BENCHMARKING PORT ASSET PERFORMANCE

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ABSTRACT
Over the past decade, the complexity of operations in maritime port areas has increased significantly. Considering the challenges ports are facing with the maintenance of aging infrastructures, the need for asset management efficiency within the port industry is imperative. The willingness to ensure continuous improvement has contributed to a growing interest in the measurement and benchmarking of port infrastructure performance. The paper describes the development of an international benchmarking model to measure and compare port asset performance. The model is illustrated by comparing the maintenance of quay walls and roads for three different European ports. The presented benchmark results, and the process itself, have provided asset managers with valuable insights into their maintenance performance.
Keywords: asset management, benchmarking, ports.

1 INTRODUCTION

As global trade has increased over the past decade [1], 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 the management of infrastructural assets, operations have become more complex due to various developments: increase in throughput, bigger ship sizes, ageing assets, increasing complexity of the port 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 [2]. Besides, the challenges mentioned ports are facing, the willingness to ensure continuous improvement contributes 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 [3]. 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 broader societal- or client perspective, indicating port attractiveness, intensity of use and the various underlying operational production factors – except the state of the infrastructural assets. This existing literature on macro performance indicators predominately focuses on the context of terminal operations, or logistics and supply chains [4]. Bichou and Gray [5] suggested and tested a framework of port performance measurement from a logistics and supply chain management approach. De Langen et al. [6] showed in their analysis that several determinant factors have affected the hierarchy of competitiveness. Tongzon [7] develops a

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model of port performance and efficiency. Other studies focused on ways to measure port efficiency. Generally, in the port performance literature most attention is drawn to benchmarking of attractiveness to clients, rather than comparing the performance of operations and processes, while the perspective or standpoint (customer, operator, regulator, etc.) one has to consider for benchmarking is debatable [8]. The perspective considered in this research is the perspective of the asset manager. Research on benchmarking the performance of asset management has so far been restricted to the maintenance activities themselves, which covers only a small part of the asset manager's job [9].

The scientific goal of this paper is the development of an integrated approach based on benchmarking, performance measurement, ports, and asset management. To verify our approach four ports have joined in the project to provide practical context for the study: the Port of Rotterdam, the North Sea Port complex (Belgium/Netherlands), the Port of Hamburg, and the Port of Gothenburg. Asset managers of the respective ports had expressed their interest in the exchange of knowledge through a benchmarking model with the aim to learn from each other and improve their performance. Interestingly, this has not been seen as a threat for port competitiveness. Data on asset management was not perceived as directly related to their competitive position towards clients. The approach developed allowed ports to handle their own data and only share the information needed for benchmarking. The main question that was addressed in the context of this research is:

How to compare the state and performance of infrastructure assets of seaports?

The research approach to answer this question rests on the execution of a case study as input for a design of an asset management benchmarking system for four European ports. The study was conducted according to the process flow presented in Fig. 1. The design steps are based on the process for Systems Development Research by Nunamaker et al. [10] and the Design Science Research methodology by Peffers et al. [11].

First of all, a conceptual design was constructed by selecting theories and concepts which are adjusted based on expert knowledge in order to fit the purpose of this research. The second phase of the research identified the major components that are required to design a model for practical use. The objective is to design a model that provides clear guidance to asset managers for the development of performance measurements to benchmark. A methodology-based framework helps ports in creating opportunities with regard to obtaining efficiency. In the third phase the design was tested by means of a case study, known as the Proof of Concept, which demonstrated the model and its methodology in order to assess the designed benchmarking model on its usefulness and practicability. At last, the results are evaluated and the most important findings of the research are summarised. Furthermore, recommendations for future research are presented.

In line with the research approach (see Fig. 1) the paper is structured as follows. Section 2 outlines the state-of the-art in knowledge on port asset management and presents a literature based framework for performance measurement. This conceptual framework covers aspects of four different streams of literature: benchmarking, performance measurement, ports, and asset management. Section 3 describes the model design and testing process leading to the final benchmarking model. In section 4, the case studies are introduced that illustrate the practical application of the model. The case studies draw on publicly available data as well as on the private databases of the ports. Finally, section 5 summarises the main results and implications, explains the limitations of the study and makes suggestions for further work.

