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# Efficiency of inland waterway container terminals: Stochastic frontier and data envelopment analysis to analyze the capacity design- and throughput efficiency

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ABSTRACT

Although terminal efficiency has been thoroughly studied for deep-sea container ports and terminals, up till now, there has been little scientific literature on the efficiency of inland waterway container terminals (IWTs). This paper therefore focuses on determining and analyzing terminal characteristics that influence efficiency. Our analysis led to a number of conclusions. First, there exist important differences between IWTs and maritime terminals in terms of design capacity and thus also in operations. Different combinations of inputs and output have been tested with the SFA and DEA methodologies. Important terminal inputs turned out to be yard and crane, but also terminal operating hours and terminal area are important. When capacity is excluded as an input it turns out that the importance of inputs becomes more diverse under SFA. Furthermore, when the inputs and output are varied it shows that this leads to a variation in best and worst performers (the efficiency depends on defined inputs and output). Finally, terminal operating hours are an important input for IWTs which is an important difference with maritime terminals which are open 24/7. In terms of how efficiency is defined, there arises a considerable difference between design efficiency (capacity) and the operational efficiency (terminal throughput).

## 1. Introduction

The European Union (EU) envisions a greater importance of inland waterway (IWW) transportation, as that would mean a shift towards a more environmentally-friendly transport sector (Caris et al., 2014). Despite the urgency stressed by the EU, the modal shift is not taking place as fast as was set in the European Commission's policy goals (Jonkeren et al., 2011). Therefore, there is a need for further research into the efficiency of IWW transport and container terminals. Inland waterway container terminals (IWTs) are playing an increasingly significant role within the intermodal transport chain due to ongoing globalization and growing containerized freight flows. This results in larger container flows between continents, fast growing container ports (such as Shanghai, Antwerp, Rotterdam), and thus also growing container hinterland transportation by inland waterways. The growing flows in the hinterland transportation systems also imply increasing requirements for IWTs along the main rivers (e.g. the river Rhine in Europe). For these IWTs, requirements for being efficient and delivering high quality services at a competitive price are becoming ever more important. For maritime container terminals efficiency has been thoroughly studied (e.g. Cullinane et al., 2002, 2006; Tongzon, 1995, 2001).

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However, up till now, there has been very little scientific literature on the efficiency of IWTs. Given the growing importance of IWTs in policy and practice as described above, scientific attention to their efficiency and to policy implications for cities and regions is needed. IWTs differ in a number of ways from maritime terminals and this influences terminal designs and terminal efficiencies. First, the locations in inland ports are suboptimal in size and lay-out leading to inefficient terminal designs as compared to maritime container terminals. Maritime terminals are often constructed on new locations that are tailor-made to the design requirements. Secondly, once IWTs are started it is often difficult to expand them because the location does not offer expansion possibilities, whereas this is often the case for maritime terminals. Thirdly, IWTs often start small and, when volumes allow, grow larger by adding more equipment, more labor, implementing better equipment or by extending the opening hours while keeping the area of the IWT the same. This means that the design capacity and the operations are much more flexible when compared to maritime terminals. Fourthly, often the smaller IWTs have difficulties in growing towards larger volumes due to limited demand. Finally, when terminals cannot expand further either the terminal has to move (disinvestments need to be made) or second locations are opened which is also suboptimal.

The focus in this paper is on the design efficiency (capacity) and also the operational efficiency (throughput) of the various IWTs. This paper uses an analytical approach based on two methodologies: Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). In Section 2, a literature review on the topic of inland terminal efficiency is introduced. As scientific literature on the efficiency of inland terminals is scarce, also the literature on seaport terminals is studied. In Section 3, the materials and methods used in the analysis are presented. Subsequently, a brief description of Stochastic Frontier Analysis (SFA) and data envelopment analysis (DEA) is given. In Section 4, the dataset is discussed. Then, the results of the analysis are presented in Section 5. Finally, in Section 6, the conclusions are presented, followed by the implications for policy and practice, and recommendations for further research.

## 2. Literature review: inland waterway terminal efficiency

Efficiency can be defined as the quality of being able to do a task successfully and without wasting time or energy (Sinclair, 1992). Kim and Marlow (2001) present a similar definition: ‘efficiency refers to how well the resources expended are used’. Efficiency is often linked to input, process, and output. Input then consists of resources, such as land, labor and capital, that are given to something such as a machine or a project to make it work. Process refers to resources consumed in the process. Output is the ability of a process to deliver products or services according to specifications or the amount of something that they make or produce. Efficiency can then be measured by comparing the amount or value of goods (output) with the time and money spent on producing them and the number of workers who produce them (input). According to Ockwell (2001), efficiency is either a minimizer or a maximizer concept. Minimizing is then applied to inputs, whereas maximizing is applied to outputs. In addition to this, Cantos and Maudos (2001) proved that rail freight companies that are more efficient in costs behave inefficiently with regard to revenue. This means that companies that are efficient in minimizing inputs (cost efficient) tend to be inefficient in maximizing outputs.

