Port performance measurement in the context of port choice: an MCDA approach

Jafar Rezaei, Linde van Wulfften Palthe and Lori Tavasszy
Faculty of Technology, Policy and Management, Delft University of Technology, Delft, The Netherlands
Bart Wiegmans
Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, and
Frank van der Laan
Department of Business Analysis and Intelligence, Port of Rotterdam Authority N.V., Rotterdam, The Netherlands

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Abstract

Purpose – Port performance and port choice have been treated as separate streams of research. This hampers the efforts of ports to anticipate on and respond to possible future changes in port choice by shippers, freight forwarders and carriers. The purpose of this paper is to develop and demonstrate a port performance measurement methodology, extended from the perspective of port choice, which includes hinterland performance and a weighting of attributes from a port choice perspective.

Design/methodology/approach – A review of literature is used to extend the scope of port performance indicators. Multi-criteria decision analysis is used to operationalize the context of port choice, presenting a weighted approach using the Best-Worst Method (BWM). An empirical model is built based on an extensive port stakeholder survey.

Findings – Transport costs and times along the transport chain are the dominant factors for port competitiveness. Satisfaction, reputation and flexibility criteria are the other important decision criteria. The results also show how the availability of different modal alternatives impact on the position of a port. A ranking of routes for hinterland regions is done.

Originality/value – The paper focuses on two extensions of port performance measurement. So far, not all factors that determine port choice have been included in port performance studies. Here, first, factors related to hinterland services are included. Second, a weighting of port performance measures is proposed. The importance of factors is assessed using BWM. The approach is demonstrated empirically for a case of the European contestable hinterland regions, which so far have lacked quantitative analysis.

Keywords MCDA, Best-Worst Method, BWM, Multi-criteria decision analysis, Port performance measurement

Paper type Research paper

1. Introduction

Port performance and port choice are among the most popular topics when it comes to port studies. Despite this, they have largely been treated by researchers as two separate streams of work. As a result, port performance measurement has insufficiently developed from the perspective of port choice. This hampers the efforts of ports to compete successfully and to anticipate on possible future changes in port choice by shippers and carriers (Parola *et al.*, 2017).

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Until now, other perspectives than port choice have dominated the literature on port performance. For example, performance included the economic efficiency and effectiveness of a port (e.g. Talley, 2006), services to local users of the port (e.g. de Langen, 2007) or the governance of the organization (e.g. Vieira *et al.*, 2014). If a port is selected more frequently for a certain hinterland region, it will have a larger market share and is then regarded as more competitive than a port that is selected less frequently for that same hinterland region. The aim of this paper, therefore, is to integrate port choice factors into port performance measurement.

There are two main approaches that can be considered to measure port performance from the perspective of port choice. The traditional approach involves the direct measurement of indicators through observation, interviews and surveys (Bichou, 2006; Bichou and Gray, 2004; Calderinha and Felicio, 2014). Quantitative analysis is done to understand relationships between these factors (e.g. Tongzon, 1995; Wiegmans and Dekker, 2016). Research on port choice has so far been done mostly from within a behavioral framework (see e.g. Martínez Moya and Feo Valero, 2017 for a review) and differs from the previous in three important ways. First, the focus is on the decision by the users of the ports, implying that the relative importance of performance indicators, as perceived by the user, has to be known. Second, the approach is comprehensive from the view of the decision maker (DM): all relevant criteria for the choice should be taken into account. Third, it typically involves modeling, in order to allow to test the validity of the assumed relations between decision factors, weights and port choices.

This paper focuses on two extensions of port performance measurement. So far, not all factors that determine port choice have been included in port performance studies. Here, first, factors related to hinterland services are included. Port choice factors are derived from the joint literature of port performance and port choice. Second, a weighting of port performance measures is proposed, which is based on the attractiveness of ports *vis-a-vis* each other. The importance of factors is assessed using MCDA. The approach is demonstrated empirically for a case in Europe.

The remainder of the paper is organized as follows. The next section presents the literature review. Section 3 outlines the methodology. Section 4 discusses the application of the method for seven European ports and their hinterland regions, including the performance indicators and the data acquisition approach. Section 5 presents and discusses the results, including the relative importance of the respective indicators for the different actors and the performance measurement for European ports. Section 6 contains the conclusions of the paper.

2. Literature review

Companies such as port authorities and port terminal operators use different performance management techniques to obtain insight into the quality, cost-effectiveness and profitability of their operations. Performance carries an efficiency component as to how well the resources expended are used and, in this respect, ports and terminals transform inputs in a process into outputs (Tongzon, 2009; Wiegmans and Dekker, 2016). In the literature, deep-sea container port and container terminal performance in terms of efficiency have been studied extensively. Cullinane and Wang (2007) implemented panel data approaches in order to be able to implement medium- and long-term efficiency analysis. They found that efficiency levels of container ports vary (sometimes drastically) over time. This means that port and terminal performance results of non-panel data have to be treated with care. Roll and Hayuth (1993) analyzed a data set of 20 ports on port performance by applying data envelopment analysis. In their conclusions, they focused on the relative rankings of the ports toward each other. Turner *et al.* (2004) found that scale economies exist at the container terminal level in container ports. A more recent finding is from Schøyen and Odeck (2013). In their analysis of Norwegian container ports, they find that the ports need to increase their scale due to the container port operations performing under increasing returns to scale. Zhang *et al.* (2018) developed a model to analyze port competition for the integrated intermodal network design and pricing strategy problem. Their main conclusion links dry port locations clearly with geography.

Bichou and Gray (2004) developed a logistics and supply chain management approach to port performance measurement. The framework they developed can be beneficial for port efficiency by focusing port strategies on activities that generate the most added value in logistics and supply chains. Ha and Yang (2017) introduced a hybrid multi-stakeholder framework for the modeling of port performance indicators. The framework offers a diagnostic instrument for performance evaluation of terminals and ports. Although they take into account the different port stakeholders to measure port performance, the stakeholders do not include different types of users and the weighting of these indicators is not obtained from stakeholders, but from subject matter experts. The paper especially builds on the direction given by the last three papers, by incorporating the different user-stakeholders throughout the transport chain and by also incorporating the different weights they attribute to port performance factors.

The main components of the transport chains (both imports and exports) are the deep-sea transport link, the port and terminal, and the hinterland link. Therefore, ports should not be viewed as a separate entity but as part of a transport chain. Several studies analyze port choice factors from different angles. An overview of factors on port choice can be found in Table I.