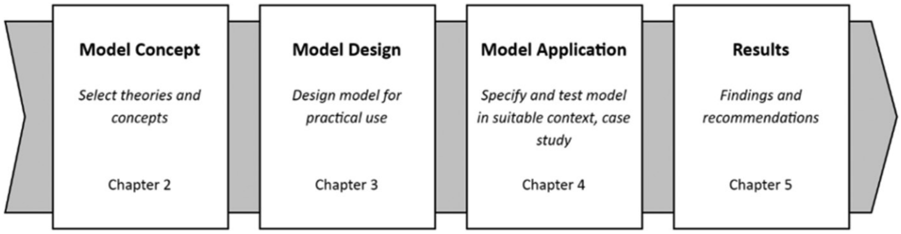

Figure 1: Research approach.

2 CONCEPTUAL MODEL FOR BENCHMARKING OF PORT ASSET PERFORMANCE

After a short introduction on research in asset management in ports, 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, it elaborates on the benchmark procedures and underlying approaches of performance measurement. Based on these insights, this section presents a conceptual framework for performance measurement which is used as basis for the model design.

2.1 Port asset management

In asset management Life-Cycle-Cost (LCC) analyses form the mainstream in research. In many fields of practice applications these methods are still far from satisfactory [12]. In literature the following papers address some of the complicating factors which indicate reasons for less satisfactory application in practice. Van den Boomen et al. [13] show that LCC analyses are poor in predicting the uncertainties in failure behaviour of an asset. Ankobya (2001) explains how the life cycle of port assets affect the ROI of port investments. For instance a breakwater has an investment life of 50 years, quays last for 30 years and container cranes for 15 year. The choice of a particular life cycle results in different running costs and valuation for the port. De Gijt, Louwen and Voogt [14] propose an alternative method to take into account the life cycle aspects in material costs, construction costs and demolition cost, related to the environmental aspects such as transport of material, reuse of material, production of material. They suggest to build a structure based on an standard uniform design. Attwater et al. [15] conclude that even though organisations have well-defined asset management systems, they are not clear about how to measure the performance of assets and propose such a framework. Maletič et al. [16] argue that asset management decision making needs to obtain a right balance between performance, costs and associated risks in pursuing business objectives. In practice, software solutions supporting integral asset management capture details about day-to-day inspection, scheduled maintenance, planned shutdown, job card and maintenance history and show the costs of these activities.

From the papers discussed it can be observed that the focus is on the development of individual strategic asset management programs with the principle outcomes being the ability to reliably understand, predict and influence the total life-cycle cost of its infrastructure assets. The infrastructure assets, such as roads, locks, bridges, treatment plants and breakwaters, are often characterised by long service lives and corresponding technical life cycles. While the life cycles are long, the time value of money plays a role in asset management decision-making on capital investments, maintenance operations and expenditures [18]. Although van den Boomen et al. [18] provoke a stepwise LCC approach enhances the understanding of discounting principles, their constraints and their field of applicability, for reliability and maintenance engineers in practice, it is still an academic approach which cannot be compared or referred to other approaches to understand the underlying factors.

Like Parlikad and Jafari [19] in their paper 'Challenges in infrastructure asset management' we stress that the reliability and maintenance engineers in practice demand for a more practical and easily applicable approach. Parlikad and Jafari [19] stress that the asset management research community needs to work closely with practitioners in order to understand the real challenges they face, and the solutions they are looking for. Regulatory and government roles (as port authorities are) play an important factor in the way industries in different sectors and countries approach asset management and whole-life thinking. It is clear that the industry will benefit from working closely with academia and by sharing best practices and lessons learnt between organisations and sectors.

To bring this type of governance a step further Kunttu et al. [20] emphasise there is a need for a systematic assessment framework for concretising value, benchmarking it and ultimately optimising the offered service solutions. A benchmarking method and tool helps to compare different sites according to their operational and maintenance environments. The benchmarking tool helps to identify and visualise the potential sources of value. With this approach based on categorising sites to comparable units and benchmarking them against each other, the service provider is able to improve its capability in showing improvement potential in asset management and make recommendations of applicable asset management policies.

2.2 Benchmarking

Benchmarking is an effective tool that supports management in their pursuit of continuous improvement. Performance benchmarking enables asset managers to compare processes with numerical standards [21]. It is a technique for assessing an organisation's performance against the performance of other organisations [22]. 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 have focussed on performance measures and setting targets. Papers typically address aspects of departmental benchmarking along with limited success stories. According to Meybodi [23], 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. Although benchmarking in general is perceived as important and effective, it does have limitations which should be considered to overcome potential pitfalls [24]:

- benchmark is done at too high a level,
- outcomes are not linked to underlying activities,
- improper approach and view on the benchmarking process, or
- too many performance measurements are needed.