Because the scientific attention to the efficiency of IWTs is limited, the literature review has been broadened to also include several papers regarding maritime terminal efficiency. On the operational side of maritime terminals, Tongzon (1995) analyzed the determinants of container port and terminal efficiency and performance, and found the following factors: container mix, work practices, crane efficiency, vessel size and cargo exchange. These factors play a much more limited role when analyzing the efficiency of IWTs, except for the crane efficiency due to the much more flexible operation of the IWT. Cullinane et al. (2002, 2006) found that the efficiency of terminals is closely related to their size. For IWTs growth in size is much less a given factor caused by smaller customer bases limiting the growth potential of IWTs. Tongzon (2001) also found that the terminal area is one of the main variables that influences the efficiency of a port. This places the IWT at a disadvantage as these terminals often operate on not optimally configured terminal areas. If a terminal already operates at its ideal level, further improved efficiency can only be achieved by large investments in increased capacity (Kozan, 1997). The same tendency can be observed for IWTs although the area extension is often prohibited and the expansion is more concentrated on more or different handling equipment and additional labor.

When analyzing efficiency of IWTs, it should be borne in mind that certain factors are in control and some are outside the control of the terminal operator. Factors <u>in control</u> of the terminal operator are mostly decisions related to the terminal infrastructure and to terminal operational characteristics. In this respect, the efficiency of a container terminal depends on the efficient design (capacity) and use (operations) of labor, land and equipment. Given the flexibility in the design capacity of IWTs (e.g. large changes in handling equipment possible, large changes in operating hours possible, changes in labor), analyzing the efficiency of the IWT design capacity is needed. In most cases, maritime terminals possess an efficient terminal design and analyzing the efficiency of the terminal design is not needed. However, to IWTs certain suboptimal conditions might apply.

Factors <u>outside the control</u> of the terminal operator could be (Wiegmans et al., 2004):

1. Network productivity: relates to the size and load factor of vessels, the arrival pattern of vessels, and the number of containers exchanged per call. Although terminal operators are increasingly involved in inland waterway transport and information technology projects both resulting in more accurate information on container flows and thus possibly decreasing this type of inefficiency.
2. Actor productivity relates to subjects such as exporters who provide containers according to vessel schedules. If containers are late (from the exporter) this might cause the terminal operator to wait for the container to arrive at the terminal and tranship it onto the waiting inland waterway vessel. An alternative might be to reschedule it for a next inland waterway vessel which also influences actor productivity.

**Table 1**
Variables inside & outside the control of maritime and IWT operators.

| Variables | Maritime terminal | Inland waterway terminal |
|---|---|---|
| *Inside control* | | |
| Total terminal area | Maximized | Depends on available site |
| Yard | Separate process | Integrated process |
| Quay length | Maximized | Often historically determined |
| Quay Cranes QCs | High capacity | High capacity |
| Yard Cranes ZCs | Used in yard, separate process | Used in yard, integrated process |
| Reach Stackers RSs | Not-used | Used for flexibility |
| Operating hours/day | 24/7 | Ranging from 8/5 to 24/7 |
| Employees | Minimized | Core asset: important in best-practice approach |
| Draught | Accommodate largest vessels | Depending on waterway/canal characteristics |
| Capacity | Fixed and maximized | Not fixed and based on handling equipment |
| *Outside control* | | |
| Throughput | Variable | Variable |

3. Process relates to, for example, the efficiency of the customs department and the weather conditions. If a container is checked thoroughly by the customs department this might cause a delay in the deep-sea port leading to a delayed inland waterway vessel resulting in additional waiting time (inefficiency) at the inland container terminal.

Part of the inefficiency of IWTs can thus be explained through these factors outside of the terminal operator's control. At IWTs we might expect that there is more scope for operational flexibility in the event of disruptions of the container handling process – when compared with large deep-sea terminals – as volumes, and thus disruption impacts, are lower. However, this also means that IWTs might keep more additional 'spare' capacity available to be flexible when disruptions occur. In a slightly wider context, Douma et al. (2009, 2011) found that aligning barge and terminal operations benefits from the introduction of slacks (time) in the appointment between inland waterway vessel and the terminal and also that information sharing results in more efficiency for inland waterway transport. However, this concerns the visits to different terminals in port areas while areas the effects on the inland terminals are unclear. Research by Verdonck et al. (2014) into the operation of an intermodal barge terminal shows that the performance of the terminal is not significantly affected by fleet size changes. Furthermore, theoretical models to support barge planning could not be used as terminals operate in a dynamic environment where continuous improvisation is crucial.

Based on the variables inside and outside the control of the terminal operator, the literature and the data, the main differences are depicted in Table 1.

In the next section, materials and methods used to further analyze the inputs and outputs of IWTs will be discussed.

## 3. Materials and methods

### *3.1. Throughput capacity and efficiency measurement*

Estimating the required container terminal throughput capacity is a difficult task for terminal operators, as building too large terminals results in overcapacity and inefficiency, whereas building too small terminals will result in congestion, capacity constraints, and the need for container terminals to expand. In the short run, terminal efficiency depends on the company's ability to combine inputs to produce an output target. Or, in other words, it depends on input price, technology (including management, X-inefficiency, etc.), and output price (McCarthy, 2001). The firm's production technology is characterized by a production function (and its dual, the cost function), which describes the maximum possible output (minimum possible cost), given the inputs (output target). When a firm is not able to produce the maximum possible output (or at the minimum possible cost), the firm is regarded as inefficient. There can be various reasons for this. First, the employees may not have an incentive to behave optimally (X-inefficiency). Secondly, the firm maximizes profits (or minimizes cost), but for a reason (e.g. noise- or container wall color regulation, lack of information, or 'unexpected events' like the weather), the optimal output cannot be reached. For maritime terminals, the design capacity is often optimized and the inputs are – to a large extent – fixed. However, for IWTs the design capacity is much more variable as inputs can be changed much more easily and the impacts of these changes being of much more influence on the handling capacity as compared to the maritime terminals. For example, a small IWT might start with operating 5 days a week for 8 hours a day but when volumes grow it might decide to double the operating hours to 16 per day and also to start operating on Saturday resulting in a considerable handling capacity increase while keeping the other inputs constant. Therefore, in this paper, the efficiency of the design capacity of IWTs and the actual throughput efficiency are analyzed in more detail. For maritime terminals, often the analysis of throughput efficiency would suffice, but the design (and thus also the efficiency) of IWTs could be inefficient.

