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Setting key performance targets for Croatian shipyards

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Abstract. The aim of this paper is to use the Data Envelopment Analysis (DEA) method to measure and analyze different relative efficiencies of five Croatian shipyards. The indicators are chosen to capture different aspects of shipbuilding performance in Croatia. Window analysis is used to determine shipyard efficiency and observe possible changes in shipyard efficiency over time. This leads to identifying a subset of efficient *best practice* shipyards, whereas for others the magnitude of their inefficiency is ascertained along with the specified efficient input and output targets. The importance of window analysis is that its results serve as an early warning system to all inefficient shipyards. In identifying the sources of inefficiencies and formulating proposals for improving shipyard performance observed over a six-year period (2007-2012), the results presented in this paper can be used to enhance and alter decisions.

Key words: shipbuilding, data envelopment analysis, Croatian shipyards, window analysis, scale efficiency

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1. Introduction

Ships are the most complex products that Croatia produces and exports to international markets. Furthermore, the shipbuilding industry is the driving force behind the development of various supporting manufacturing and service activities, which makes it a vitally important industry as a powerful generator of employment including the local, regional and national development of Croatia.

The shipbuilding industry constitutes one of the most important sectors in the Croatian industry, accounting for 2.5% of total employment, 1.2% of GDP and about 12% of total exports. Due to the size and complexity of the shipbuilding, on the basis of sub-contracts and their operations, a significant portion of Croatian industry directly depends on the shipbuilding sector which

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also represents a significant source of employment in the counties of Istria, Primorje-Gorski Kotar and Split-Dalmatia [4:43]. Therefore, establishing performance targets in the shipbuilding industry therefore can be a challenge to shipbuilding policy makers.

Shipbuilding, like any other industry, is permanently faced with the need for a steady increase in productivity. Given that formulating a method for assessing shipbuilding productivity is somewhat harder than in other industries, the suggestion is that measuring shipyard productivity and making comparisons between shipyards requires careful consideration (for a more detailed discussion on the productivity metric in shipbuilding, see [7]).

Productivity measures are partial in the shipbuilding industry when based on different indicators. Although choosing between them can be justified by the purpose of the productivity measurement, there is often a need for a comprehensive approach. Such an approach may involve simultaneous evaluation of different types of productivity that can be indirectly achieved by a performance measurement technique that includes all parameters used to calculate these productivities and, at the same time, provides a comparison of efficiency levels among shipyards over a period of time. Therefore, the purpose of this paper is to propose Data Envelopment Analysis (DEA) as a suitable efficiency measurement method that satisfies the aforementioned requirements, and to present the results of analyzed efficiencies of shipyards in Croatia.

DEA is a linear programming-based non-parametric technique used for evaluating the relative efficiency of homogenous operating entities or decision-making units (DMUs) on the basis of empirical data on their multiple inputs and multiple outputs. It leads to an efficient frontier determined by the existing DMUs which are identified as *best practice units* (benchmarks) and given a rating of 1, whereas the degree of inefficiency of other entities is calculated on the basis of their distances from the efficient frontier and attributed to input excesses and output shortfalls.

The first literature survey focusing on DEA applications is the study of Liu et al. [10]. It covers DEA papers published in journals indexed by the Web of Science database from 1978 through August 2010. Among the multifaceted applications, the top-five industries addressed are banking, healthcare, agriculture and farm, transportation and education. The citation-based main path analysis is applied to these areas to uncover their development trajectories.

In international literature, papers focusing on the efficiency measurement of shipyards based on DEA are scarce. However, an interesting and cited article is worth mentioning, in which DEA was used to analyze and evaluate management efficiency of 19 shipbuilding enterprises, calculate the output shortfall and input redundancy and provide sensitivity analyses [13]. The result implied objectivity, accuracy and practicability of DEA to address these issues.

Since, to the author's knowledge, reported studies that estimate relative efficiency of Croatian shipyards based on the DEA do not exist, this research can serve as a basis for future related studies.