The port performance factor analysis has led to the selection of the following factors to be included in the analysis: Maritime freight rates; maritime transit time; first port of call; last port of call; satisfaction with deep-sea connection; frequency of shipping lines; terminal handling charges (THC); international ship and port facility security; customs service; port reputation; satisfaction with terminal operations; number of container terminals; inland freight rates; inland transit time; reputation of inland transport connection; frequency of inland lines; and number of inland transport operators.

These factors can be clustered according to the part of the maritime supply chain that they relate to (sea leg, port or inland leg) and the way that they are measured (quantitative/qualitative). The factors were separated out which relate to the flexibility concerning shipping options inherent in the system. This provides us the set of ordered indicators shown in Table II.

In this paper, different stakeholders throughout the transport chain are incorporated, accounting for the different weights they attribute to the different port choice factors. In our approach, decision/choice models provide a new context for making performance measurement more policy relevant by including the weights of different criteria from a market perspective and taken from a transport and supply chain perspective. The research gap addressed is the analysis of port performance measures that include weights from a transport and supply chain perspective.

As mentioned earlier, in this study we use an MCDA approach to measure port performance. Here we report some studies that have used MCDA approach in port choice and port performance measurement. Chou (2007) proposed a fuzzy MCDM model to formulate and solve a transshipment container port selection problem. Chou (2010), Ugboma *et al.* (2006) and Lirn *et al.* (2004) used AHP, while Onut *et al.* (2011) proposed a fuzzy analytic network process (ANP) to solve the port choice problem. Wang *et al.* (2014) used a hybrid fuzzy-Delphi–TOPSIS method for port choice problem. Ha and Yang (2017) used AHP, decision-making trial and evaluation laboratory and ANP to measure port performance. Da Cruz *et al.* (2013) used multi-criteria analysis and principal component analysis for port performance measurement, while Barros and Athanassiou (2015) used DEA to evaluate the efficiency of European ports. In the next section, the port performance measurement methodology is presented.

Factors	Actor perspective	Source
Number of sailings, inland freight rates, proximity of port, congestion, possibility of intermodal links, port equipment, port charges, quality of customs handling, free time, port security and size of port	Shipper	Slack (1985)
Port location, port facility, cargo volume, service level	Not specific	Song and Yeo (2004)
Number of port calls, draught, trade volume, port cargo traffic, ship turnaround time, annual operating hours, port charges and availability of intermodal transports	Liner shipping company	Tang *et al.* (2008)
Availability of hinterland connections, reasonable tariffs and immediacy of consumers	Deep-sea container operator	Wiegmans *et al.* (2008)
After interview with shipping companies: cost, quality of hinterland connections, capacity, reliability, port location and cargo base. For hinterland services: cost, reliability, frequency of service, flexibility, total door-to-door transport time and customer service quality	Shipping companies	Aronietis *et al.* (2010)
Accessibility to port premises for pickup and delivery, overall port reliability, provision of adequate, on-time information, incidence of delays, port security, speed of stevedore's cargo (un)loading, ocean carrier schedule reliability/integrity, terminal operator responsiveness to requests, availability of labor, efficiency of documentary processes, port authority responsiveness to requests, incidence of cargo damage, invoice accuracy, connectivity/operability to rail, truck, and warehousing, and availability of capacity	Supply chain partner	Brooks and Schellinck (2015)
Accessibility, connectivity, efficiency, service quality, level of integration, flexibility, port charges, carbon footprint, transit time, frequency, availability, freight rates, reputation, on-time delivery, reliability	Shipper, third-party logistics providers	Magala and Sammons (2008)
Liner shippers' perspective: vessel turnaround time, intermodal links, seaport facilities and equipment, proximity to import/export area and channel depth. From seaport authorities and terminal operators perspective: seaport facilities and equipment, channel depth, intermodal links, vessel turnaround time, and proximity to import/export area	Shipping line, seaport authority and terminal operator	Da Cruz *et al.* (2013)
Port service, hinterland condition, availability, convenience, logistics cost, regional center, connectivity	Shipping line	Yeo *et al.* (2014)
Port efficiency and performance, political stability, port costs, port infrastructure, cargo volume and port location	Group of experts	van Dyck and Ismael (2015)
Port costs, geographical location, quality of hinterland connections, productivity, and capacity. For shipper: costs, quality of operations, reputation of operator, and port location	Shippers, carriers, freight forwarders	Nazemzadeh and Vanelslander (2015)
(Deep) sea transport costs, port handling charges, inspection costs/customs duties, inland transport costs, inland handling charges, reliability, frequency of service, flexibility, total door-to-door transport time, customer service	Not specific	de Jong (2015)
Maritime transport time, maritime transport cost, port cost, port dwell time, water depth, number of feeder services, number of port calls, number of IWT services, number of rail services, hinterland transport cost, hinterland transport time, container demand Europe	Not specific	Mueller (2014)

(*continued*)

Table I.
An overview of port performance factors from literature

Factors	Actor perspective	Source
Shipping lines: costs at port, customs and government regulation, hinterland connection, terminal operator, port location, port facility, shipping services, port information system. Forwarder: port location, hinterland connections, shipping services, customs and government regulation, costs at port, port information system, terminal operator, port facility. Shipper: port location, hinterland connections, port costs, customs and government regulation, shipping services, port information system, port facility, terminal operator	Shipping line, forwarder, shipper	Yuen *et al.* (2012)
Location of port, efficiency of cargo handling, quality of terminal operating companies, quality of equipment, quality of shipping services, information services in port, good reputation related to damage and delays, customer focus, connection to hinterland modes, personal contacts in port, overall score	Shippers and freight forwarders	de Langen (2007)
Port service, hinterland condition, availability, convenience, logistics cost, regional center and connectivity	Shipping companies and ship owners	Yeo *et al.* (2008)
Most significant for carriers: handling cost of containers, proximity to main navigation routes, proximity to feeder ports, proximity to import/export area, port basic infrastructure. For ports: handling cost of containers, proximity to feeder ports, port basic infrastructure, proximity to main navigation routes, proximity to import/export area	Carriers and port operators	Lirn *et al.* (2004)
Efficiency, shipping frequency, infrastructure, location, port charges, quick response to port users' needs, reputation for cargo damage	Freight forwarders	Tongzon (2009)

Table I.