Data Envelopment Analysis (DEA) is widely used as Operations Research (OR) technique. Stochastic Frontier Analysis (SFA) is more often used in economic research fields. DEA and SFA are the most important research methods to evaluate the efficiency of individual and organizational performance (Lampe and Hilgers, 2015). These two widespread methods are also used for measuring port and terminal efficiency (Wang and Cullinane, 2006). In this paper, especially the outcomes of both methods are analyzed. For an in-depth analysis and comparison of the two methods, a good meta-analysis has been written by Odeck and Brathen (2012).

According to Murillo-Zamorano (2004) no approach is strictly preferable to the other. The advantages of the Stochastic Frontier analysis over DEA are: it accounts for noise; and, it can be used to conventionally test hypotheses. But, the disadvantages are: the need to specify a distributional form for the inefficiency term; the difficulty in accommodating multiple outputs; and, the need to specify a functional form for the production function. The two research methods will be discussed below.

### 3.2. Stochastic frontier analysis and data envelopment analysis

*Stochastic Frontier Analysis (SFA)*; Determining the technical efficiency of IWTs can be based on the estimation of a production frontier. Stochastic production frontier models were introduced simultaneously by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). Inefficiency is then determined as the distance to the stochastic frontier. In SFA, inefficiency is estimated as a transformation of the (estimated) parameters of a postulated distribution, and can be used to explain inefficiency. Inefficiency reduces the maximum feasible output for circumstances or occurrences that are beyond the control of the terminal operator (e.g. severe weather conditions, labor unrest, misinformation, X-inefficiency, congestion, etc.); as a result of these circumstances realized container terminal output is likely to be lower. For IWTs, this inefficiency holds for the designed terminal capacity and also for the throughput. The production frontier model can be written as:

$$Y_{it} = X_{yt}\beta + (V_{ti} - U_{it}) \tag{1}$$

where $Y_{it}$ is (the logarithm of) the production of the terminal operator in the tth time period i (it can be capacity or throughput); $X_{it}$ is a kx1 vector of (transformations of) N inputs (7 or 8 in the case of the terminal operator) in the tth time period; β is a vector of technology parameters to be estimated; and $V_{ti}$ are random variables assumed to be iid N(0, $\sigma_U^2$), and independent of the $U_{it} = (U_i \exp(-\eta(t-T)))$, where the $U_i$ are non-negative random variables which are assumed to account for technical inefficiency in production and to be iid as truncations at zero of the N($\eta$, $\sigma_U^2$), and $\eta$ is a parameter to be estimated. If the technical efficiency is lower than 1, it shows the potential improvement towards the maximum feasible output. If technical efficiency is 1 it shows that the firm concerned realizes the maximum feasible output.

*Data envelopment analysis (DEA)* is a mathematical programming approach to estimate productive efficiency. It was first introduced by Charnes et al. (1978), extending the ideas of Farrell (1957) to estimate technical efficiency by setting a production frontier. This technique offers the advantage of requiring relatively few assumptions, and, additionally, multiple inputs and multiple outputs can be included (Cooper et al., 2011). As described in Zhu (2003), the DEA model is based on the following variables and parameters:

$n$ = number of $DMUj$ ($j$ = 1,2,...,$n$)
$m$ = number of inputs $x_{ij}$ ($i$ = 1,2,...,$m$) used by $DMUj$
1 = number of outputs $y_{rj}$ ($r$ = 1,2,...,$s$) produced by $DMUj$

$\sum_{j=1}^{n} \lambda_j x_{ij}$ ($i$ = 1,2,...,$m$) = possible inputs achievable by $DMUj$
$\sum_{j=1}^{n} \lambda_j y_{rj}$ ($r$ = 1,2,...,$s$) = possible outputs achievable by $DMUj$
$\lambda_j$ ($j$ = 1,...,$n$) = nonnegative scalars

In order to estimate the efficient frontier, two approaches are available in DEA: *input-oriented* and *output-oriented*. In the input-oriented model, the objective is to minimize the inputs with the outputs kept constant, whereas in the output-oriented model the objective is to maximize the outputs with constant inputs. Most terminals can be characterized by an input oriented approach. In the input-oriented model, the efficiency frontier is calculated as follows:

$$\theta^* = min\theta$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leqslant \theta x_{i0}; \quad i = 1,...,m$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} \geqslant y_{r0}; \quad r = 1,...,s$$
$$\lambda_j \geqslant 0\,; \quad \forall\, j$$

where $DMU_0$ represents one of the $n$ DMUs under evaluation, and $x_{i0}$ and $y_{r0}$ are respectively the $i$th input and $r$th output for $DMU_0$ respectively. Solving the above equations for each one of the $n$ DMUs, $n$ weights and $n$ optimum solutions can be found. Each optimum solution $\theta_j^*$ is the efficiency indicator of DMU *j*, and by construction satisfies $\theta_j^* \leqslant 1$. Those DMUs with $\theta_j^* < 1$ are considered inefficient, and $\theta_j^* = 1$ are efficient. Given the focus of our paper on the analysis and comparison of the results concerning design capacity and throughput, for detailed further reading we refer to an extensive discussion of both methods in Cullinane et al. (2002, 2006). In the next section, the data is discussed.