2. Data and analytical framework

The Croatian Shipbuilding Corporation – Jadranbrod is the national association of major Croatian shipbuilders and a corporate body coordinating the Croatian shipbuilding industry's access to international markets. During a six-year period (2007-2012) on which this study is based, it members comprised six major Croatian shipyards (Uljanik, Brodosplit, 3. maj, Brodotrogir, Kraljevica and Viktor Lenac). Only the latter was not involved in newbuilding activities, which is the main reason for its exclusion from this study. The remaining shipyards represent five entities and their relative efficiency was evaluated in this paper.

The selection of shipyard performance indicators for the purposes of this study was based on the following criteria: relevant human resource requirements, production and finance relative to aspects of shipbuilding efficiency; exact measurability of indicators; availability and accessibility of data on indicators; ensuring timely, comprehensive, understandable and, above all, useful information both for managers and owners of the respective shipyards.

Taking into account the above criteria, five indicators were selected and included in the analysis. Number of employees (as of December 31 of every year), number of effective working hours and total expenditures represent inputs, while total delivered compensated gross tonnage and total revenues represent outputs. Possible obscurities and uncertainties regarding the selection of these indicators are briefly discussed in the following two paragraphs.

Because of the bankruptcy of Kraljevica in August 2012 due to its over-indebtedness, data on the number of effective working hours was not available for that year. As recommended in [9], the missing value was substituted with the sufficiently large number. $M >> \max_{i,j}\{x_{ij}, i=1,2,...,m, j=1,2,...,n\}$.. A simple test, proposed in this paper, was conducted and showed that M was large enough to result in the automatic exclusion of the missing data from the analysis. Given that this provided an assumption of the most pessimistic value for the missing data, it might pose some unfairness to Kraljevica because its true performance is better than what was assumed. Accordingly, the issue of justifying this method of dealing with blank data remains unresolved.

Compensated gross tonnage (cgt) is an indicator of the amount of work necessary to build a ship. It is calculated using the formula $\mathrm{cgt} = \mathrm{A} * \mathrm{gt}^{\mathrm{B}}$, where A represents mainly the impact of ship type, B is the impact of ship size and gt is the *gross tonnage* of the vessel [11]. Gross tonnage is calculated from the molded volume measured in cubic meters from the formula $\mathrm{gt} = \mathrm{K1} * \mathrm{V}$, where

K1 is the coefficient calculated by the formula $\mathrm{K1} = 0.2 + 0.02\log10\mathrm{V}$, and V is the molded volume of all enclosed spaces in the hull and superstructure. On the other hand, the ship's *deadweight tonnage* (dwt) is a measure of how much weight a ship is carrying or can carry safely. It is the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew. The reason for choosing cgt over dwt and gt is the fact that dwt and gt are mainly used to measure weight and volume respectively from a shipowner's perspective, but they are not suitable for measuring shipbuilding output from the shipyard's perspective. The parameter cgt takes into account different ship types and complexity of construction and design, and, therefore, is internationally accepted as a measure of shipyard output. Knowing that continuity of construction orders is the most important variable in shipbuilding efficiency, the total cgt of orders and total cgt of new orders were also included in the model. The motive for their omission was to avoid redundancy that would have been caused by using time series data along with the fact that a ship production cycle can take up to three years. This means that, for example, a ship ordered in 2009 and delivered in 2012 would be included in an analysis several times (as a new order in 2009, delivered in 2012 and, in the meantime, recorded in the book of orders).

Data for the selected three inputs and two outputs were taken from the Croatian Shipbuilding Corporation – Jadranbrod (partly published in [3]) and financial reports of the observed shipyards published on the official website of the financial agency FINA [8].

The basic DEA models usually used in applications are CCR [5] and BCC [1]. The first is characterized by constant returns-to-scale (CRS) activities. In order to adapt it to processes with variable returns-to-scale (VRS), by either increasing (IRS) or decreasing (DRS), the CCR model was extended to the BCC model [1]. In addition, a management strategy can be aimed at either reducing the input amounts or at augmenting the output levels, while in both cases keeping the rest of the variables at their original levels. Accordingly, DEA models are molded to reflect input or output-orientation.

