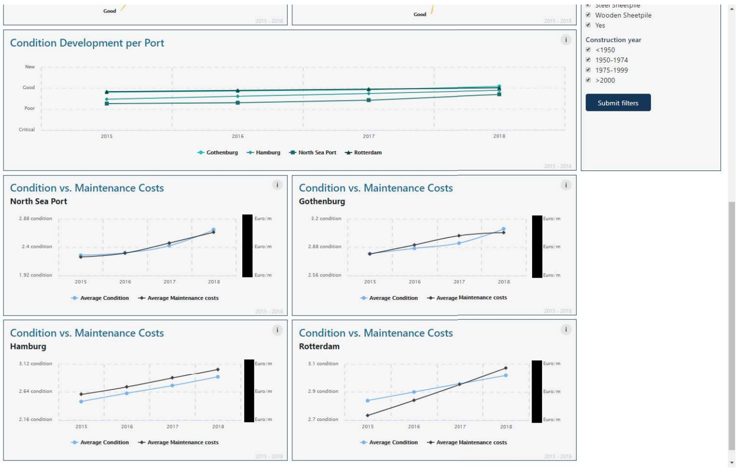



Figure O.15: Dashboard - Quay wall condition (2)

# P

# Informative Talk with a Waterways Asset Manager

The Proof of Concept is presented to other ports during the Workshop on Dredging and Surveying (WSDS) 2019 in Bergen. The ports were predominantly represented by asset managers who are responsible for dredging activities. Figure P.1 was included in the presentation to welcome the asset managers.

An informative talk with a waterways asset manager of the Port of Rotterdam has taken place prior to the meeting in Bergen. During the meeting the possibilities for the waterways were discussed. Based on this meeting, the asset managers discussed the possibilities of the benchmarking model with sector partners that attended the presentation in Bergen. The respective asset managers indicated their interest in developing benchmarks, since they believe that the model is suitable for performance measurement related to their activities. They immediately came up with ideas on how to specify the performance measurement template and the dashboard for the new asset type. Consequently, they started with the composition of a group, comparable to the quay and road sub-groups. Adding this asset type is in line with the goal of extending the benchmarking model.

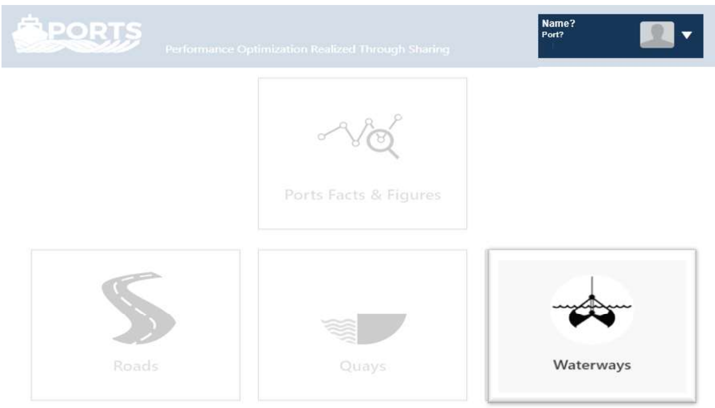



Figure P.1: Reserved spot for the waterways asset (dredging)

# Q

# Expert Validation Workshops

On June 18th and 19th workshops are held at the office of Port of Rotterdam. In this appendix, the purpose of the workshops, the workshop procedure, the workshop participants, and the compositions of the groups are described.

## Q.1. Purpose of the Workshops

For the validation of the model multiple workshops in smaller groups have taken place. The benchmarking model and its demonstration are reviewed by asset managers and other experts. During this interviews experts were asked to give their opinion on the correctness and clearness of both the working method and the results presented in the dashboard. The model validation has been performed to see if the Proof of Concept does what it supposed to do. Validation determines the correctness and completeness of the model, and ensures that the system will satisfy the actual needs of the asset managers. Moreover, one of the requirements of the model is that it provides (novel) users a clear guideline for benchmark development. Therefore, participants are asked to give their opinion on the performance measurement template. The template should be clear and the benchmarks, as presented in the demonstration, should be reproducible. Based on the expertise of the group members specific subjects are addressed.

