Citation (APA)
van Koningsveld, M., Verheij, H. J., & de Vriend, H. J. (2021). Part IV - Ch 1 Performance of ports and waterways. In M. V. Koningsveld, H. J. Verheij, P. Taneja, & H. J. de Vriend (Eds.), *Ports and Waterways: Navigating a changing world* (pp. 359-363). TU Delft OPEN Publishing.

1 Performance of ports and waterways

1.1 System performance

Supply chains and the enabling transport systems are dynamic systems, with complex interactions between components and behaviour that cannot always be explained by the behaviour of the individual components. Consequently, the performance of such systems is not simply the sum of the performances of its elements.

Despite this complexity, quantification of performance, in whatever terms, is crucial to the continuous improvement of supply chains. The success of this process determines the transport costs for the client, as well as the choice of shippers for the mode and corridor of transport. Thus, it determines the competitive edge of all actors in the chain. It is clear that a good overview of how the system elements interact and the system functions is key to this success.

More in general, Part II and Part III of this book have dealt with the design, operations and management of the elements of a transport system, namely ports, port terminals, and waterways. Part IV concerns their joint functioning in the transport system as a whole. It defines system performance, describes how one can quantify it and investigates a number of phenomena influencing it.

We illustrate this by the example of port adaptation to hydrogen transport (Figure 1.1; also see Lanphen, 2019). Hydrogen is expected to become an important carrier of clean and renewable energy and port authorities are already considering what role they wish to play in the hydrogen supply chain.

Figure 1.1: Artist impression of the world's first liquefied hydrogen carrier, the Suiso Frontier, (actually launched December 2019) (© Kawasaki Heavy Industries).

Hydrogen can be produced from different sources, among which fossil fuels and natural gas, but also water (via electrolysis). At the moment, production from natural gas is the most cost-effective. This may change if the byproduct CO_2 has to be captured and stored, or if CO_2-prices are raised. Hydrogen can be stored and transported in different forms, called carriers (gaseous, liquefied, or chemically bound). Depending on the carrier and the location, long-distance transport can take place by ship or by pipeline.

Because of the low density and the low boiling point under atmospheric conditions, gaseous hydrogen has to be stored and transported under high pressure. Liquified hydrogen is stored and transported at a temperature of -253°C. Chemically bound hydrogen, e.g. in the form of ammonia (NH_3) or methylcyclohexane (MCH), can be stored and transported under less extreme conditions, but involves efficiency losses due to the chemical binding and retrieval processes.

Figure 1.2 gives a schematic overview of the hydrogen supply chain. It shows that many actors have to agreed about the choices to be made to ultimately bring the hydrogen from producer to distributer. Although there may be power differences, none of these actors can decide on their own; they are all interdependent. For the port authorities of the exporting and the importing port, for instance, it makes a lot of difference in which form the hydrogen is transported, with regard to the processing plant, terminal type (liquid or dry bulk), for the safety zones and for the facilities and the storage capacity at the terminal. They cannot independently optimise these investments and their timing, however; the plans and interests of the other parties involved have to be taken into account. This requires not only a good overview of what, where, when, who and how in the supply chain, but also a certain degree of coordination and collaboration.