Since an improvement in shipyard performance requires a reduction of all three inputs and augmentation of both outputs, both model orientations are suitable. Nevertheless, a reduction of the inputs would result, among other things, in layoffs in the shipbuilding industry, which could lead to a decrease in its production volume, and thus indirectly to layoffs in related business areas. Consequently, output-orientation is better suited and is therefore selected for the present analysis. Hence, the concept of efficiency will be explained by using output-oriented models.

Suppose there are n DMUs (DMU$_j$, $j = 1, 2, ..., n$), each of which consumes m inputs to produce s outputs. Let the input and output data for DMU$_j$ be $x_j = \{x_{ij}, i = 1,2,...,m\}$ and $y_j = \{y_{rj}, r = 1,2,...,s\}$, respectively. The data set can then be given by the matrices $X = (x_{ij}, i = 1,2,...,m, j = 1,2,...,n)$ and

$Y=(y_{rj}, r=1,2,...,s, j=1,2,...,n)$, where X is the (m x n) input data matrix and Y the (s x n) input data matrix. The following procedure is based on [6], pp. 43-46, 87-89, 140-142.

In evaluating the relative efficiency of a real DMU$_o$ ($o \in \{1, 2, ..., n\}$), one of the fundamental DEA principles is reflected in a two-phase linear programming procedure that seeks a virtual DMU characterized by inputs $X\mu$ and outputs $Y\mu$. These are the linear combinations of inputs and outputs of the other DMUs in the decision set and are better (or at least not worse) than the inputs and outputs of the evaluated DMU$_o$. The expression $\mu=(\mu_1, \mu_2,..., \mu_n)$, $\mu > 0$ is the vector of weights assigned to the corresponding DMUs. The first phase in finding a virtual DMU can be accomplished using the following standard linear programming (LP) problem:

$$\max_{\eta,\mu} \eta \tag{1}$$

$$\text{subject to} \quad X\mu \le x_o \tag{2}$$

$$\eta y_o - Y\mu \le 0 \tag{3}$$

$$\mu \ge 0 \qquad \text{(DEA–CCR)} \tag{4}$$

$$e\mu = 1 \qquad \text{(DEA–BCC)} \tag{5}$$

When taken together, conditions (1)-(4) and (1)-(5) form the CCR and BCC models, respectively. Among them, (2), (3) and (4) consist of m, s and n constraints, respectively. In the case of Croatian shipyards, n is 5, m is 3 and s is 2. Vector μ shows the proportions contributed to the projection of DMU$_o$ by efficient DMUs onto efficient frontier. The last constraint (5), where e is a suitably dimensioned vector of unity values, distinguishes the CCR model from the BCC model and causes significant differences in their production frontiers. Due to the fact that every inefficient DMU is farther from its CCR-projection than from its BCC-projection, CCR-efficiency is more difficult to achieve. Therefore and regardless of the selected orientation, CCR-efficiency scores are never higher than BCC-efficiency scores. Nevertheless, the efficiency score θ^* is the reciprocal of the corresponding optimal objective value η^* which, in the case of inefficiency of DMU$_o$, is also the augmentation rate of its outputs ($\eta^* \ge 1$).

The constraints (2) and (3) indicate that, when $\eta^* > 1$, $(X\mu, Y\mu)$ outperforms $(x_o, \eta^* y_o)$. Considering this feature, the input *excesses* and the output *shortfalls* are expressed as

$$t^- = x_o - X\mu, \qquad t^+ = Y\mu - \eta y_o,$$

respectively, with $t^- \in \mathbf{R}^m$, $t^- \ge 0$ and $t^+ \in \mathbf{R}^s$, $t^+ \ge 0$ for any feasible solution (η, μ).

After the first phase, in which η was maximized, the second phase should be performed in order to detect possible remaining input excesses and output shortfalls, which is carried out by maximizing their sum while maintaining $\eta = \eta^*$.