## 4. Inland waterway container terminal dataset

A gross dataset has been collected (via https://www.inlandlinks.eu/nl/terminals/filter (accessed 1 March 2016) in combination

**Table 2**
Descriptive statistics of the input and output parameters (n = 44).
Source: Own data and calculations.

| Variable and unit | Mean | Standard error | Median | Standard deviation | Range | Minimum | Maximum | Skewness |
|---|---|---|---|---|---|---|---|---|
| *Input* | | | | | | | | |
| Working hours hours/week | 82.9 | 4.023 | 75 | 34.84 | 123 | 45 | 168 | 1.426 |
| Terminal area m2 | 73808.5 | 19491.466 | 40000 | 129291.759 | 792500 | 7500 | 800000 | 4.679 |
| Stacking Yard TEU | 6404.6 | 1559.46 | 3750 | 10344.290 | 49500 | 500 | 50000 | 3.634 |
| Quay Length M | 308.7 | 30.103 | 275 | 199.684 | 900 | 100 | 1000 | 1.729 |
| Draught M | 4.5 | 0.328 | 4.5 | 2.178 | 10 | 2.0 | 12 | 1.643 |
| Cranes No | 1.6 | 0.139 | 2 | 0.923 | 4 | 0 | 4 | 0.185 |
| Reach stackers No | 2.3 | 0.268 | 2 | 1.775 | 8 | 0 | 8 | 1.738 |
| Handling capacity TEUs/year | 139 318 | 13017.908 | 135000 | 86351.034 | 380000 | 20000 | 400000 | 0.746 |
| *Output* | | | | | | | | |
| Handling capacity TEUs/year | 139 318 | 13017.908 | 135000 | 86351.034 | 380000 | 20000 | 400000 | 0.746 |
| Throughput TEUs/year | 83 433 | 9085.673 | 65000 | 60267.543 | 217500 | 2500 | 220000 | 0.668 |

with an extensive search including terminal company websites) containing data of 127 container terminals in Europe. Countries with relatively large contributions to the dataset are Germany, Belgium, and the Netherlands which are all located in or close to the Rhine estuary. This is not surprising, given the importance of Western Europe in the European inland navigation network. In the research, a dataset of 44 IWTs is considered. All variables are available for 32 IWTs, 6 terminals miss one variable and 6 terminals miss two variables. Given the limited data availability, we have looked for ways to 'construct' the missing data. Scientific discussions do not agree if it is better to focus on a smaller 'clean' dataset or to 'construct' missing data to not lose valuable data (Harrell, 2015). Given the difficulties in obtaining data about intermodal freight transport (IFT) and terminals, we have chosen to construct the missing data to not lose valuable data and also to end up with a dataset as large as possible while at the same time not to 'construct' too much data. Different options exist for constructing the missing data: averages, means, data comparable to 'closest' comparable terminals, etc. We tried average, mean, and closest terminal(s) and given the relatively large differences between terminals, data has been constructed based on closest terminal(s).

After the construction of the data, for the 44 IWTs all variables are available to undertake SFA, and DEA both on theoretical terminal capacity (design efficiency) and on actual terminal throughput (operational efficiency). We analyzed the operational efficiency both including and excluding terminal capacity as one of the inputs). For the other 83 terminals, more than two variables were missing, so these IWTs have to be excluded from the analysis. For input, characteristics of the terminal (working hours, terminal area, stacking yard, quay length, draught, number of cranes, number of reach stackers) are used. For output, capacity or actual throughput is used. The variables can be found in Table 2.

## 5. Analyzing the efficiency of inland container terminals

### *5.1. Inland waterway container terminals: SFA results*

The SFA was performed using the software package FRONTIER 4.1. The program follows a 3-step procedure to estimate the maximum likelihood estimates of the parameters of the stochastic production function. First, OLS estimates of the function are obtained. Secondly, a two-phase grid search of $\gamma$ is conducted. Thirdly, the resulting values of the second step are used as starting values in an iterative procedure (using Davidon-Fletcher-Powell Quasi-Newton method) to obtain the final maximum likelihood estimates (MLE's). The SFA analysis concerning capacity and throughput give the following MLE results (Tables 3–5).

**Table 3**
SFA results for throughput with capacity as input.

| | Coefficient | Standard-error | t-ratio |
|---|---|---|---|
| Beta 0 | −0.71206267 | 0.11322445 | −6.2889478 |
| Beta 1 | 0.08178976 | 0.06830059 | 1.1974972 |
| Beta 2 | −0.05862190 | 0.01196203 | −4.9006641 |
| Beta 3 | −0.08632140 | 0.01235440 | −6.9870952 |
| Beta 4 | 1.13761350 | 0.01922558 | 59.171880 |
| Beta 5 | −0.02877098 | 0.03212249 | −0.89566481 |
| Beta 6 | −0.06707663 | 0.02441124 | −2.7477763 |
| Beta 7 | 0.26449594 | 0.03243783 | 8.1539349 |
| Beta 8 | −0.03199454 | 0.03371949 | −0.94884430 |
| Sigma-squared | 0.31829755 | 0.04310212 | 7.3847303 |
| Gamma | 0.99999999 | 0.00000003 | 0.29115064E+08 |

Notes: mu is restricted to be zero; eta is restricted to be zero; log-likelihood function = −0.55168918 + 01.
LR test of the one-sided error = 0.30934393E+02.