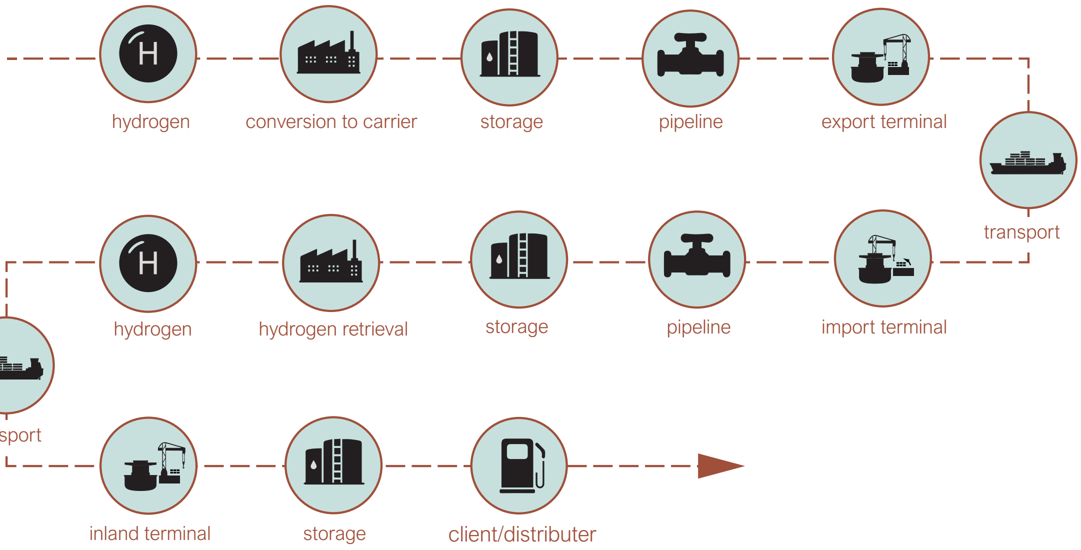

Figure 1.2: Schematic of a hydrogen supply chain (modified from Lanphen, 2019, by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).

1.2 Design and performance evaluation

Performance is a vague notion as long as it has not been expressed in more specific identifiers and there are no clear overall objectives. For a supply chain common objectives are:

- cost-effective operation,
- sufficient throughput,
- sufficient capacity of all elements in the chain,
- timely delivery,
- safety (i.e. acceptable risk),
- environmental friendliness, and
- security.

De Vries et al. (2021a,b) identified this need to 'objectify' performance concepts. With objectification they mean turning the implicit into an explicit engineerable 'object', on the one hand, and specifying clear design 'objectives', on the other. They propose using the Frame of Reference (FoR) as a method to systematically transform 'vague' performance concepts into functionally specified engineering designs.

Objectives, in the sense of the FoR approach (Part I – Section 2.2.2), are typically formulated in normative terms, i.e. 'cost-effective', 'sufficient', 'timely', 'acceptable', etc. In order to be suitable for optimisation, they need to be expressed in terms of quantifiable parameters (in FoR-terms: Quantitative State Concepts (QSCs)) that can be used to develop indicators, viz. assemblages of QSCs that indicate whether or not there is a problem (comparing an observed or estimated state with a desired state).

Quantification considerations

The quantification method and Quantitative State Concepts (QSCs) to be used, as well as the required level of detail and accuracy, depend on the situation.

In the concept design phase, it is typically important to narrow down to a few options from a broad range of alternatives. Since the main goal is to 'rank and filter', often in a context of still-changing demands by the client, it is generally sufficient to estimate order-of-magnitude dimensions per alternative, and determine how sensitive these alternatives are to changing boundary conditions. Accuracy is important to the extent that the ranking should be trustworthy, but insufficient time, resources and information are available to elaborate each alternative to the last nut, bolt and Euro. Performance metrics are estimated by rules of thumb or determined with more rigorous parametric calculation methods, though often with coarse estimated inputs.

In the detailed design phase it is important to demonstrate that a design satisfies a number of criteria, imposed by the client, by law and/or by the environment (i.e. safety, stability, baring capacity, operability, robustness). Since the main goal of this phase is to 'select and implement', the required accuracy is much higher, since design flaws can lead to significant cost overruns and severe damages. Performance metrics in this case follow from detailed engineering studies, that are driven by high-quality inputs derived from site surveys, detailed measurements and advanced models and simulations, and may take months to years to complete.

In the operational phase, performance metrics can be measured directly or estimated with operational models that predict winds, currents, waves and subsequent impacts on operations on a daily basis. When the aim is to enable timely (and often costly) intervention in operations, i.e. temporary suspension of operations due to imminent weather conditions, it is important that performance metrics and associated intervention triggers are accurate and trustworthy.