Definition 1 (Efficiency):

If an optimal solution $\left(\eta^*, \mu^*, t^{-*}, t^{+*}\right)$ *obtained in this two-phase process satisfies* $\eta^* = 1$ *and has no slack* ($t^{-*} = 0$, $t^{+*} = 0$), *then the DMU*$_o$ *is called* efficient, *otherwise it is* inefficient.

Definition 2 (Reference Set):

For an inefficient DMU$_o$, *its* reference set E_o *is defined based on an optimal solution* μ^* *by*

$$E_o = \left\{ j \,\middle|\, \mu_j^* > 0 \right\} \; \left(j \in \left\{1, 2, ..., n\right\}\right).$$

An optimal solution can be expressed as

$$x_o = \sum_{j \in E_o} x_j \mu_j^* + t^{-*},$$

$$\eta^* y_o = \sum_{j \in E_o} y_j \mu_j^* - t^{+*}.$$

These relations suggest that the efficiency of $\left(x_o, y_o\right)$ for DMU$_o$ can be improved if the output values are, firstly, enlarged radially by the ratio η^* and, secondly, augmented by the output shortfalls recorded in t^{+*} and, thirdly, the input excesses recorded in t^{-*} are eliminated. The first improvement removes technical inefficiency, while the second and the third improvements remove mix inefficiency. Together, they can be calculated using the formula called the *projection:*

$$\hat{x}_o = x_o - t^{-*},$$

$$\hat{y}_o = \eta^* y_o + t^{+*}.$$

Investigating the sources of possible inefficiency of a DMU is an interesting and meaningful efficiency research subject. Therefore, the next important step is to investigate if they are caused by inefficient operation of the DMU itself or by disadvantageous conditions under which the DMU operates or by both. For this purpose, comparisons of the output-oriented CCR and BCC scores deserve special consideration. The CCR model assumes the CRS production possibility set, i.e., it is postulated that the radial expansion and reduction of all observed DMUs and their nonnegative combinations are possible, and hence the CCR score is called the *global technical efficiency* (TE). On the other hand, the BCC model assumes that the VRS production possibility set is formed by convex combinations of the observed DMUs, and the BCC score is called the *local pure technical efficiency* (PTE). If a DMU is BCC-efficient but has a low CCR score, then it is operating locally efficiently but not globally efficiently due to the scale size of the DMU. Thus, it is reasonable to characterize the *scale efficiency* (SE) of a DMU by the ratio of the two scores.

Definition 3 (Scale Efficiency):

Let the CCR and BCC scores of a DMU be θ^*_{CCR} and θ^*_{BCC}, respectively. The scale efficiency is defined by

$$SE = \frac{\theta^*_{CCR}}{\theta^*_{BCC}}. \tag{6}$$

$\theta^*_{CCR} = \frac{1}{\eta^*_{CCR}}$ and $\theta^*_{BCC} = \frac{1}{\eta^*_{BCC}}$, where η^*_{CCR} and η^*_{BCC} are the optimal objective values of LPs (1)-(4) and (1)-(5) respectively.

Obviously, the scale efficiency cannot exceed one. For a BCC-efficient DMU with CRS characteristics, it is equal to one. Using the afore described concepts, relationship (6) demonstrates a decomposition of efficiency as $\theta^*_{CCR} = \theta^*_{BCC} \times SE$ or

[Technical Eff. (*TE*)] = [Pure Technical Eff. (*PTE*)] × [Scale Eff. (*SE*)].

This unique decomposition depicts sources of overall technical inefficiency (TE), i.e., whether it is caused by inefficient operation (PTE) or by disadvantageous conditions displayed by the scale efficiency (SE) or by both. In addition, the request for the monitoring of a shipyards' efficiency, which provides each shipyard's management with meaningful insights into its dynamics, results in the time-dependent extension of DEA models, known as window analysis. The fundamental idea is to include data for several periods into the analysis, and then to regard each DMU as if it was a different DMU in each of the periods examined.