**Table 4**
SFA results for handling capacity as output (instead of throughput).

| | Coefficient | Standard-error | t-ratio |
|---|---|---|---|
| Beta 0 | 5.3189590 | 1.7392641 | 3.0581664 |
| Beta 1 | 0.53021173 | 0.27816840 | 1.9060819 |
| Beta 2 | 0.23042242 | 0.11637865 | 1.9799372 |
| Beta 3 | 0.19105745 | 0.0996024 | 1.9182010 |
| Beta 4 | 0.11127564 | 0.15772939 | 0.70548449 |
| Beta 5 | −0.08739365 | 0.16051990 | −0.54444123 |
| Beta 6 | 0.01049614 | 0.21059086 | 0.049841414 |
| Beta 7 | −0.00253815 | 0.14614793 | −0.01736704 |
| Sigma-squared | 0.50277391 | 0.18446499 | 2.7255791 |
| Gamma | 0.85560432 | 0.15129604 | 5.6551666 |

Notes: mu is restricted to be zero; eta is restricted to be zero; log-likelihood function = −0.28937972E+02.
LR test of the one-sided error = 0.79934469E+00.

**Table 5**
SFA results for throughput without capacity as input.

| | Coefficient | Standard-error | t-ratio |
|---|---|---|---|
| Beta 0 | 4.3614297 | 1.9395373 | 2.2486960 |
| Beta 1 | 0.74212059 | 0.35402871 | 2.0962159 |
| Beta 2 | 0.17531375 | 0.14718982 | 1.1910725 |
| Beta 3 | 0.11220399 | 0.12115622 | 0.92611004 |
| Beta 4 | 0.20900530 | 0.21460133 | 0.97392360 |
| Beta 5 | −0.01346332 | 0.22907630 | −0.05877221 |
| Beta 6 | 0.45753603 | 0.29980408 | 1.5261168 |
| Beta 7 | −0.11233541 | 0.20240502 | −0.55500306 |
| Sigma-squared | 0.87538114 | 0.30237259 | 2.8950413 |
| Gamma | 0.81305273 | 0.15719260 | 5.1723347 |

Notes: mu is restricted to be zero; eta is restricted to be zero; log-likelihood function = −0.42515679E+02.
LR test of the one-sided error = 0.26183260E+01.

For terminal efficiency with capacity included as input, and with throughput as output (Table 3) it shows that the yard (B4) and the crane (B6) are important inputs for the terminal. All the other inputs influence the terminal efficiency to a small extent. The importance of the yard and the crane aligns well with the scientific literature analyzing maritime terminal efficiency (e.g. Carlo et al., 2014; Steenken et al., 2004).

When capacity is excluded as input (Table 5), a considerable and remarkable change in importance of inputs can be observed. The operating hours (B1) becomes important which is logical given the large impact an increase in operating hours has on terminal capacity and terminal throughput. A maritime container terminal operates 24/7, whereas a small IWT might start to operate from Monday to Friday from 08.00 to 17.00 h with possibilities to increase operating hours. When capacity is used as an input for this small IWT, it might seem that the terminal operates efficiently, while the operating hours can be doubled or tripled leading to more capacity and throughput with the same inputs. Also the quay (B4) becomes more important as input to the terminal operator when capacity is excluded. This might have to do with the ability of the IWT to handle two inland waterway vessels at the same time (or not). Finally, also the crane (B6) remains an important input.

The analysis of the IWT efficiency with capacity defined as output (and without throughput, see Table 4) shows hours (B1) and terminal area (B2) are important inputs to the terminal operator. Also the yard and the quay show some importance to the terminal operator as an input. Without the 'limiting' effect of capacity as input it shows that the terminal efficiency depends on a more diverse constellation of inputs as compared to the terminal efficiency based on throughput with capacity as an input.

Comparing the efficiency results with different combinations of inputs and output leads to a number of conclusions (Table 6). First, the highest efficiencies are realized when throughput is defined as output and when capacity is defined as one of the inputs, while the lowest efficiencies occur when capacity is excluded as input. When capacity is defined as output, the terminal efficiency arrives in between. Secondly, the differences between the terminal throughput efficiency with capacity as input and the terminal capacity efficiency can be considerable. Different groups of terminals can be distinguished: 1. High throughput and high capacity efficiency, 2. High throughput and low capacity efficiency, 3. Low throughput and low capacity efficiency, 4. low throughput and high capacity efficiency, and 5. the rest. The first group signals that the terminal design capacity (or the terminal lay-out) is efficient and also the operations are efficient. For the second group, the terminal design is not efficient but the operations are executed efficiently given the low capacity efficiency. The terminals in the third group show low efficiencies for both analyses. Terminals in the fourth group have an efficient terminal design but the operations do not live up to this promise. The last group of terminals operates somewhere in between, not really high, and also not really low. Thirdly, the three different analyses lead to very different top and bottom performers.