The specific context of this research asks for a particular approach. The objective is to measure and compare performance of port asset management. The peers are located in different

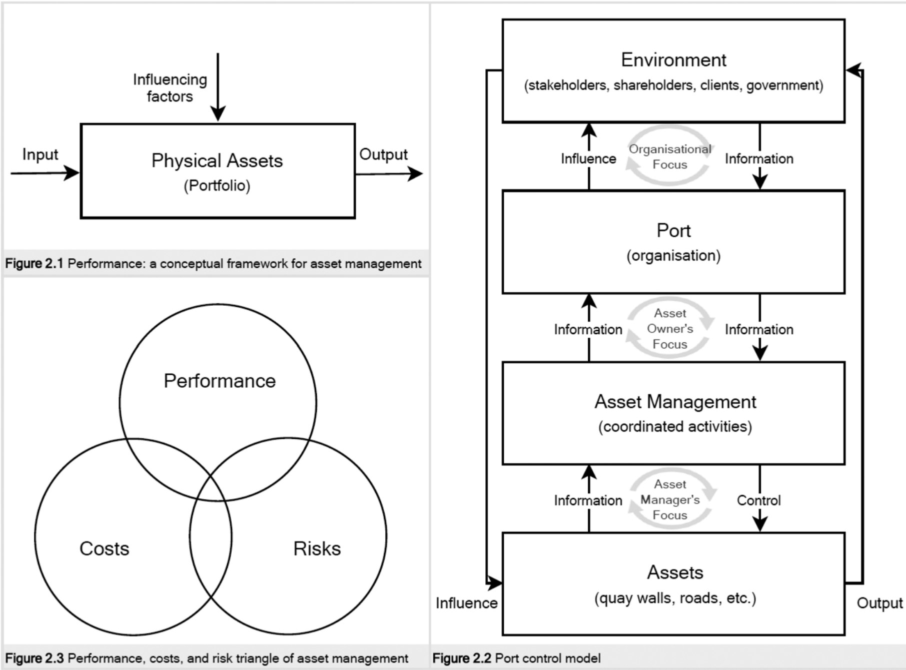

Figure 2: Framework for performance measurements.

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.

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

1. Processes of asset managers: position of the benchmark in the input-output performance measurement framework. The processes involved when managing assets are reflected in an input-output diagram, in accordance with the performance theory of Pollitt and Bouckhaert [25].
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 [26] 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.

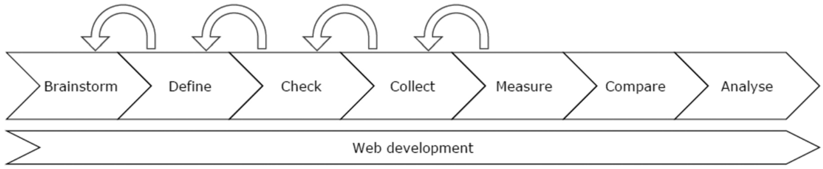

Figure 3: Benchmark development process. A step-wise method in the development of benchmarks.

3 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. We describe the benchmarking model obtained by connecting identified criteria (what to measure) with a measuring method (how to measure). The focus in this study is on asset management within the port industry, where the case studies are focusing on two particular asset types: quay walls and port roads. The main design requirements follow the objective of this paper: *the design of a benchmarking model for asset managers active in port industries to measure and compare performance, and assist ports with the identification of improvement potential of the ports' own performance*.

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 shared informational awareness [27].

3.1 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 its own structure and format in collecting and storing asset information [28]. 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 benchmarks are adjusted accordingly.

3.2 How to measure

This research has 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 Fig. 3, 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 manner, as is good practice in developing and using performance indicators [29]. 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 [30]. This approach also highlights the importance of a clear definition, ‘if you cannot define it you cannot measure it’. Neely et al. [31] collected recommendations for defining performance measures, these suggestions are incorporated in the template.

The resulting framework for performance measurement 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 [32]. 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 [33]. 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: Specification of tools and participants for each process in the development of a benchmark.

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

4 MODEL APPLICATION

This section describes the case studies within the respective ports, specifies the benchmarks, discusses the benchmarking process and presents the obtained benchmark results.

4.1 Selected assets in ports

The model was tested by means of four case studies consisting of two distinct asset types, the quay wall and road assets, as set out in Table 2. For 2018 real data was collected, and for the other years (i.e. 2015–2017) test data is used instead of real data. It was decided to use test data due to time constraints as collecting historical data over a longer term is time consuming. Also, the demonstration concerned a Proof of Concept. As the involved asset managers of the respective ports are responsible for quay walls or roads in the port area, the case study was limited to these two asset types. As more and more larger vessels are calling at the port, the growing pressure on these assets was lading to several time-consuming and costly management challenges.