Main criteria	Sea leg	Port	Inland leg
Transport chain performance	Maritime freight rates Maritime transit time First port of call Last port of call	Terminal charges Security (ISPS)	Inland rates Inland transit time
Qualitative performance	Satisfaction with deep-sea connection	Customs service Port reputation Satisfaction with terminal operations	Reputation of connection
Flexibility	Frequency of shipping lines	Number of container terminals	Frequency of inland lines Number of inland transport operators

Table II.
Port performance indicators relating to port choice

3. Methodology

The methodology proposed in this paper consists of four phases: identifying the decision analysis context; quantifying the criteria; weighting the criteria; and calculating overall performance. These steps are developed in more detail below.

Phase 1: identifying the decision analysis context

To measure the port performance from different perspectives, it is necessary to first identify the stakeholders, $s \in S$, a set of ports, $r \in R$ and a set of performance measurements (criteria), $c \in C$. Since it is suggested that the stakeholders are the ones who are interested in the entire transport chain, the main route DMs for the chosen trade lane should be defined. Identifying the freight forwarders, shippers and carriers that play a significant role on the chosen trade lane, multiple channels may be deployed for this process. The set of alternatives to be defined results from an empirical study into the defined trade lane. Interesting routes are those through ports with the following requirements: currently have a large market share on the trade lane; serve as a gateway port or have a desire to do so instead of transshipment port; have a fast and efficient inland connection to the area; and have plans and possibilities to grow in the future. By assessing the ports on these four requirements, an outline can be drawn of potential competitive ports for the trade lane. The routes origin–port–destination form the alternatives that are evaluated in the model. The last part is identifying the criteria. The maritime part, port operations part and inland connection part should all be tested on these criteria.

Phase 2: quantifying the criteria

Some of the criteria can be measured objectively (such as costs). Data on these criteria can be collected via available data sources. Some other criteria are subjective, such as the reputation of a port; data can be collected via measurement tools from decision makers or experts. As the collected data are then numbers with different scales (e.g. cost in euro and time in hour or day), they are normalized by applying the following formula (see Rezaei (2018) for other approaches):

$$\begin{cases} \bar{x} = \frac{x - x_{\min}}{x_{\max} - x_{\min}}, & \text{for a positive criterion like speed,} \\ \bar{x} = \frac{x - x_{\max}}{x_{\min} - x_{\max}}, & \text{for a negative criterion like cost.} \end{cases} \tag{1}$$

Phase 3: weighting the criteria

Basically, the weights of the criteria combined with the performance reveal how the port users are attracted toward an alternative port. The method that is proposed in this paper to identify weights of criteria is the Best-Worst Method (BWM), a multi-criteria decision-analysis method. We chose this method due to several reasons: it is a structured method which uses fewer data points compared to other pairwise comparison-based weighting methods (such as AHP) and leads to more reliable results (Rezaei, 2015, 2016); it is able to handle both subjective and objective criteria; the scale used for the pairwise comparisons in this method contains only integer numbers which avoids the problem of imbalanced scale (Salo and Hämäläinen, 1997); and the consistency of the pairwise comparisons, in this method, is defined based on Tchebychev distance, which implies that the weights of the criteria are obtained such that the consistency of all individual pairwise comparisons are taken into account. The method has been successfully applied in several application areas including supply chain management (Wan Ahmad *et al.*, 2017, Rezaei *et al.*, 2015, 2016; Sahebi *et al.*, 2017; Ahmadi *et al.*, 2017; Gupta and Barua, 2018; Vahidi *et al.*, 2018), technology selection (van de Kaa *et al.*, 2017, 2018; Ren, 2018) and research (and development) assessment (Salimi, 2017; Salimi and Rezaei, 2016, 2018).

The steps in this method are as follows:

- Step 1: the DM determines a set of decision criteria (here performance measurements).
- Step 2: the DM chooses the best (e.g. the most important) and the worst (e.g. the least important) criteria from among the set of criteria identified in Step 1 from his/her own perspective.
- Step 3: the DM conducts pairwise comparison between the best criterion and the other criteria. The aim is to determine the preference of the most important criterion

to the other criteria, using a number from 1 to 9 (1: equally important, 9: extremely more important), which results in a Best-to-Others vector BO, where a_{Bj} represents the preference of the best criterion B over criterion j:

$$BO = (a_{B1}, a_{B2}, \ldots, a_{Bn}). \tag{2}$$

- Step 4: the DM conducts pairwise comparison between the other criteria and the worst criterion. Here, the aim is to determine the preference of the other criteria over the worst criterion, using a number from 1 to 9 (1: equally important, 9: extremely more important), which result is an Others-to-Worst vector OW, where a_{jW} represents the preference of the criterion j over the worst criterion W:

$$OW = (a_{1W}, a_{2W}, \ldots, a_{nW}). \tag{3}$$

- Step 5: calculating the optimal weights $\left(w_1^*, w_2^*, \ldots, w_n^*\right)$ such that the maximum absolute differences $|w_B - a_{Bj}w_j|$ and $|w_j - a_{jW}w_W|$ for all j is minimized. To this end, the following linear programming problem should be solved:

$$\min \xi^L$$

Subject to:

$$\left|w_B - a_{Bj}w_j\right| \leqslant \xi^L, \forall j,$$

$$\left|w_j - a_{jW}w_W\right| \leqslant \xi^L, \forall j,$$

$$\sum_j w_j = 1,$$

$$w_j \geqslant 0, \forall j. \tag{4}$$

Solving this problem results in the optimal weights $\left(w_1^*, w_2^*, \ldots, w_n^*\right)$ and ξ^{L*}. Here, the ξ^{L*} is considered as an indicator of consistency of the comparisons – values close to zero show a high level of consistency. The weighting should be performed among the main criteria and for each group of sub-criteria belonging to these main criteria. The optimal weights from the main criterion and their associated sub-criteria are then multiplied to get the global weights.

Phase 4: calculating the overall performance of the alternatives

The previous two phases are combined to calculate the performance of each specified route/alternative. Having T sub-criteria for transport chain performance, Q sub-criteria for qualitative performance and F sub-criteria for flexibility, the sum of the weighted scores of the set of criteria is defined as the overall score for rout ro as follows:

$$\text{Performance}_{ro} = \sum_{t=1}^{T} w_t^{\alpha} a_r^{\alpha} + \sum_{q=1}^{Q} w_q^{\beta} a_r^{\beta} + \sum_{f=1}^{F} w_f^{\gamma} a_r^{\gamma}, \forall r, \tag{5}$$

where $w_t^{\alpha}, w_q^{\beta}, w_f^{\gamma}$ are the global weights for the sub-criteria of transport chain, qualitative performance and flexibility performance, respectively, and a_r^{α}, a_r^{β}, a_r^{γ} are the normalized scores for route r on the corresponding sub-criteria transport chain, qualitative performance and flexibility performance, respectively. The higher the overall score for an alternative, the higher the performance of that alternative.