From the above-mentioned issues a few general considerations regarding quantification emerge:

- *Accuracy* – especially in the concept design phase inputs are generally based on estimates (e.g. demand, vessel mix, (un)loading rates, discount rate), and models used are typically schematic representations of reality (e.g. Schijf's model of water level drawdown described in Part III – Section 4.1, or the queuing models described in Section 2.4). But even in the detailed design and operational phase not everything can be measured exactly, so for the assessment of some metrics one needs to use estimates or models. It is important to carefully consider the appropriate level of accuracy of quantifications.
- *Variability* – performance metrics may be variable at different temporal and spatial scales, so a snapshot or local observation may not be representative. Designing for a pre-defined operability level requires sufficiently long time series of waves and water levels. Currents that influence port accessibility will vary with tides, day-to-day weather conditions and port configuration, which generally requires point measurements to be combined with models to arrive at synoptic information. It is important to consider the types of variability that may affect decision making and incorporate these in the QSC.
- *Interpretation of measurements and trends* – due to the complexity of port and waterway systems, changes in local performance metrics are not always easily translated to performance metrics at system scale; cause-effect relationships may be intricate and adequate countermeasures may not be obvious: Prolonged droughts may lead to lower water levels. Reduced loading rates, to avoid grounding, may lead to an increased number of trips to move the same amount of cargo. As a result, a depth-bottleneck on an inland waterway, may lead to increased traffic and congestion in a seaport several hundreds of kilometres downstream. It is important to select the appropriate system boundaries and include the appropriate level of detail.

Understanding the functioning of the supply chain and its components is therefore a prerequisite of designing effective QSCs.

Performance indicators

As mentioned in Part I – Section 2.2.2 we define indicators as assemblages of QSCs that indicate whether or not there is a problem. A problem can be identified from comparing an observed or estimated state with a desired state. For port and waterway problems we typically look for indicators regarding supply chain performance. Examples are indicators for:

- *cost-effectiveness (depending on the actor's perspective)* – Net Present Value (NPV) of a terminal operation, cost per ton hydrogen, cost per Twenty Feet Equivalent Units (TEU), demurrage costs associated with vessel waiting times, etc.;
- *throughput* – number of TEU, cars or passengers handled per unit time, tons of dry or liquid bulk handled per unit time, etc.;
- *capacity* – maximum number of vessels that can pass per unit time through a waterway or a lock; maximum amount of cargo that can be handled per unit time at a port terminal, etc.;
- *timely delivery* – percentage of deliveries on time, average delay, waiting times as a factor of service time, etc.;
- *safety* – number of accidents as percentage of the number of operations or events (e.g. ship encounters), number of casualties relative to the number of personnel days, risk defined as probability of occurrence of an undesired event times the damage done, etc.;
- *environmental sustainability* – energy consumption, fossil fuel consumption, emissions (CO_2, SO_x, NO_x, PM-x etc.), production of turbidity, waste or pollutants, nature-inclusiveness of structures, etc.;
- *security* – value of stolen goods, costs of vandalism, amount of illegally imported goods.

To function as indicators each of the examples mentioned above requires a QSC for quantification and a reference value to determine whether or not the current or and estimated state is to be considered problematic. A set of indicators can be like a set of meters on a dashboard: they enable monitoring the system's performance and trigger corrective measures if necessary.

1.3 Performance analysis

When investigating the performance of a supply chain (sub)system, it is important to separate it from the adjacent systems, such that changes in its state don't interact with the states of the other systems. In space-time problems, this means that the system boundaries have to be chosen far enough away in space and time to avoid this interaction, such that the boundary conditions can be considered as a given. In a supply chain, the system components (nodes and branches) are connected, so one simply has to assume that this interaction does not take place. Once the (sub)system's separate performance has been determined, its interaction with the adjacent (sub)systems can be analysed.