**Table 6**
Overall Efficiencies of IWTs with different combinations of inputs and output.

| Terminal number | Throughput with capacity | Capacity | Throughput without capacity |
|---|---|---|---|
| 1 | 0.99901448 | 0.78802461 | 0.74934730 |
| 2 | 0.42037236 | 0.80771327 | 0.55640910 |
| 3 | 0.18679462 | 0.29359887 | 0.082452621 |
| 4 | 0.69043232 | 0.89095904 | 0.81950326 |
| 5 | 0.92472790 | 0.66562167 | 0.66387295 |
| 6 | 0.52346686 | 0.44265894 | 0.29557164 |
| 7 | 0.77952432 | 0.81755142 | 0.79365599 |
| 8 | 0.46637878 | 0.77701820 | 0.66194545 |
| 9 | 0.42059156 | 0.42843404 | 0.31679913 |
| 10 | 0.99944224 | 0.48182463 | 0.61322625 |
| 11 | 0.39281617 | 0.74994263 | 0.48773323 |
| 12 | 0.69133713 | 0.72757731 | 0.68052041 |
| 13 | 0.79126298 | 0.74569358 | 0.67642734 |
| 14 | 0.99968760 | 0.80375179 | 0.78522798 |
| 15 | 0.73010563 | 0.66305072 | 0.62877765 |
| 16 | 0.99928535 | 0.57598821 | 0.66394445 |
| 17 | 0.42389390 | 0.80524697 | 0.60091343 |
| 18 | 0.85373229 | 0.46011630 | 0.46047542 |
| 19 | 0.66575260 | 0.65910058 | 0.58694159 |
| 20 | 0.95552380 | 0.38470589 | 0.44645093 |
| 21 | 0.99968315 | 0.31406740 | 0.43007233 |
| 22 | 0.89029235 | 0.79257784 | 0.75809916 |
| 23 | 0.81850718 | 0.41784463 | 0.45692951 |
| 24 | 0.96198865 | 0.90258747 | 0.87364744 |
| 25 | 0.41547604 | 0.81235884 | 0.65302458 |
| 26 | 0.99908261 | 0.67671592 | 0.75122706 |
| 27 | 0.78285551 | 0.73617552 | 0.68411949 |
| 28 | 0.21122070 | 0.78200303 | 0.38045793 |
| 29 | 0.62257494 | 0.76498647 | 0.68051758 |
| 30 | 0.85120968 | 0.32692492 | 0.38495919 |
| 31 | 0.82967902 | 0.85456336 | 0.80480162 |
| 32 | 0.64313124 | 0.69964473 | 0.62763970 |
| 33 | 0.86708368 | 0.37984529 | 0.39056465 |
| 34 | 0.45980452 | 0.54099525 | 0.38603039 |
| 35 | 0.42287933 | 0.62041785 | 0.37491450 |
| 36 | 0.74149509 | 0.79677605 | 0.70394225 |
| 37 | 0.99868876 | 0.62804343 | 0.66416228 |
| 38 | 0.87875550 | 0.38068183 | 0.41075728 |
| 39 | 0.98419163 | 0.63655239 | 0.70398994 |
| 40 | 0.86281899 | 0.66910041 | 0.64963581 |
| 41 | 0.97642974 | 0.35954939 | 0.42497126 |
| 42 | 0.76895856 | 0.73782047 | 0.62665579 |
| 43 | 0.60268017 | 0.37006721 | 0.27624111 |
| 44 | 0.98895450 | 0.65072279 | 0.62274694 |
| Mean | 0.73846783 | 0.63226366 | 0.57477963 |

### *5.2. Inland waterway container terminals: DEA results*

In general, IWTs operate in a less competitive environment when compared to maritime container terminals in ports. Furthermore, IWTs strive to keep a certain share of spare capacity available to be able to flexibly cope with disruptions of vessel arrivals and departures. Therefore, input oriented DEA has been chosen to analyze the efficient use of inputs, as this is key to save cost in IWTs. The software package DEAP has been used to analyze the DEA efficiencies. In the analysis, the focus has been on the input-oriented DEA, constant returns to scale (CRS) and variable returns to scale (VRS) models were used to analyze the efficiency of the chosen inland container terminals. Also the output-oriented DEA has been performed with both CRS and VRS but these do not lead to very large differences with the input-oriented DEA.

Table 7 displays the DEA results for throughput with capacity, capacity (defined as output), and throughput without efficiency. The efficiencies derived from both the CRS and the VRS models are shown, and also the scale efficiencies. A first conclusion is that DEA analysis with throughput and excluding capacity as an input leads to the highest terminal efficiencies (highest mean efficiency). The lowest efficiencies tend to result from the analysis with capacity defined as output. This signals that not all terminals are efficiently designed. However, this is difficult to adapt for, as many terminal lay-outs are limited in their often not optimal terminal area, which is often leading to non-optimal operations. Secondly, according to the DEA results, only 8 out of 44 IWTs are fully efficient (efficiency equal to 1.000) for the three different combinations of inputs and output. Thirdly, the scale orientation determined by the sum of the weights ($\Sigma\lambda$) is presented, to indicate the direction of the scale inefficiency. These results prove that a