The asset managers involved represent the respective ports, namely the Port of Rotterdam (PoR), North Sea Port (NSP), Port of Hamburg (PoH), and Port of Gothenburg (PoG). Each of the ports has different characteristics which are shown in Table 2.

The benchmarking initiative stems from the strategic collaboration between these ports. Both port and asset level generic benchmarks are defined in the model design. A more detailed report is provided of 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 asset type. The two cases are shown in Table 3.

The Port of Gothenburg is excluded from Case 2 as the roads are much more deteriorated by the winter conditions (freezing, ice & snow) making them not comparable with the other ports.

4.2 Specification of the benchmarking model

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

Table 2: Port characteristics.

	PoR	**PoH**	**NSP**	**PoG**
Cargo (million tons)	436.8	128.7	68.9	38.0
Port	12,464.0	7,400.0	9,100.0	425.0
Benchmark	24.0	17	12.5/17.0	9.2
Year	77.5	43.0	56.0	8.3

Table 3: Case studies quay wall and road.

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

to the collaborative approach of the method, and points out the challenges that we came across. The process is at least as important – learning benefits arise from a collaborative process, and value lies in the dialogue before, during and after the benchmark. The model facilities this process.

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. This section also briefly touches upon the road case, at the end of each subsection. During the case study it was 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 includes 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. It was decided that the height is characteristic for classification which represents differences ranges in depth. Square meters is not a common unit for comparing as the dialogue is always on length and height [34]. In the terminology for the road asset comparable definitions and standards are defined. The most important differences are the classification (based on material), the soil type (natural underground) and the unit of measurement (per square meter). Therefore, although multiple discussion have taken place, eventually all asset managers agreed on the total length as unit of measurement for quay walls.

Asset figures

The asset figures provide information on the portfolios of the benchmarking partners. This information creates understanding to whom one is benchmarking against and depicts some

Table 4: Quay wall terminology.

Term	Definition
Quay wall	Earth retaining 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: $x \le 10, 10 < x \le 15, and\ x \ge 15$ 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	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.
Construction type	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.

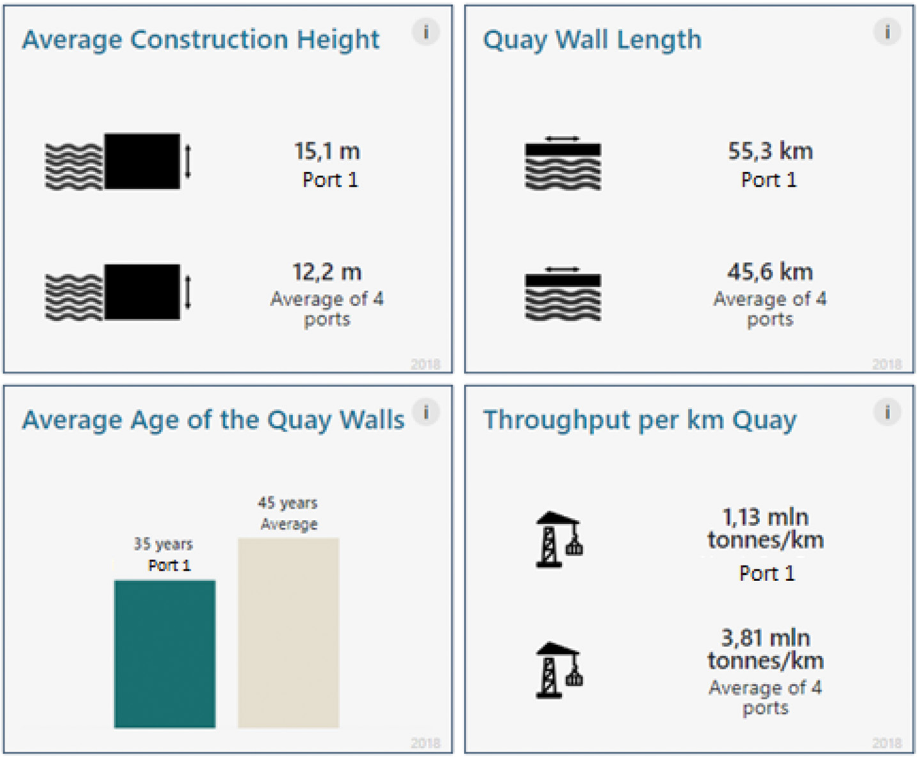

Figure 4: Visualisation of quay wall figures as presented in the dashboard.

key characteristics of the portfolio. This information is presented in the benchmark overview of each asset type. Characteristics that are shown include utilisation of assets, economies of scale and obsolescence of the asset portfolio. Figure 4 depicts 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. For the road asset a comparable overview is created.