Section 4 introduces the case for the application of the method for a port/hinterland system in Europe.

4. MCDA applied to port competition in the heart of Europe

Considering the first phase of study (see Section 3, identifying the decision analysis context), for the application, a number of regions and ports within Europe is selected. In total, seven ports (Rotterdam, Antwerp, Hamburg, Koper, Piraeus, Genoa and Gdansk) and five hinterland destinations regions (South Germany, Switzerland, Austria, Czech Republic and Hungary) are considered. Besides, the objective to present a simple and transparent empirical model for demonstration purposes, the choice of regions and ports was based on the following. The regions form part of the so-called contestable hinterland in the heart of Europe (Notteboom, 2009), where several ports claim part of these regions as their hinterland. The ports included are those that already have a dominant role in container transshipment in Europe toward the European heartland (North-West Europe) and those have a high or growing share of these regions due to closeness to the major shipping routes from China (South and North Europe). These ports are seen as the main contenders for volumes to and from the five hinterland regions. For the maritime, leg flows were considered originating from the same one region in Asia, Shanghai in China. Figure 1 shows a map with the locations of the different ports and regions. As can be seen, different angles to enter Europe are considered, having a diverse set of possible routes. On all these routes, road and rail service are available. Inland waterways shipping is mostly feasible along the Rhine river, providing direct connectivity for the ports of Rotterdam and Antwerp toward Switzerland.

In order to get to the actual score of relative attractiveness of the routes, first, the performance needed to be measured and the weights needed to be established for the criteria. A survey was designed in order to address both topics according to the final users' experience and preferences. In the first part of the survey, the respondents were asked to perform the pairwise comparisons for their best and worst criteria. In this part, we provided an explanation of the nine-point scale which is used for the BWM, along with a full example on how to perform the pairwise comparisons. The results of this part are used for the estimation of the weights further on in this section. In the second part of the survey the respondents were asked to rate specific ports or connections that they had experience with on the qualitative criteria. The results from this part of the survey are used for the quantification of the qualitative criteria in the next sub-section of this section (please note that the objective measures such as costs are collected from data sources and not via survey, see the next section).

Following the first phase of study (see Section 3, identifying the decision analysis context), a set of important actors (including freight forwarders, shippers and carriers active on the Asia–Central and Eastern European trade lane) were identified. An online survey was designed and distributed among approximately 200 potential respondents, who were identified through Port of Rotterdam. After two reminders, and through phone calling the major actors, during a period of two months, we got responses from 19 major actors including 12 major freight forwarders, 5 carriers and 2 shippers. The respondents are the top-level managers of these companies. The respondents' main experience with the ports is distributed as follows: 24 percent for Hamburg, 24 percent for Koper, 19 percent for Rotterdam, 12 percent for Antwerp, 7 percent for Genoa, 7 percent for Piraeus and 7 percent for Gdansk. With respect to different regions, the respondents have the following experience: 31 percent Austria, 27 percent Czech Republic, 15 percent Southern Germany, 21 percent Hungary and 6 percent Switzerland.

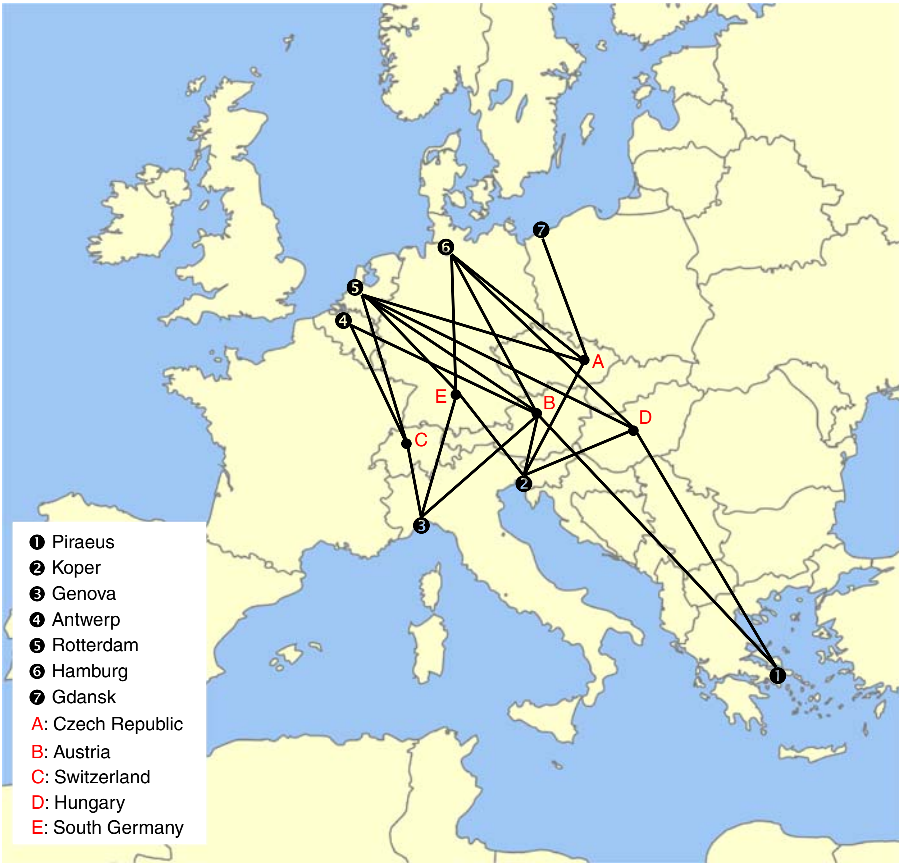


Figure 1.
Ports and hinterland regions considered in Europe

Performance measurement

The remainder of this section describes the data acquisition per criterion. The qualitative criteria are estimated according to the perception of the final user and are scored with the survey. Data collection for the quantitative criteria is done through multiple sources, as described below.