**Table 7**
DEA results for each terminal.

| Terminal | Throughput with cap. Input-oriented | | | | Capacity as output. Input-oriented | | | | Throughput without cap. Input-oriented | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | crste | vrste | scale | | crste | vrste | scale | | crste | vrste | scale | |
| 1 | 0.786 | 1.000 | 0.786 | drs | 0.785 | 1.000 | 0.785 | drs | 0.862 | 1.000 | 0.862 | drs |
| 2 | 1.000 | 1.000 | 1.000 | – | 0.781 | 0.884 | 0.883 | irs | 0.781 | 0.884 | 0.883 | irs |
| 3 | 0.515 | 1.000 | 0.515 | irs | 0.122 | 1.000 | 0.122 | irs | 0.143 | 1.000 | 0.143 | irs |
| 4 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 5 | 0.910 | 1.000 | 0.910 | irs | 0.880 | 1.000 | 0.880 | irs | 0.880 | 1.000 | 0.880 | irs |
| 6 | 0.404 | 0.766 | 0.528 | irs | 0.250 | 0.737 | 0.339 | irs | 0.421 | 0.737 | 0.572 | irs |
| 7 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 8 | 1.000 | 1.000 | 1.000 | – | 0.656 | 1.000 | 0.656 | irs | 0.656 | 1.000 | 0.656 | irs |
| 9 | 0.910 | 1.000 | 0.910 | irs | 0.369 | 0.985 | 0.374 | irs | 0.391 | 0.985 | 0.397 | irs |
| 10 | 0.932 | 0.933 | 0.999 | drs | 0.958 | 1.000 | 0.958 | irs | 0.962 | 1.000 | 0.962 | irs |
| 11 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 12 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 13 | 0.660 | 0.994 | 0.664 | irs | 0.478 | 0.979 | 0.488 | irs | 0.694 | 0.979 | 0.709 | irs |
| 14 | 0.935 | 0.938 | 0.997 | irs | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 15 | 0.734 | 0.796 | 0.923 | irs | 0.774 | 0.899 | 0.861 | irs | 0.820 | 0.899 | 0.911 | irs |
| 16 | 0.440 | 0.907 | 0.485 | irs | 0.419 | 0.910 | 0.461 | irs | 0.902 | 0.991 | 0.910 | irs |
| 17 | 0.611 | 1.000 | 0.611 | irs | 0.238 | 0.921 | 0.259 | irs | 0.371 | 0.921 | 0.403 | irs |
| 18 | 0.280 | 0.914 | 0.307 | irs | 0.188 | 0.914 | 0.206 | irs | 0.524 | 0.918 | 0.571 | irs |
| 19 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 20 | 0.219 | 1.000 | 0.219 | irs | 0.206 | 1.000 | 0.206 | irs | 0.812 | 1.000 | 0.812 | irs |
| 21 | 0.373 | 0.994 | 0.375 | irs | 0.280 | 0.979 | 0.286 | irs | 0.667 | 0.979 | 0.682 | irs |
| 22 | 0.766 | 0.976 | 0.785 | irs | 0.735 | 0.962 | 0.764 | irs | 0.887 | 0.962 | 0.922 | irs |
| 23 | 0.252 | 0.915 | 0.275 | irs | 0.176 | 0.911 | 0.194 | irs | 0.623 | 0.911 | 0.684 | irs |
| 24 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 25 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 26 | 0.556 | 1.000 | 0.556 | irs | 0.555 | 1.000 | 0.555 | irs | 0.893 | 1.000 | 0.893 | irs |
| 27 | 0.781 | 1.000 | 0.781 | irs | 0.693 | 0.995 | 0.696 | irs | 0.766 | 0.995 | 0.770 | irs |
| 28 | 0.790 | 0.989 | 0.799 | irs | 0.174 | 0.824 | 0.211 | irs | 0.182 | 0.824 | 0.221 | irs |
| 29 | 0.785 | 1.000 | 0.785 | irs | 0.463 | 1.000 | 0.463 | irs | 0.566 | 1.000 | 0.566 | irs |
| 30 | 0.339 | 1.000 | 0.339 | irs | 0.305 | 1.000 | 0.305 | irs | 0.686 | 1.000 | 0.686 | irs |
| 31 | 1.000 | 1.000 | 1.000 | – | 0.881 | 1.000 | 0.881 | irs | 0.881 | 1.000 | 0.881 | irs |
| 32 | 0.957 | 0.995 | 0.962 | irs | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 33 | 0.274 | 0.615 | 0.445 | irs | 0.248 | 0.609 | 0.407 | irs | 0.596 | 0.719 | 0.829 | irs |
| 34 | 0.351 | 0.840 | 0.418 | irs | 0.136 | 0.822 | 0.166 | irs | 0.337 | 0.822 | 0.411 | irs |
| 35 | 0.597 | 0.610 | 0.979 | irs | 0.338 | 0.514 | 0.657 | irs | 0.437 | 0.518 | 0.844 | irs |
| 36 | 0.773 | 0.863 | 0.896 | irs | 0.648 | 0.805 | 0.805 | irs | 0.688 | 0.822 | 0.837 | irs |
| 37 | 0.633 | 0.646 | 0.980 | drs | 0.902 | 1.000 | 0.902 | drs | 1.000 | 1.000 | 1.000 | – |
| 38 | 0.265 | 0.669 | 0.396 | irs | 0.220 | 0.658 | 0.334 | irs | 0.665 | 0.759 | 0.877 | irs |
| 39 | 0.407 | 1.000 | 0.407 | irs | 0.362 | 1.000 | 0.362 | irs | 0.740 | 1.000 | 0.740 | irs |
| 40 | 0.492 | 0.687 | 0.716 | irs | 0.474 | 0.691 | 0.686 | irs | 0.792 | 0.823 | 0.963 | irs |
| 41 | 0.298 | 0.875 | 0.341 | irs | 0.288 | 0.875 | 0.329 | irs | 0.702 | 0.906 | 0.775 | irs |
| 42 | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – | 1.000 | 1.000 | 1.000 | – |
| 43 | 0.320 | 0.646 | 0.496 | irs | 0.228 | 0.636 | 0.359 | irs | 0.458 | 0.636 | 0.720 | irs |
| 44 | 0.750 | 0.876 | 0.856 | irs | 0.899 | 0.949 | 0.947 | irs | 1.000 | 1.000 | 1.000 | – |
| Mean | 0.684 | 0.919 | 0.737 | | 0.593 | 0.919 | 0.632 | | 0.745 | 0.932 | 0.795 | |