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 [35]. This benchmark is brought forward because a major part of the activities involved with asset management is 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 the 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 [28]. 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. This tree is defined after putting the benchmarks into context by positioning it within the three theoretical concepts as outlined in Fig. 2. The hierarchy concerns the link between the theoretical and numerical construction of the benchmark. Such a breakdown is shown in Fig. 5, where the length refers to the unit of measurement. Additional filters can be included to allow for customised views (e.g. asset specific characteristics, such as asset type and construction year, or environmental conditions, such as climate and soil type).

Mathematical equations are provided in order quantify the benchmark, leading the identification of the data requirements. A key formula of the benchmark is a weighted average cost formula (equation 1). 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 (i.e. running meters) of all assets observed. Some costs are only attributable to length since also

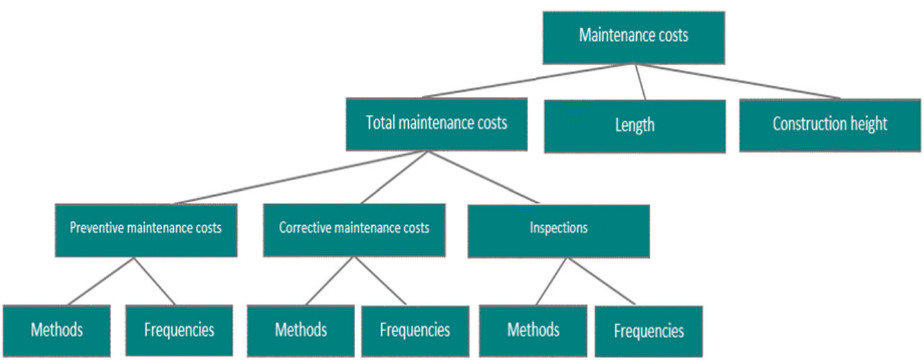

Figure 5: Hierarchical view of maintenance costs (quay wall case).

elements such as fenders are included. The summation of these values divided by the total weight of all assets is the average as presented in the dashboard.

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

For the road asset a comparable formula was defined; however, for this asset, the costs are divided by the surface which is denoted as the unit of measurement.

4.3 Benchmarking process

Throughout the process of benchmark design, multiple iterations have taken place to agree on all the items. 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 challenging to unify different perspectives. Points of discussion can be clustered into the following subject areas: (1) lack of uniform definitions and their interpretations, (2) general challenges of international collaboration, (3) restrictions in resources and (4) the operational perspective of the asset managers which tempted to go into too much detail. Some notable examples are outlined in this section.

- Throughout the process it became clear that unambiguous definitions cannot 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 some asset managers stated that corrective maintenance is also done 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 asset utilisation, as this factor has a significant impact on the degradation of the asset. Given time constraints, however, it appeared to be infeasible to include this information on the short term.
- Often the sharing of thoughts and an iterative process was needed for asset managers to come to an agreement. For example, as asset information was stored differently, a unit of measurement was introduced. Next, a standardised template helped asset managers to collect data in a similar way. Definitions such as the asset's condition needed to be aligned. During site visits it appeared that asset managers did not always agree on the rating of an observed asset's condition. Definitions on conditions were described in more detail and photos were added.
- Decision rules were introduced to deal with the dynamics of group decision-making [36]: in the event of disagreement definitions in literature were decisive. A majority vote helped in decisions on practical matters. Lastly the steering committee had the final vote regard-

ing major decisions. The time constraints set by the goal of Proof of Concept put a certain strain on decision-making. The decision rules were a mechanism to make sure a decision was made and have therefore sped up the process. Moreover, the organisational structure with a clear division of roles facilitated a systematic and targeted approach.

4.4 The final benchmarking model

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 scheme (Fig. 6).

