

Projecting sale prices of new container ships built in 2005–2015 based on DWT and TEU capacities

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Abstract

This paper presents mathematical relationships that allow forecast of the estimated sale price of new container ships, based on data concerning vessels built in 2005–2015. The presented approximations allow estimation of the price based on deadweight capacity (DWT) or the number of containers the ship will carry (TEU). The approximations were developed using linear regression and the theory of artificial neural networks. The presented relations have practical relevance in the estimation of container ship sale price needed in transport studies or preliminary parametric design of the ship. It follows from the above that the use of artificial neural networks to predict the price of a container ship brings more accurate solutions than linear regressions.

Introduction

Maritime transport stakeholders often need to know the estimated price of different vessels. Depending on the available information, the pricing of new vessels can be either approximate or specific.

Price estimation of means of transport is most often carried out at the stage of general transport studies, aiming at the choice of the mode of transport (Rawson & Tupper, 2001; Watson, 2002). In regard to maritime transport means, factors taken into account include vessel's period of operation or possible sale of the vessel after that period. When a cargo ship is considered, this analysis also takes into account limitations of the port infrastructure and transport system adopted (Rawson & Tupper, 2001).

An estimated cost of a ship is also carried out at its design stage, to determine the construction costs and, possibly, the cost of ship operation. Since ship design is a multi-stage process, at each stage design parameters are optimized relatively to the criteria and design constraints, where economic analysis plays an essential role. The proper conduction of this analysis is the basis for the development of ship

design of highest operational value (Buczowski, 1974; Bertram 2000, Chądryński, 2001).

Prediction of the estimated sale price of the ship is of particular importance when concurrent methods of ship design could be used. In this case, the estimated sale price should be known at the preliminary design stage.

The preliminary design stage consists of parametric and geometric design. Estimating the price of the ship in this phase is difficult. The problem arises from the fact that the price of the vessel depends, inter alia, on the unit costs of ship construction, which in turn include the costs of materials, equipment, labour and the additional costs of the yard (Schneekluth & Bertram, 1998; Michalski, 2004). In general, the total of these costs is not known at the stage of parametric design, because at this phase a detailed specification of materials and equipment is not known. During the parametric design, only general design parameters of the ship are known, such as main hull dimensions, general geometric indicators, and general assumptions regarding the cargo capacity or speed of the ship. For this reason, at this stage the economic analysis covers only basic

technical parameters of the vessel, such as weight/displacement, speed or cargo capacity.

In contrast, in the subsequent stages of design, when more information is available on the ship to be built, a detailed estimation is performed, considering the unit costs of materials, equipment, and labour and additional costs of the shipyard. Methods presented in (Schneekluth & Bertram, 1998; Abramowski, 2013; Michalski, 2004) apply to the detailed cost estimation of sea transport means, i.e. vessels.

Aim of the research

This article describes methods of cost estimation for the purpose of transport studies or preliminary parametric design of a container ship. The aim of the study was to develop mathematical relationships that allow performing cost estimation of container ships built in the years 2005–2015 on the basis of their basic operating parameters.

The practical aim of the research was to develop a mathematical function, f , for predicting the price of a container ship, P , using technical parameters, represented as $X_1X_2...X_n$.

$$P \approx f(X_1, X_2, \dots, X_n) \tag{1}$$

where:

- P – sale price;
- $X_1X_2...X_n$ – technical parameters of the vessel;
- n – number of parameters;
- f – searched-for mathematical function.

The analysis took into account a set of 241 new container ships built in the years 2005–2015, whose parameters ranged as follows:

- DWT: 2,310–165,538 t;
- number of containers (TEUs): 58–13,344;
- service speed: 10–27 knots;
- sale price: 2.5–170 million USD.

In addition to the above parameters the study included:

- displacement and weight of ship;
- gross tonnage (GT);
- main hull dimensions: length between perpendiculars, breadth, moulded depth, moulded draft;
- power plant output, fuel consumption.

The study assumed that the function f in equation (1) can be determined using linear regression and the theory of artificial neural networks.

Use of linear regression for container ship price approximation

Statistical analysis showed that the price of a container ship is mainly dependent on container capacity (TEUs) and DWT capacity. Of all the investigated statistical relationships, the following proved to be the best:

$$P = 21,241,378 + 0.818338 \cdot \text{TEU}^2 \tag{2}$$

$$P = 19,146,189 + 0.00602853 \cdot \text{DWT}^2 \tag{3}$$

where:

- P – price of a container ship in USD;
- TEUs – number of containers;
- DWT – deadweight capacity [t].