The performance measures for the maritime leg were recorded as follows:

- Maritime freight rates can be estimated using the Shanghai Containerized Freight Index (Shanghai Shipping Exchange, 2016). The rates are quoted in US$ per 20-foot container (TEU) and derived from an audited process involving submission from multiple panelists, including carriers, NVOs and forwarders (JOC, 2016). For quantifying this factor for 2016, the average over the last year is calculated. This comes down to a maritime freight rate of 537 €/TEU from Shanghai to North Europe and 630 €/TEU from Shanghai to the Mediterranean.
- In order to estimate the maritime transit time, first, the number of loops on each connection is found through Alphaliner (2016). Only the loops calling both in Shanghai and in one of the considered ports are taken into account. For each of these loops, 28 in total, the maritime transit times are found through the carrier offering that loop. Since nearly all carriers formed alliances, either one of the carrier in the alliance is used to

find the maritime transit times. These are 2M, CMA CGM (2016), Evergreen Line-CKYH, Hapag Lloyd (2016), UASC (2016) and NYK (Maersk Line, 2016a, b; Mediterranean Shipping Company, 2016; Shipment Link, 2016; UASC, 2016; NYK Line, 2016a, b). The final scores for these sub-criteria are the averages of all transit times of all loops in both directions.

- First port of call is valued by taking the total number of loops calling in a port per week, and simply counting how many of the loops call at the considered port first. Since the frequencies are already in number of calls per week, the number of first port of calls is given as a percentage of the frequency. The source for the loops is Drewry in Q3 for 2015.
- Similar to the previous sub-criterion, last port of call is given in percentage of the total number of calls in a port. This information is gathered from Drewry for Q3 in year 2015.

Table III shows the data about ports as first or last port of call (FPOC and LPOC, respectively).

The performance measures for the port leg were recorded as follows:

- The sub-criterion satisfaction with deep-sea connection is scored through the survey. After the respondent was asked with what port they have experience, they were asked to what degree they are satisfied with the deep-sea connection from Asia to that port. The respondent answered with extremely low, very low, low, medium, high, very high or extremely high (1–7).
- The frequency of shipping lines is also used in the calculation of the sub-criteria first port of call and last port of call. The source for these loops is again Drewry for Q3 in year 2015, and this is calculated for both import and export calls. This indicates how often per week a vessel calls in the studied port.
- THC is one of the mandatory ancillary charges which are not always included by the basic ocean freight rate. It is a pass-through charge based on the costs of handling the container in the terminals, including loading and discharging to/from the vessel. THC vary per port and are charged per container. Different THC can be charged for outgoing containers, incoming containers and empties. Also, a reefer container normally is more expensive than a dry container. For the estimation of the THC in this study, several carriers where consulted on their THC per port. Among these where Hapag Lloyd (2015), MSC (2015), Hamburg Süd (2016b), UASC (2016), CMA CGM (2016), NYK Line (2016a, b), Maersk Line (2016a, b) and Mitsui O.S.K. Lines (2016). For this study, the charge for a dry container (TEU or FEU) is taken and averaged over import and export.
- The International Ship and Port Facility Security Code (ISPS) consists of a set of security measures applicable to ships and port facilities in order to minimize the likelihood of security incidents. It was developed by the International Maritime Organization in the response to the perceived threats to ships and port facilities in the

	Piraeus	Koper	Genoa	Antwerp	Rotterdam	Hamburg	Gdansk
FPOC	5	1	2	1	11	5	0
LPOC	1	0	0	7	10	1	0
Frequency	6	3	6	10	25	17	2
%FPOC	83	33	33	10	44	29	0
%LPOC	17	0	0	70	40	6	0

Table III. Position of ports in liner schedules wake of the 9/11 attacks in the USA (International Maritime Organization, 2015). Charges for security are borne by the shippers and translated to the end user as either ISPS, SEC or CSF. The latter two refer to the sealing of a container which was previously opened and so this does not refer to all containers. In this study, the general ISPS charge from the port authorities to the carriers are considered. For the estimation of the ISPS charge per port, several rate sheets from carriers where consulted (Hamburg Süd, 2016a; MSC, 2015; UASC, 2016; CMA CGM, 2016; NYK Line, 2016a, b). All these values where averaged.

- The sub-criterion customs service is scored through the survey and thus based on the experience of the freight forwarders, carriers, and shippers. After the respondent was asked with what port they have experience, they were asked to rate the customs service at those ports. The respondent answered with extremely bad, very bad, bad, medium, good, very good or extremely good (1–7).
- The sub-criterion port reputation is also scored through the survey and thus based on the experience of the freight forwarders, carriers and shippers with that port. After the respondent was asked with what port he/she has experience, they were asked to rate the reputation of those ports. The respondent answered with extremely bad, very bad, bad, medium, good, very good or extremely good (1–7).
- The criterion satisfaction with terminal operations is scored through the survey and based on the perception of the freight forwarder, carrier and shipper on the quality of the terminal operations at that port. After the respondent was asked with what port they have experience, they were asked to what degree they are satisfied with the terminal operations at those ports. The respondent answered with extremely low, very low, low, medium, high, very high or extremely high (1–7).
- The number of container terminals is a measure for the flexibility to what extent containers can switch last minute from terminal, if any delays or deficiencies occur in the original container terminal. Since all incoming containers come from the deep sea and all outgoing containers are destined for Asia, only deep-sea terminals with a gateway function and a minimum draught of 14 m are included when measuring the number of container terminal sub-criteria.

Table IV summarizes the scores for the seven ports as explained above.

Performance of the inland leg-related services was measured as follows:

- The sub-criterion reputation of inland transport connection is scored through the survey and based on the experience of the freight forwarder, carrier and shipper. After the respondent was asked with what port they have experience and in which countries they are active, they were asked to rate the inland transport connection

Table IV. Summary of criteria related to the seaport's services and facilities

Ports	Terminal handling charges (€/TEU)	ISPS (€/unit)	Customs service (1,…,7)	Port reputation (1,…,7)	Satisfaction with terminal operations (1,…,7)	Number of container terminals (no. of container terminals)
Piraeus	106	11	4.20	3.80	3.40	3
Koper	145	11	5.12	5.24	5.00	1
Genoa	179	13	4.20	4.40	4.40	2
Antwerp	179	12	5.44	5.00	5.11	4
Rotterdam	202	13	5.50	5.93	5.29	6
Hamburg	223	16	5.65	6.06	5.41	4
Gdansk	103	14	4.60	5.00	4.40	2

between those ports and countries. Since this sub-criterion involves the rating of different transport modes (road, rail and barge) for each possible inland transport leg, there are many more dimensions found when scoring this sub-criterion. The respondents use a seven-point scale.