The data requirements follow from specification of the model in which all required information is listed. Various actions can be considered in order to improve the performance ('control data input' in Fig. 6), such 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. Figure 7 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 Fig. 8.[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

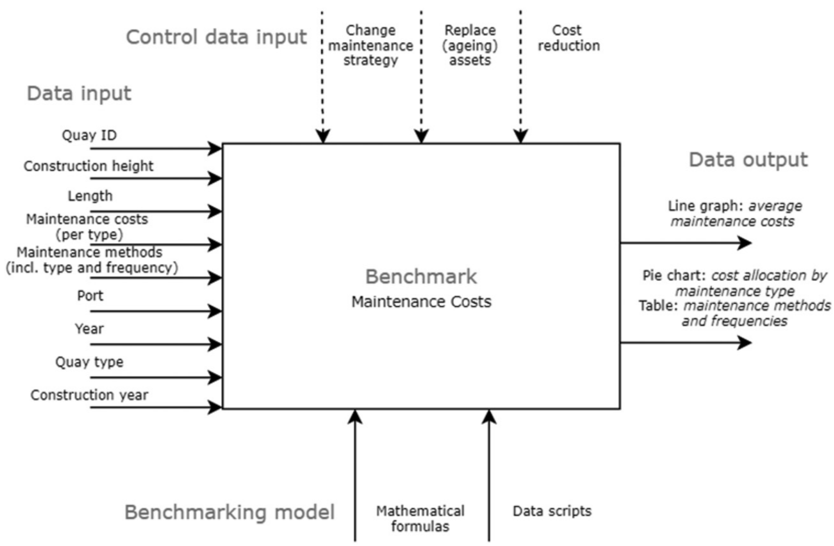

Figure 6: IDEF0-scheme for the maintenance costs (quay wall asset case).

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

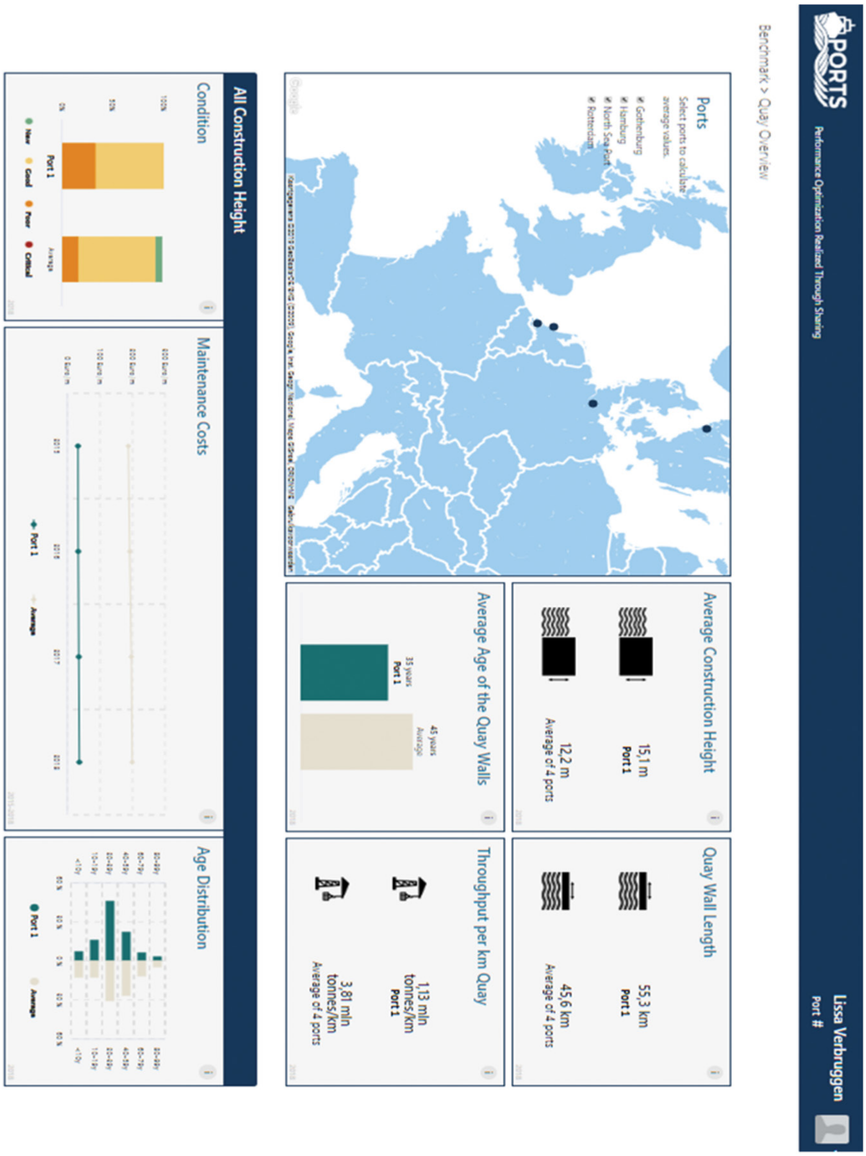

Figure 7: Overview of the asset benchmarks in the dashboard (quay wall case).