Note: crste = technical efficiency from CRS DEA, vrste = technical efficiency from VRS DEA, scale = scale efficiency = crste/vrste.

clear terminal majority operates under increasing returns to scale. This also aligns well with the desire of the terminal operators to have sufficient spare-capacity available. Fourthly, also in IWT efficiency, a relationship seems to exist between the efficiency of an IWT and its size (in terms of throughput and capacity), because almost all fully efficient terminals are large terminals in the dataset. Overall, lower efficiency levels tend to occur in multiple combinations of inputs and output DEA analyses (multiple columns of Table 7). Finally, DEA on capacity and on throughput (without capacity) results in the same best performing terminals while there is quite some difference in worst performing terminals.

## 6. Conclusions, discussion and further research

The focus in this paper was on the design efficiency (capacity) and the operational efficiency (throughput) of inland waterway container terminals (IWTs), using an analytical approach based on two methodologies: Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). The literature review led to the identification of important differences between maritime terminals and IWTs influencing design- and operational efficiency of IWTs. First, the IWT locations are often suboptimal in size and lay-out leading to by definition inefficient terminal design capacities as compared to maritime container terminals. This is leading to the need for analyzing capacity efficiency and operational efficiency of IWTs. Secondly, at the maritime terminals quay, yard, and transport are often separated processes while at IWTs they are not separated. Thirdly, maritime terminal operate 24/7, while small IWTs might only operate part of the day from Monday to Friday. Fourthly, IWTs often start small and, when volumes allow, grow larger by adding more equipment, more labor, implementing better equipment or by extending the opening hours while keeping the area of the IWT the same. This means that the design capacity and the operations are much more flexible when compared to maritime terminals. Finally, when terminals cannot expand further either the terminal has to move (disinvestments need to be made) or second locations are opened which is also suboptimal.

A dataset of 44 IWTs was used for the SFA analysis, containing data on the physical properties and handling characteristics of IWTs. For terminal efficiency with capacity included as input, and with throughput defined as output it shows that the yard (B4) and the crane (B6) are important inputs for the terminal. This importance of yard and crane aligns well with the scientific literature analyzing maritime terminal efficiency (e.g. Carlo et al., 2014; Steenken et al., 2004). However, when capacity is excluded as input (Table 5), a considerable and remarkable change in importance of inputs can be observed. Especially, the terminal operating hours (B1) becomes important which is logical given the large impact an increase in operating hours has on terminal capacity and possible terminal throughput. The analysis of the IWT efficiency with capacity defined as output (and without throughput, see Table 4) shows hours (B1) and terminal area (B2) are important inputs to the terminal operator. Without the 'limiting' effect of capacity as input it shows that the terminal efficiency depends on a more diverse constellation of inputs as compared to terminal efficiency based on throughput with capacity defined as an input.

Comparing the different SFA efficiency results with different combinations of inputs and output results in two important conclusions. First, the highest efficiencies are realized when throughput is defined as output and when capacity is defined as one of the inputs. Secondly, the three different analyses lead to very different best and worst performers (almost no overlap).

From the DEA a first conclusion is that DEA analysis with throughput defined as output and excluding capacity as an input leads to the highest terminal efficiencies (highest mean efficiency). The lowest efficiencies tend to result from the analysis with capacity defined as output. This signals that not all terminals are efficiently designed. Secondly, the clear terminal majority operates under increasing returns to scale. Thirdly, also in IWT efficiency, a relationship seems to exist between the efficiency of an IWT and its size, because almost all fully efficient terminals are large terminals in the dataset. Finally, DEA on capacity and on throughput (without capacity) results in the same best performing terminals while there is quite some difference in worst performing terminals.

The combination of the literature review and the analysis leads to a number of new theoretical developments. In terms of how efficiency is defined, there is a considerable difference between design efficiency (the capacity) and the operational efficiency (the terminal throughput). Also, more factors are outside the control of the IWT terminal operator (as compared with the maritime terminal) leading to a more difficult operational environment. Finally, terminal operating hours are an important input for IWTs which is an important difference with maritime terminals which are open 24/7 leading to less efficient IWTs. Overall, this means that for very small new terminals, governments must be willing to be financially committed in the beginning. If small terminals have limited growth potential, governments must be prepared for ongoing and serious financial involvement or the decision must be taken not to be involved. In the end, the efficiency of IWTs differs from the efficiency of maritime terminals and in this respect must be treated with care.

To further develop this research on IWTs efficiency, more terminals must be included in the dataset. Also increasing the number of input parameters and more specification of these parameters could lead to a more precise analysis (such as the employee type and number, type and capacity of cranes). A more methodological oriented research might consist of the gross database where terminals with more than two missing variables are also included in the analysis by 'constructing' these missing variables. A last interesting research direction is a better understanding of the relationship between rail and inland waterway handling at the same terminal and its influence on terminal efficiency. But this again calls fro additional and quite specific data gathering.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tra.2017.09.007.

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