3. Empirical results and discussion

In selecting an appropriate returns-to-scale (RTS) type, due care should be exercised, and knowledge of the production frontiers characteristics of the process to be scrutinized is crucial. Due to the inability of determining the type of RTS with certainty in the case of shipyard performance, and the need to calculate and mutually compare different types of inefficiency, the analysis was carried out under both (CRS and VRS) assumptions in order to reveal its causes.

The relative efficiency evaluation of Croatian shipyards was carried out on empirical data relating to five shipbuilding indicators over a six-year period from 2007 to 2012. The nature of the selected indicators allowed comparisons of shipyard performance on an annual basis.

The window is the period within which the comparisons were carried out, and its duration ranges from one to six years. An interesting task would be to consider each year separately (six one-year windows) or analyze simultaneously all years (one six-year window). However, given that the rule of thumb prescribed that the number of entities should be at least three times the number of indicators [2], the first variant was considered inappropriate. Moreover, investigating the relative efficiency of a shipyard seems to be more important, not only with respect to other shipyards in the same year, but also in relation to their performances, including their own operation, throughout the other periods. Therefore, one window that spans the entire period was used. The relative efficiency scores generated by the CCR and BCC models are listed in Table 1.

Efficiency scores								
Model	Year	Shipyard					Average per year	Minimum efficiency result
		Uljanik	3. maj	Brodosplit	Brodotrogir	Kraljevica		
CCR	2007	0.989471	0.579515	0.540750	0.615596	0.517772	0.648621	0.517772
	2008	0.673208	0.615115	0.526834	0.578804	1	0.678792	0.526834
	2009	0.602423	0.384188	0.401137	0.752879	0.384303	0.504986	0.384188
	2010	0.811752	0.800119	0.672833	0.437546	0.359695	0.616389	0.359695
	2011	0.961587	1	1	0.458368	0.288310	0.741653	0.288310
	2012	0.416618	0.710666	0.341255	1	1	0.693708	0.341255
Average per shipyard		0.742510	0.681600	0.580468	0.640532	0.591680	0.647358	
BCC	2007	1	0.702027	0.953058	0.680048	0.930775	0.853182	0.680048
	2008	0.861590	0.673647	0.902891	0.658117	1	0.819249	0.658117
	2009	0.805576	0.430734	0.703289	0.757495	0.694724	0.678364	0.430734
	2010	1	0.999999	0.791232	0.438780	0.618386	0.769679	0.438780
	2011	1	1	1	0.466826	0.999995	0.893364	0.466826
	2012	0.572126	0.790191	0.999985	1	1	0.872460	0.572126
Average per shipyard		0.873215	0.766100	0.891743	0.666878	0.873980	0.814383	

Table 1: *Comparison of CCR and BCC efficiency scores (2007–2012)*

The Uljanik shipyard seems quite interesting in terms of the CCR model, as it was the only shipyard to exhibit continuous relative inefficiency, but nonetheless, on average, it was still the most efficient one. It was ranked the most efficient shipyard in two separate years, and never scored the worst efficiency result. Although the above results provide approximate efficiency trends for Croatian shipyards, they will not be the subject of any further analysis for reasons given below.

When looking at only the last two years, on average, Kraljevica exhibited the highest BCC-efficiency score. In the light of its bankruptcy in 2012, this result was completely unexpected and required a closer inspection. The first step was to examine input and output values of this particular shipyard. On this occasion, the number of employees identified was arguable. Specifically, the numbers ranged between 480 and 521 in the previous five years, whereas in 2012, as a result of layoffs, it was only 42. This sharp reduction in an input explains to a great extent the achievement of the shipyard's BCC-efficiency in 2012, and therefore questions the validity of this efficiency score. Moreover, since employee numbers represent the year-end values, it remains unclear as to when in the year did the layoffs occur. This further contributes to unreliability of this particular data, and thus the year 2012 was excluded from the analysis. This also resolves the issue of a possible incorrectness in replacing the missing data previously mentioned. The new efficiency results for the period 2007-2011 are listed in Table 2.