- This criterion number of inland transport operators related to the offering of rail connections on a certain inland leg. There are in total 21 possible inland connections identified for the seven ports considered in this study. Not all inland destinations are connected to each port; only the realistic connections are included.
- The sub-criterion frequency of inland lines for the rail freight network can be found through the rail operators. For some of the links, Rail Cargo Operator Austria (2016) provided the relevant data. Where this information was not given, the frequencies where found through the rail operators. Each operator active on a certain link has their own schedule except if they operate together on a link, which is sometimes the case. Some parties, which have more a logistics/forwarding function, operate by having allocated slots on certain rail connections. If frequencies would still not be found through the previous two ways, these parties were consolidated.
- Inland freight rates are confidential information that most companies do not like to bring out. Rail Cargo Operator provided some of the information, where known. The rates are set for the heaviest 20 ft container. On the links that the inland freight rates were not known, alternative sources were consulted to get a view of the costs. First, this is gathered through carriers offering an inland tariff calculation tool.
- Information on inland transit times was given by RCO. Where this was not available, this was added by checking the schedules of the previously identified operators active on a connection. If it involved an indirect rail connection, an extra day was added for each transfer point along the way.

A summary of the inland transport legs' performance is provided in Tables AI–AIII.

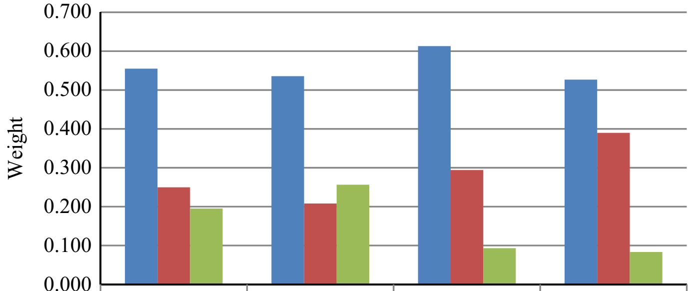
5. Results

Since the construction of criteria is set up of three main criteria, each having their own sub-criteria, the BWM is applied four times. After the respondents defined the best and worst criterion BWM (Step 2), first, they were asked to express to what extent they prefer the best criterion over all the other criteria (Step 3) and, second, to what extent they prefer the other criteria over the worst criterion (Step 4). After gathering the data, the BWM calculations are done resulting in the following outcomes.

Weights of the main criteria

Figure 2 shows the weights given for the main criteria. Three groups were defined according to different scenarios for decision-making about chain choice: the carrier providing door-to-door transport, the freight forwarder and the shipper arranging its own transport. A distinction is also made between their weights.

The main criterion "transport chain performance" is by far the most important criterion according to all respondents. Freight forwarders are the only ones that give a greater importance to the main criterion flexibility than to qualitative performance, whereas, for forwarders, it is the second most important main criterion, for carriers and shippers, it is not that much important. Carriers give, compared to freight forwarders and shippers, the greatest weight to the qualitative performance criterion. Shippers tend to focus their importance on the criterion transport chain performance, which is by far the most important and also gets the greatest weight compared to the other groups.



	Overall	Forwarder	Shipper	Carrier
Transport chain performance	0.555	0.536	0.613	0.527
Qualitative performance	0.250	0.208	0.294	0.390
Flexibility	0.195	0.256	0.093	0.083

Figure 2.
Weights of the main performance criteria

Weights of the sub-criteria

Table V shows the local and global weights of the sub-criteria according to the three groups of actors.

For convenience, Figure 3 visualizes the global weights of the criteria for all groups, sorted from high to low. The order of criteria is quite stable across groups. Minor differences occur between groups which are discussed below.

Total costs seem to be the most important sub-criterion for all groups. This is in line with the general findings in the literature as portrayed in Table I, where nearly every study identifies costs as an important criterion when studying port choice. Overall, the second most important sub-criterion is maritime transit time, followed by inland transit time as the third most important. Both criteria on reputation and satisfaction and the frequencies are, after costs and time, the most important. This confirms the importance of analyzing routes when comparing ports.

Freight forwarders value time as second after costs and tend to give a greater value to inland transit time than maritime transit time. The fourth and fifth most important criteria for freight forwarders are frequency of inland lines and reputation of inland transport operator indicating that they give greater value to the inland transportation leg. The least

Sub-criterion	Overall		Forwarder		Shipper		Carrier	
	Local	Global	Local	Global	Local	Global	Local	Global
Total costs	0.376	0.209	0.370	0.207	0.400	0.222	0.338	0.188
Maritime transit time	0.225	0.125	0.189	0.105	0.283	0.157	0.293	0.163
First port of call	0.112	0.062	0.122	0.068	0.091	0.050	0.103	0.057
Last port of call	0.087	0.048	0.088	0.049	0.092	0.051	0.068	0.038
Inland transit time	0.200	0.111	0.228	0.127	0.134	0.075	0.198	0.110
Satisfaction deep sea	0.281	0.070	0.247	0.062	0.383	0.096	0.231	0.058
Customs service	0.237	0.059	0.220	0.055	0.257	0.064	0.284	0.071
Port reputation	0.105	0.026	0.098	0.025	0.094	0.024	0.178	0.044
Satisfaction terminals	0.153	0.038	0.161	0.040	0.155	0.039	0.095	0.024
Reputation inland	0.225	0.056	0.274	0.069	0.111	0.028	0.212	0.053
Frequency of shipping	0.397	0.078	0.330	0.064	0.565	0.110	0.381	0.074
Number of terminals	0.119	0.023	0.115	0.023	0.109	0.021	0.163	0.032
Frequency inland lines	0.299	0.058	0.371	0.072	0.173	0.034	0.184	0.036
No. inland operators	0.185	0.036	0.185	0.036	0.153	0.030	0.273	0.053