within Port 2 has incurred significantly higher expenses compared to Port 1. The maintenance costs of Port 2 could be lowered by changing the maintenance strategy, replacing (ageing) assets, or reducing costs by changing the asset requirements. Revision of the maintenance strategy can be done by evaluating the maintenance costs in more detail. A more profound analysis of this measure is done by comparing maintenance strategies. Port 1 has a more prevention focused maintenance strategy. Port 2 has a significant higher share in corrective activities, which may imply a deliberate run-to-failure strategy. The cost allocation tells something about the executed strategy, and one can use this for interpretation. For example,

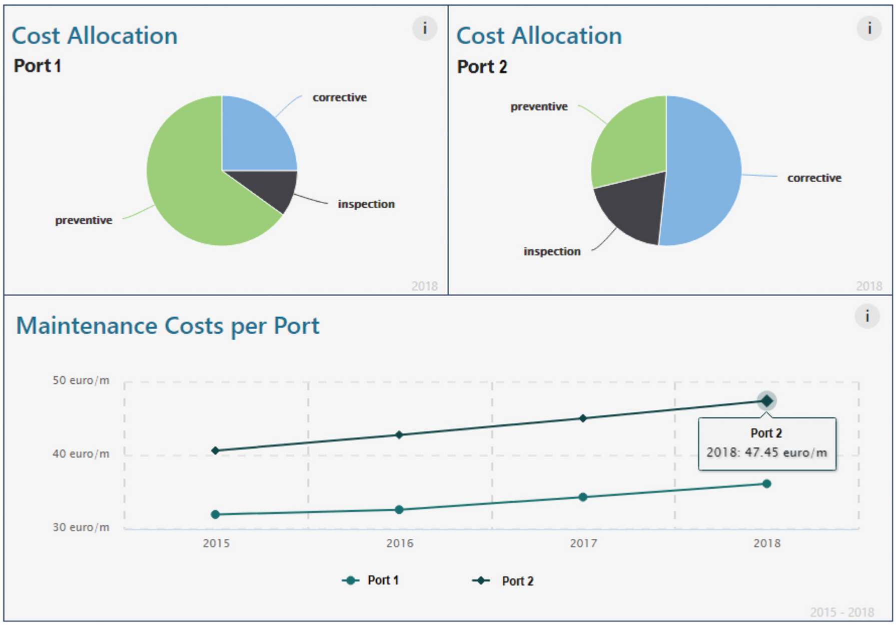

Figure 8: In-depth analysis of the maintenance costs in the dashboard (quay wall case).

a possible conclusion could be that more preventive maintenance results in lower costs, as observed here for a time period of 4 years. Of course, one would need to control for other underlying differences that could explain the observed differences. With such insights actions can be considered in order to improve performance ('control data input'), such as accepting a lower condition level at lower costs (i.e. cost reduction), or a shift towards more preventive action (i.e. change maintenance strategy).

For roads, an identical approach was followed. The dashboard of the road asset is depicted in Fig. 9. Port 2 shows clearly higher maintenance costs due to a higher throughput per kilometre.

5 CONCLUSIONS

The main contribution of the study is that it proposes a system design for benchmarking of asset performance of ports. 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, the study illustrates the complexity of obtaining a benchmarking model which is relevant for operational purposes.

The final evaluation of the model was done through expert interviews and group-wise evaluation of the process. The model was verified and validated by the asset managers with the following main conclusions. New performance information from quantitative and qualitative data. This information is presented in an easily analysable and comprehensible form. The dashboard gives interesting insights into operations, which is perceived as refreshing. The model is not yet suitable to provide accurate insights into performance as it is just a Proof of Concept. However, the insights gained from the benchmarking process and results are considered to be valuable. The benchmarking process supports the asset managers throughout