Efficiency scores								
Model	Year	Shipyard					Average per year	Minimum efficiency result
		Uljanik	3. maj	Brodosplit	Brodotrogir	Kraljevica		
CCR	2007	1	0.582478	0.622201	0.653979	0.562628	0.684257	0.562628
	2008	0.828261	0.623118	0.645782	0.608369	1	0.741106	0.608369
	2009	0.737372	0.444870	0.578656	0.781684	0.429298	0.594376	0.429298
	2010	1	0.801304	0.752798	0.499199	0.406935	0.692047	0.406935
	2011	1	1	1	0.727666	0.438667	0.833266	0.438667
Average per shipyard		0.913127	0.690354	0.719887	0.654179	0.567506	0.709011	
BCC	2007	1	0.702027	0.953058	0.686596	0.999997	0.868336	0.686596
	2008	0.862215	0.673647	0.902891	0.662986	1	0.820348	0.662986
	2009	0.805576	0.445007	0.703289	0.796155	0.784492	0.706904	0.445007
	2010	1	0.999999	0.792029	0.590777	0.690814	0.814724	0.590777
	2011	1	1	1	0.868966	0.999998	0.973793	0.868966
Average per shipyard		0.933558	0.764136	0.870253	0.721096	0.895060	0.836821	

Table 2: *Comparison of CCR and BCC efficiency scores (2007–2011)*

According to both models, average shipyard efficiency is less than one throughout the entire period, meaning that all shipyards are inefficient in (pure) technical terms. In addition, the efficiency results differ significantly depending on the model, which, in average terms, is most prominent in the cases of Brodosplit and Kraljevica for the year 2007. Among the 25 observed entities, six turned out to be BCC-efficient, and mostly in the last year. All of them were also CCR-efficient. None of the five shipyards was efficient throughout the entire period. On average and according to both models, efficiency scores were highest in 2011 and the lowest in 2009, which was the only year when neither of the shipyards achieved efficiency. Interestingly enough, the disparities among shipyards, best seen from the absolute and relative differences between the best, the average and the worst efficiency scores, are most pronounced in exactly those years (in 2011 according to CCR model, and in 2009 according to BCC model).

When it comes to an analysis and assessment of inefficiency, the respective sources and their amounts, as well as the proposed improvements should be identified. This valuable information serves as the starting point for setting goals and making successful decisions. Unlike basic DEA models, window analysis does not provide these results. Hence, a new model was constructed [12]. Five data sets on five selected indicators, one for each of the years examined, were included in the basic CCR and BCC models for each shipyard. Thus, each of 25 is treated as a separate entity. The construction of this model is justified given that it calculates additional crucial results, while not affecting relative efficiency scores identified by window analysis using one five-year window. The mean differences between projected and empirical values of each indicator are displayed in Table 3. They represent inefficiencies that can be eliminated by conducting the previously described two-phase procedure. For illustration purposes, in 2010, the BCC mean efficiency score was 0.814724 which signifies that on average the shipyards have an 18.53% BCC-inefficiency (18.53 = (1 − 0.814724)*100). With the aim of operating efficiently, the first phase requires the shipyards to remove technical inefficiency using techniques to increase both outputs by 22.74% and maintaining the original input amounts (based on the previously mentioned radial augmentation of outputs by the ratio η^*, 22.74 = (1/0.814724 − 1)*100). The delivered cgt represents a major output shortage, with an average required increase of 97.58%. The percentage difference indicates that overall efficiency cannot be accomplished by solely eliminating the technical inefficiency. Therefore, after increasing both outputs radially, and to avoid further wastage and inefficiency in relation to the benchmarks, in the second phase the shipyards should remove the mix inefficiency through further output augmentation. The different percentages of improvements required for eliminating inefficiency mean that, when considering delivered cgt, the mix inefficiency is more pronounced than technical inefficiency for the majority of inefficient shipyards in the particular year. At the same time, when it comes to total revenues, the situation is reversed.