## Q.2. Workshop Participants

A divers group of experts has been asked to attend the workshop. A mix of different viewpoints (operational, tactical, and strategic) and functions has been chosen to cover all aspects of asset management. The following themes are elaborated on in the group specific discussion of the workshop:

- *Group 1:* operational viewpoint of the asset manager, participants have a job comparable to the asset managers of the working group. Considering their functions, particular attention was paid to the asset characteristics. Assessment on the aspects of life cycle management has been discussed as well. Participants have stated what information they would like to monitor and compare with asset managers of other ports.
- *Group 2:* operational viewpoint of both asset manager and inspector. Specific attention is given to aspects that may affect the asset condition. Next, to this there has been brainstormed on other benchmarks (total costs for asset management and total life cycle costs) and assets (flora and fauna, green assets) that can be of interest.
- *Group 3:* tactical viewpoint from an expert on infrastructure networks. Since the availability benchmarks did not succeed for the Proof of Concept it is interesting to discuss its added value. Aspects of the road infrastructure network are discussed: what aspects are of importance, and what information is valuable considering the competitive position of ports.
- *Group 4:* tactical and operational viewpoint of both asset owner, asset manager advisor, and researcher. Additional attention is paid to the context of the benchmarks in the port control model: the line of sight.

- *Group 5:* tactical viewpoint from the head of the infrastructure department and asset managers that focus on performance management. In the group specific discussion is further elaborated on value of the benchmarking model. Moreover, the results of performance measurement for international comparison are compared with internal performance measurement.

Table Q.1: Workshop groups by subject

| Group | Group specific themes | Function | Organisation |
|---|---|---|---|
| 1. | Asset characteristics; Life cycle management; 'Input' | Asset Manager Infrastructure | Port of Rotterdam |
| | | Asset Manager Infrastructure | Port of Rotterdam |
| | | Asset Manager Infrastructure - Incident Management | Port of Rotterdam |
| | | Asset Manager Infrastructure - Data | Port of Rotterdam |
| 2. | Inspections and monitoring; Other asset types; Project management (life cycle costs); 'Processes' | Asset Manager Infrastructure - Flora and Fauna | Port of Rotterdam |
| | | Operational Inspector Infrastructure | Port of Rotterdam |
| | | Asset Manager Infrastructure - Projects | Port of Rotterdam |
| 3. | Availability; 'Influencing factors' | Project Manager Road Modality | Port of Rotterdam |
| 4. | Line of sight (organisational objectives); Performance measurement; Strategic view | Assistant professor TU Delft Organisation and Governance | TU Delft |
| | | Asset Owner | Port of Rotterdam |
| | | Asset Management Advisor | Port of Rotterdam |
| 5. | Performance management; Asset management objectives; Internal dashboard vs. benchmark dashboard; 'Output' | Head of Asset Management Infrastructure | Port of Rotterdam |
| | | Asset Manager Infrastructure - Performance Contracting | Port of Rotterdam |
| | | Asset Manager Infrastructure - Data | Port of Rotterdam |

## Q.3. Workshop Procedure

The set-up of the workshops is determined by the input needed to evaluate and finalise the benchmarking model. The workshop is divided into five rounds. Each round contributes to achievement of the goals of the evaluation workshops. The rounds and their deliverables are shown in Table Q.2. The duration of a workshop is one hour. The workshop starts with an introduction. The introduction was meant to make all participants acquainted with the topic. Subsequently, the process of developing benchmarks will be presented, supported by a presentation of the benchmarking project. In this presentation the project initiation, organisational structure, working method, results, and further steps are brought to attention. The second document that is presented is template for benchmark development. Participants were asked to give feedback on one of the benchmark examples presented in the case study of this research. The purpose of the template discussion is to check whether the template provides a clear guideline, it is reproducible, it contains all aspects of asset management and other relevant information. Third, the dashboard is discussed. The attendees is asked if they can grasp the essence quickly, if the dashboard is complete and correct (designed), and what they would like to see in the dashboard. Last, some specific topics are discussed based on the composition of the groups. The groups may also provide recommendations for further of the benchmarking model.

The results of the workshops can be split up in two parts:

- Evaluation of the working method
- Evaluation of the results

Table Q.2: Workshop set-up

| Duration | Content | Output |
|---|---|---|
| 5 min | Introduction, workshop content | N/A |
| 10 min | Presentation of the benchmarking project | N/A |
| 15 min | Discuss template | Feedback on the correctness, completeness, satisfaction and clearness of *working method* and template |
| 15 min | Discuss dashboard | Feedback on the correctness, completeness, satisfaction and clearness of the dashboard *results* |
| 15 min | Group specific dicussion | Different subjects are discussed in each group |

The participants are provided with information to give them the opportunity to prepare for the meeting. The following documents were supplied prior to the meeting:

- *PowerPoint presentation of the benchmarking project:* in which the following aspects are brought to attention: project incentive, background and mission, organisation of the project, benchmarking process, demo of the online platform, and benefits of the benchmarking model.
- *Performance measurement templates:* empty, maintenance costs, and condition template.
- *Dashboard:* access to online platform to have a look at the dashboards.