Table V.
Weights of the sub-criteria

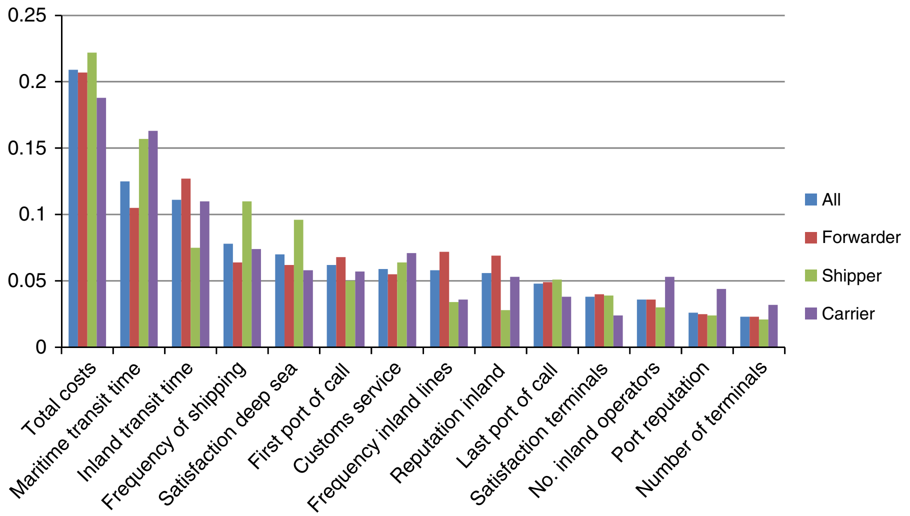


Figure 3.
Global weights of the sub-criteria

important criteria for freight forwarders are number of container terminals and a port reputation. This is not completely in line with Aronietis *et al.* (2010), who identify efficiency and port operations quality/reputation as the most mentioned criteria for the perspective of the freight forwarder. In a specific study about port choice by forwarders with a focus on Malaysia and Thailand, Tongzon (2009) finds that after port efficiency, shipping frequency, adequate infrastructure and proximity to client locations were most important. Also, Yuen *et al.* (2012) find for forwarders port location, hinterland connections and shipping services as top three criteria. The findings here appear to confirm these results.

Clearly observable is that shippers tend to give a higher value to the deep-sea transportation part, since, in their opinion, the second most important criterion is maritime transit time, the third most important criterion is frequency of shipping lines and the fourth is the satisfaction with the deep-sea connection. Shippers thus tend to choose a route with a high-quality deep-sea leg. This finding is in line with Slack (1985), who places the number of sailings as the most important criterion for shippers. He also finds that customs is relatively unimportant; this may be plausible, however, as the alleviation of trade barriers in the last three decades has made customs a more critical barrier for international trade (Hummels and Schaur, 2013). The least important criteria for the shippers are again the number of container terminals and the ports reputation. According to Nazemzadeh and Vanelslander (2015), the criteria most important to shippers are cost, location, connection, productivity and capacity. This matches only partially with the findings. A possible reason for this divergence is that their study did not consider the factors from the perspective of port choice. The results of Yuen *et al.* (2012) partly diverge, as port location and hinterland connections are the most important criteria, shipping services comes fifth and port facilities are relatively unimportant. In the context of the Asian situation, however, port location is interpreted more broadly than at regional scale, indicating proximity to the hinterland, with large differences in distances to the Chinese hinterland for the competing main ports (e.g. Singapore, Shanghai). Hence, it is understandable that in their specific situation, this criterion would dominate.

Carriers give almost as great importance to maritime transit time as to the total costs. Carriers' third most important criterion was inland transit time. Number 4 is the frequency of shipping lines and number five is customs service. The least important criteria in the eyes of the carrier are satisfaction with terminal operations and number of container terminals.

Studies specifically focusing on carriers provide similar results. Nazemzadeh & Vanelslander (2015) identified connection as the second most important criteria (after costs) for carriers involved in door-to-door transport. Tang *et al.* (2008) also mentioned the number of port calls as the main criterion, another indicator of maritime connectivity. Da Cruz *et al.* (2013) mentioned vessel turnaround time and intermodal links as main criteria for carriers. Yuen *et al.* (2012) mentioned costs, customs and hinterland connections as the top three criteria. Literature discussing port choice and terminal choice finds that these are closely related but still differ substantially since the first is concerned with strategic motives and the latter with financial motives (Wiegmans *et al.*, 2008). This would support the notion, as found here, that port and maritime connection-related factors are more important than those related to terminal handling.

Overall score of alternative chains

After having obtained the weights, one can calculate the final performance of the different routes toward the inland destinations. Only the 21 realistic connections were included here, with commercially available regular inland services between port and hinterland region. Table VI shows the results.

It is interesting to see that the port of Koper, which would be considered peripheral from the connectivity and reputational point of view, still ends up high on the list, bypassing the main EU ports for three of the five destinations. The port of Piraeus, and to a lesser extent, Gdansk and Genoa, cannot compete under the current weighting of factors. A simple manipulation of weights shows that Piraeus can gain a competitive position in relation to Hungary, if costs or travel times are prioritized. The position of the Gdansk and Genoa routes are relatively insensitive for changes in weights. Antwerp is one of the strongest competitors of Rotterdam and Hamburg. Yet, for these hinterland regions, it does not perform strongly. From this analysis, it can be established that Rotterdam and Hamburg perform better on water (sea and inland) and rail connectivity, respectively, which outweighs other factors.

Equally interesting is the clear preference for rail in relation to Austria and Czech Republic, while these also have excellent road connections. For Austria and Switzerland, as countries with a restrictive policy for trucks, especially in the Alpine area and on the transit route to Italy, it is plausible that rail routes provide a relatively high quality.

While Hamburg scores particularly well with this mode, Rotterdam generally scores better by road. The two ports offer rail services of almost equal quality, however, which is interesting in the light of the large difference in the share of rail flows between the two ports.

Czech Republic		Austria		Switzerland		Hungary		Southern Germany	
H-RL	0.6827	H-RL	0.6857	R-RD	0.7122	K-RD	0.6715	R-RD	0.6875
H-RD	0.6797	K-RD	0.6823	R-RL	0.6698	K-RL	0.6369	H-RD	0.6621
R-RD	0.6713	H-RD	0.6376	A-RD	0.6206	H-RL	0.6134	K-RD	0.6597
R-RL	0.6325	R-RD	0.6322	R-B	0.6152	H-RD	0.6061	H-RL	0.6579
K-RD	0.6232	R-RL	0.6224	A-RL	0.5629	R-RL	0.6048	R-RL	0.6550
K-RL	0.4907	K-RL	0.5800	GE-RD	0.5598	R-RD	0.6017	K-RL	0.5402
GD-RD	0.4328	A-RD	0.5369	A-B	0.5039	P-RD	0.3740	GE-RD	0.5336
GD-RL	0.3653	GE-RD	0.4973	GE-RL	0.4287	P-RL	0.3363		
		A-RL	0.4758						
		P-RL	0.3370						
		P-RD	0.3193						

Notes: ports: H, Hamburg; R, Rotterdam; A, Antwerp; GD, Gdansk; GE, Genoa, K, Koper; P, Piraeus. Modes: RD, road; RL, rail; B, barge

Table VI.
Scores of alternative chains

The share of rail flows to and from Hamburg came close to 45 percent in 2015 (Port of Hamburg, 2016) while rail shares to/from Rotterdam barely reached 10 percent (Port of Rotterdam, 2016). Apparently, the lower volumes and frequencies do not immediately translate into a reduced competitiveness of the port toward these hinterland regions.