Input and output improvements (per inefficient shipyard)						
Model	Year	*Inputs*			*Outputs*	
		Employees	Effective working hours	Total expenditures	Delivered cgt	Total revenues
CCR	2007	0.00%	-4.81%	-13.66%	65.76%	67.45%
	2008	0.00%	0.00%	0.00%	50.11%	50.11%
	2009	-5.95%	-2.39%	-17.03%	78.82%	78.82%
	2010	-6.87%	-6.57%	-23.85%	75.93%	319.70%
	2011	-14.72%	0.00%	0.00%	209.47%	82.70%
BCC	2007	-10.44%	-14.75%	-9.24%	23.26%	23.26%
	2008	-10.43%	-10.84%	-8.77%	31.51%	31.51%
	2009	-13.67%	-4.83%	0.00%	69.94%	48.82%
	2010	-16.35%	-4.70%	-5.40%	97.58%	35.14%
	2011	-7.47%	0.00%	0.00%	16.01%	7.54%

Table 3: *Sources and average amounts of inefficiency, CCR and BCC model (2007-2011)*

During the entire period, it is evident that delivered cgt and total revenues alternate as indicators most significantly affecting efficiency. On average, the first parameter is the leading source of inefficiency in the BCC model, where it is the second parameter for the CCR model. Notably, selecting the model orientation, on average, has a greater influence on the inputs rather than on the outputs.

The causes of relative inefficiency of Croatian shipyards can be local or global. Their scale inefficiencies have to be assessed to resolve this dilemma, which in the case of output-oriented models are also output-oriented. They are shown in Table 4 for all 25 entities. The types of returns to scale were also identified. They can be found in the same table.

Scale efficiency scores (RTS)							
Year	Shipyard					Average per year	Minimum efficiency result
	Uljanik	3. maj	Brodosplit	Brodotrogir	Kraljevica		
2007	1 (CRS)	0.829708 (DRS)	0.652847 (DRS)	0.952495 (CRS)	0.562628 (IRS)	0.799536	0.562628
2008	0.960620 (DRS)	0.924993 (DRS)	0.715238 (DRS)	0.917619 (CRS)	1 (CRS)	0.903694	0.715238
2009	0.915334 (DRS)	0.999693 (CRS)	0.822785 (DRS)	0.981824 (CRS)	0.547246 (IRS)	0.853376	0.547246
2010	1 (CRS)	0.801304 (IRS)	0.950467 (DRS)	0.844990 (IRS)	0.589072 (CRS)	0.837167	0.589072
2011	1 (CRS)	1 (CRS)	1 (CRS)	0.837395 (IRS)	0.438667 (IRS)	0.855212	0.438667
Average per shipyard	0.975191	0.911140	0.828268	0.906865	0.627523	0.849797	

Table 4: *Scale efficiency scores (2007-2011)*

A comparison of the empirical results found in Tables 2 and 4 indicat a wide diversity of calculated efficiencies among the shipyards. The mean values of overall technical, pure technical and scale efficiency are approximately 0.71, 0.84 and 0.85 respectively, indicating on average similar shares of pure technical and scale inefficiency in the overall inefficiency of Croatian shipyards. These shares, however, differ significantly from one shipyard to another and two contrasting examples are shortly presented. On one hand, Kraljevica has higher pure technical score rather than scale scores in all of the inefficient years of the investigated period. This difference is especially pronounced in the initial and final year, meaning that the overall inefficiency of this shipyard is largely due to scale inefficiency. The results also indicate that Kraljevica, when inefficient, exhibits mostly increasing returns to scale, i.e. it operates under a suboptimal scale. On the other hand, in the case of Uljanik, pure technical inefficiency affects overall efficiency slightly more than scale inefficiency in both of the inefficient years. In addition, Uljanik exhibits decreasing returns to scale, i.e. it operates above its optimal scale. In summary, both mentioned shipyards produce outcomes less than optimally required (best practice) from given resources. To reach the optimal scale, Kraljevica therefore needs to expand its operations, while Uljanik on the contrary needs to downsize. The way to eliminate the pure technical efficiency would be to adopt the best practices of efficient shipyards. All of the above mentioned point to the necessity of a more detailed investigation of the causes of behind the results and the obligation of implementing appropriate measures for improving shipyard efficiency.