Figure 1.3 outlines the general approach to performance analyses. The system component to be considered is separated from the adjacent ones by defining the 'boundary conditions' (bc), which are in fact the inputs from the adjacent components. In the case of a port, for instance, this can be the cargo flows shown in Figure 4.26 and Figure 4.27 in Part II – Chapter 4.

Once the objective of the analysis has been identified ('problem objectification'), it is useful to first formulate a verbal model. Such a model outlines in words how the system functions, in terms of determining factors and cause-effect relationships. It may be laid down in a 'mindmap', a flow diagram mapping out the relationships between the most important factors. This not only helps structuring the analysis, it is also an important aid in explaining the system to a lay audience.

Depending on the system's complexity and the accuracy requirements of the performance analysis, one may choose for quantification with empirical rules of thumb, an analytical model (generally a set of calculation rules, if necessary supported by tabulated information), or a numerical simulation model. In design processes, these methods are often used successively as the design proceeds. This is discussed in more detail in Chapter 2.

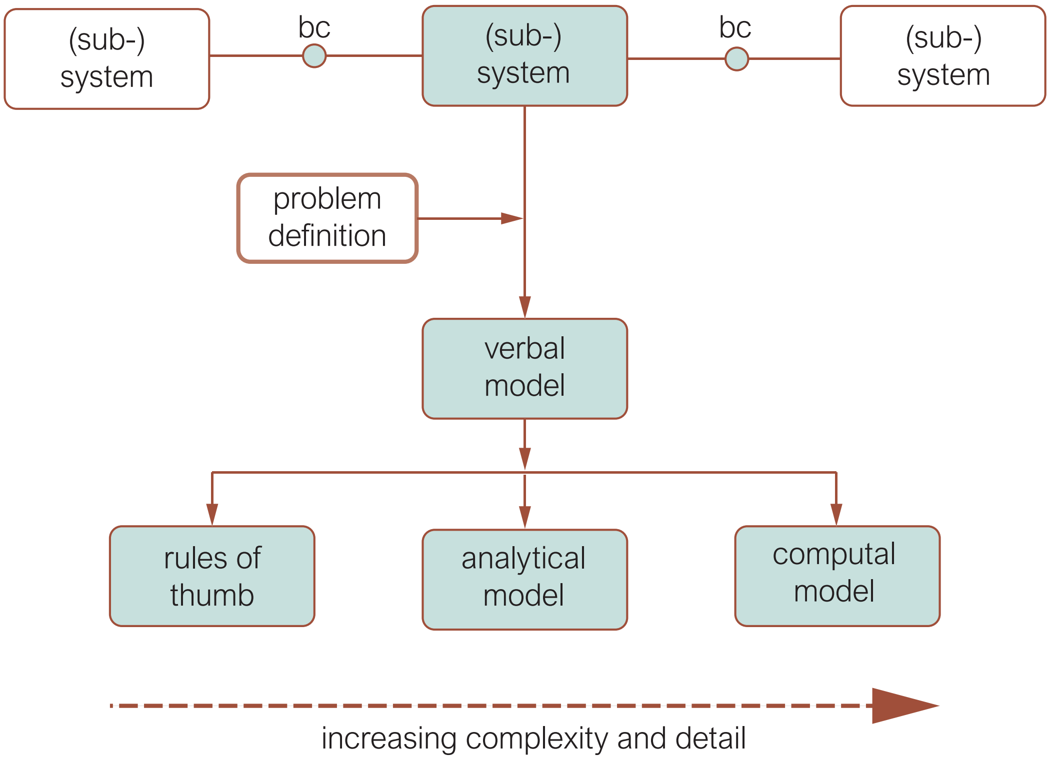

Figure 1.3: General approach to performance analysis (by TU Delft – Ports and Waterways is licenced under CC BY-NC-SA 4.0).