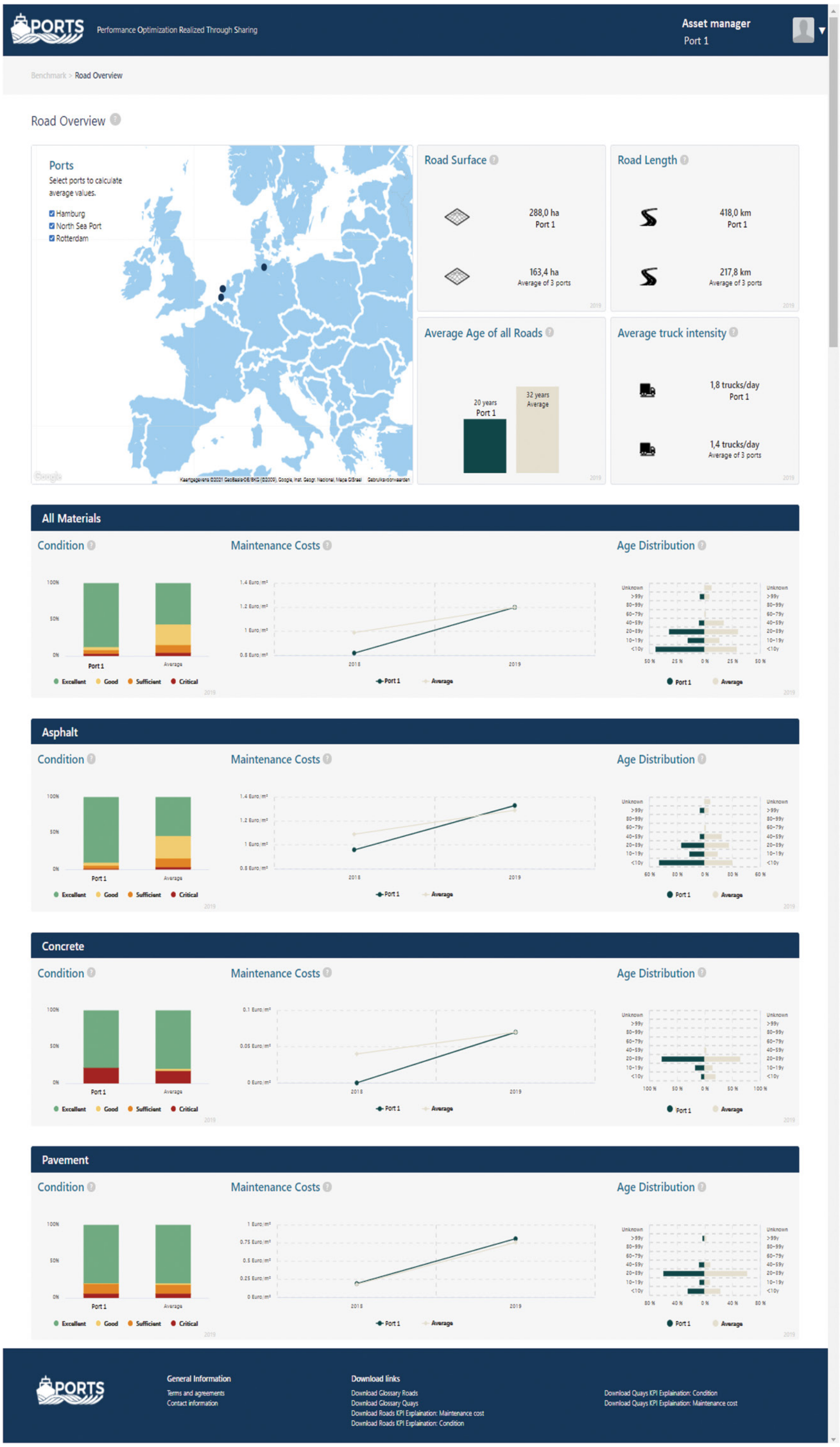

Figure 9: Overview of the asset benchmarks in the dashboard. The road asset case.

the process, by providing a structured approach to avoid the mentioned pitfalls. The benchmark results are indicators of their relative performance, which stimulates ports to have a critical look at their current operations. To conclude, the model is sufficient for basic analyses and is perceived to provide added value by the users of the system. Currently, all four ports are using the model.

Further development of established benchmarks and the addition of new benchmarks is desirable to have all the benefits from the benchmarking method. By placing 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, and detailed information on asset characteristics. These factors are expected to have a significant impact on asset performance and thus benchmark results. The model was demonstrated to asset managers responsible for dredging activities (i.e. waterways assets) in the port area. These indicated their interest in developing additional benchmarks, as they believe that the model provides suitable guidance for benchmarks related to their activities. This result further emphasises that the generic method could be applied to the development of other asset types.

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CONFIDENTIALITY

Due to confidentiality agreements, this report contains modifications in the contents and parts of the information are excluded (i.e. maintenance costs). This is mainly reflected in the port names which are coded (Port 1, Port 2, etc.). By doing so, no explicit links can be found to the ports.

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