4. Concluding remarks

The relative efficiency evaluation of the Croatian shipbuilding sector was conducted based on the reciprocal performance comparison of the five major Croatian shipyards, according to the CCR and BCC window analysis and using the same set of inputs and outputs. The analysis included time-series cross-sectional comparisons using one five-year period, thus enabling simultaneous monitoring of the efficiency dynamics of the shipyards. The empirical results suggest two important findings. First, the results indicate that pure technical and scale inefficiency for Croatian shipyards, on average, contribute equally to overall inefficiency. Regardless of the type of efficiency, Uljanik has the highest average efficiency over the observed period. Second, there are definite possibilities of increasing efficiency levels in Croatian shipyards. The average overall technical inefficiency could be reduced by 29%, if operating at optimal scales and eliminating pure technical inefficiencies.

The role of shipbuilding in the Croatian economy is larger when the activities of other shipbuilding-related industries are considered. Namely, the higher the subcontracting – the lower the number of employees in the shipyard itself. This is especially true for labor productivity that is expressed in terms of production per person. The results shown in this study should therefore be treated with caution, because it has failed to take into account the overall influence of the share of subcontracting, which should be addressed in future studies.

In order to gain a more reliable insight into the level and dynamics of relative efficiency of Croatian shipyards, the analysis can be expanded to include shipyards abroad with similar characteristics. On the other hand, comparing the shipbuilding industries of shipbuilding countries at a national level could be of even greater interest because it would result in guidelines for creating new or recreating existing shipbuilding strategies for countries included in such research. In that case, the selection of indicators needs to be reconsidered in order to meet the different research focus. These issues remain open for future research.

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References

[1] Banker, R. D., Charnes, A. and Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science, 30(9), 1078–1092. doi:10.1287/mnsc.30.9.1078.

[2] Banker, R. D., Charnes, A., Cooper, W. W., Swarts, J. and Thomas, D. (1989). An introduction to data envelopment analysis with some models and their uses. Research in Governmental and Non-Profit Accounting, 5, 125–163.

[3] Brodarski institut. Brodogradnja: Journal of Naval Architecture and Shipbuilding Industry, various issues, Zagreb.

[4] Community of European Shipyard Associations. (2011). Annual Report 2010-2011. Brussels.

[5] Charnes, A., Cooper, W. W. and Rhodes, E. (1978). Measuring the efficiency of decision making units. European journal of operational research, 2(6), 429–44. doi:10.1016/0377-2217(78)90138-8.

[6] Cooper, W. W., Seiford, L. M. and Tone, K. (2006). Introduction to Data Envelopment Analysis and Its Uses: With DEA-Solver Software and References. New York: Springer.

[7] Čagalj, A. (2009). Productivity in Shipbuilding. Shipbuilding, 60, 141–146.

[8] FINA. (2014). `http://rgfi.fina.hr` [Accessed on 25 July 2014].

[9] Kuosmanen, T. (2002). Modeling blank data entries in Data Envelopment Analysis. EconWPA (Econometrics). Working Paper No. 0210001, Wageningen.

[10] Liu, J. S., Lu, L. Y., Lu, W.-M. and Lin, B. J. (2013). A survey of DEA applications. Omega, 41(5), 893–902. doi: 10.1016/j.omega.2012.11.004.

[11] OECD Directorate for Science, Technology and Industry (STI). (2007). Compensated Gross Ton (CGT) System. Paris: Council working party on Shipbuilding.

[12] Rabar, D. (2013). Assessment of regional efficiency in Croatia using data envelopment analysis. Croatian Operational Research Review, 4, 76–88.

[13] Zhang, H. and Xu, X. (2010). Analysis and evaluation on management efficiency of shipbuilding enterprises based on the DEA. Journal of Systems & Management, 1, 49–55.