Finally, this application shows how the availability of different modal alternatives can impact on the position of a port, if the transport chain is taken as a starting point. Especially for container loads, and on short distances like in Europe, the differences in travel times and handling capabilities between modes of transport apparently play a relatively minor role. In addition, the results also confirm that, besides the weighting of port performance criteria, also the hinterland-related criteria are a relevant addition from the perspective of port competitiveness.

6. Conclusions

In this study, port performance measurement was considered from the perspective of port choice. This entails two main needs: first, to evaluate port attractiveness from a transport chain perspective, which includes a maritime leg, the port itself and an inland leg with multiple possible modes. Second, in order to make the assessment useful for port choice considerations, the user perspective should be represented in the form of weighting of port performance criteria. The problem is inherently an MCDA problem due to the presence of a set of alternatives (routes including ports), and a set of evaluation criteria. The proposed methodology consisted of four phases: identifying the decision analysis context; quantifying the criteria; weighting of the criteria; and calculating the performance of the alternatives.

We established 17 key criteria resulting from a review of the of the port choice and performance literature. We proposed the BWM for identifying the weights and developed an application of the approach for the case of Europe. Data were acquired from many different sources to measure the performance indicators and a survey was sent out to practitioners to determine the weighting.

The main findings of the empirical analysis can be summarized as follows. Transport costs and times along the transport chain are the dominant factors for port competitiveness; this is in line with the scientific literature. As measured in this study, these account for over half of the weight of all criteria. Perhaps even more interesting is that the other half is represented by qualitative (satisfaction and reputational) criteria, and the flexibility that can be offered in terms of the number of choices available for handling and shipping. The addition of the weights combined with the specific analysis of the hinterland part do provide a new and more detailed perspective at port performance measurement which, in particular for the group of large forwarders can be considered to be representative.

The application of the approach for the case of Europe shows how the availability of different modal alternatives can impact on the position of a port, if the transport chain is taken as reference point. A ranking of routes for specific hinterland regions can be done based on the integrated performance of routes at transport chain level. These results should help decision makers in industry and policy to identify improvement opportunities that ports could benefit from.

One limitation of this study is the number of respondents for the BWM part, which implies that the generalizability of the weights obtained for the decision criteria is limited. However, the performance measures which have been used to find the overall score of the alternative chains have been collected from different sources, which support the reliability of the final findings. We also discussed the final findings of the study with Port of Rotterdam, and they found the insights provided by this study very useful. As future research, port performance measurement can be developed in a direction that it supports corridor-specific performance management, by monitoring the competitiveness of the port *vis-a-vis* emerging ports, and providing guidance for increasing port competitiveness through the hinterland connections. Finally, a next important step in the research could be to evaluate the descriptive capability of this approach, by a systematic comparison of the outcomes with the actual freight flows toward regions.

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Appendix. Inland transport performance

Rail	Reputation of inland transport connection (1,…,7)	Number of inland transport operators (no. of operators)	Frequency of inland lines (departures/ week)	Inland freight rates (€/TEU)	Inland transit time (days)
1. Piraeus – Austria	2.50	2	1	500	5/6
2. Piraeus – Hungary	2.00	2	1	450	5/6
3. Koper – Czech Republic	4.75	1	13	694	7
4. Koper – Austria	4.78	2	5	440	2
5. Koper – Hungary	5.40	2	18	271	2
6. Koper – South Germany	3.67	1	3	456	3
7. Genoa – Austria	4.00	*X*	*X*	*X*	*X*
8. Genoa – Switzerland	4.00	1	2	575	3
9. Genoa – South Germany	*3.50*	*X*	*X*	*X*	*X*
10. Antwerp – Austria	3.33	2	7	690	4
11. Antwerp – Switzerland	5.00	2	11	370	3
12. Rotterdam – Czech Republic	4.38	1	6	450	3
13. Rotterdam – Austria	4.00	1	4	350	4
14. Rotterdam – Switzerland	5.00	2	7	383	2
15. Rotterdam – Hungary	4.13	1	4	500	4
16. Rotterdam – South Germany	4.20	1	6	361	2
17. Hamburg – Czech Republic	5.75	2	30	300	2
18. Hamburg – Austria	5.89	4	30	250	3
19. Hamburg – Hungary	5.40	3	6	350	3
20. Hamburg – South Germany	5.83	2	11	311	1
21. Gdansk – Czech Republic	4.20	1	1	400	3

Table AI. Inland transport performance: rail

Waterways	Reputation of inland transport connection (1,…,7)	Number of inland transport operators (no. of operators)	Frequency of inland lines (departures/ week)	Inland freight rates (€/TEU)	Inland transit time (days)
1. Antwerp – Switzerland route	5.00	4	10	295	8.5
2. Rotterdam – Switzerland route	4.50	4	11	295	7.5

Table AII. Inland transport performance: waterways

Road	Reputation of inland transport connection (1,…,7)	Number of inland transport operators (no. of operators)	Frequency of inland lines (departures/ week)	Inland freight rates (€/TEU)	Inland transit time (days)
1. Piraeus – Austria	3.75	10	30	1,890	2.05
2. Piraeus – Hungary	4.00	10	30	1,563	1.41
3. Koper – Czech Republic	4.50	10	30	821	0.96
4. Koper – Austria	5.33	10	30	523	0.33
5. Koper – Hungary	5.50	10	30	620	0.38
6. Koper – South Germany	4.00	10	30	548	0.34
7. Genoa – Austria	4.75	10	30	1,045	1.08
8. Genoa – Switzerland	4.00	10	30	555	0.35
9. Genoa – South Germany	3.50	10	30	691	0.45
10. Antwerp – Austria	3.67	10	30	1,158	1.18
11. Antwerp – Switzerland	4.00	10	30	631	0.39
12. Rotterdam – Czech Republic	4.50	10	30	1,019	1.07
13. Rotterdam – Austria	4.13	10	30	1,262	1.24
14. Rotterdam – Switzerland	4.50	10	30	763	0.50
15. Rotterdam – Hungary	4.50	10	30	1,524	1.38
16. Rotterdam – South Germany	4.60	10	30	911	1.01
17. Hamburg – Czech Republic	5.75	10	30	732	0.48
18. Hamburg – Austria	5.67	10	30	988	1.05
19. Hamburg – Hungary	5.70	10	30	1,218	1.21
20. Hamburg – South Germany	5.83	10	30	826	0.96
21. Gdansk – Czech Republic	4.40	10	30	844	0.97

Table AIII.
Inland transport performance: road

Corresponding author
Jafar Rezaei can be contacted at: j.rezaei@tudelft.nl