Equation (2) is characterized by:

- correlation coefficient $R^2 = 0.73$,
 - standard error $\sigma = \$ 16.8$ million,
- while equation (3) is characterized by:
- correlation coefficient $R^2 = 0.73$,

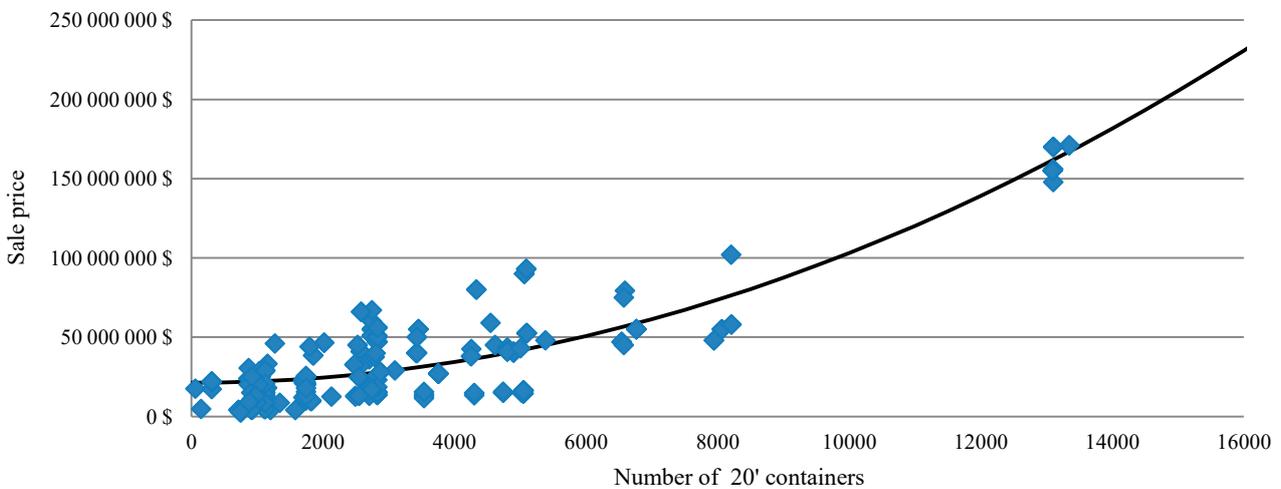


Figure 1. Approximations of container ship price depending on the number of containers. Relationship (2) in comparison with reference data

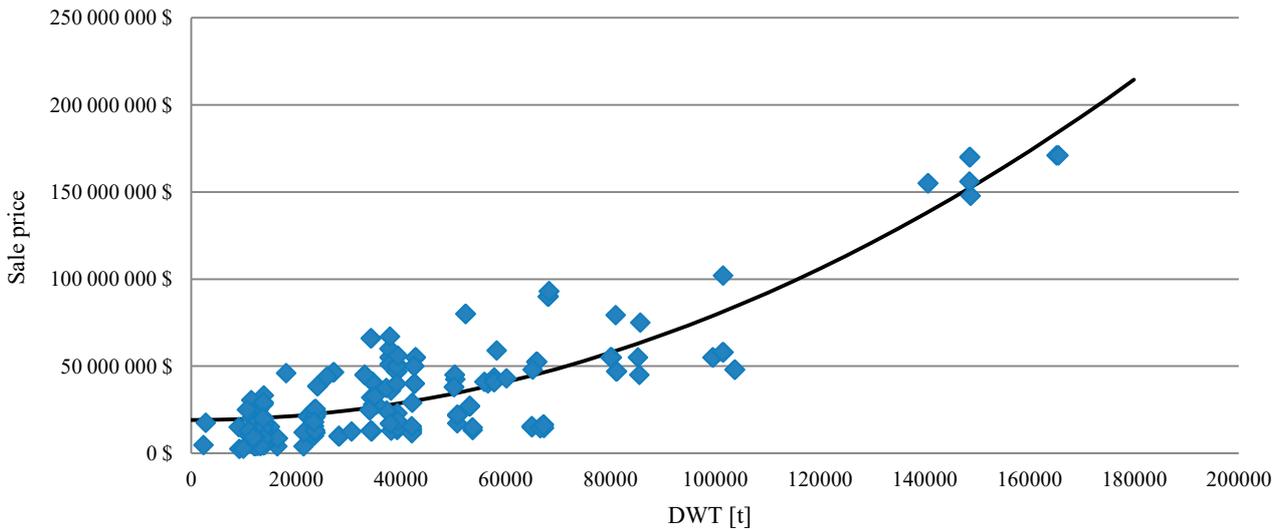


Figure 2. Approximations of container ship price depending on DWT capacity. Relationship (3) in comparison with reference data

- standard error $\sigma = \$ 17.2$ million.
- Figures 1 and 2 show the comparison between reference data and results obtained through the relations (2) and (3), respectively.
- A model was then developed for predicting the sale price of a container ship based on the DWT capacity and TEU capacity:

$$P = -40,849,078 + 639,829 \cdot \ln(\text{DWT})^2 \cdot 4.913 \cdot 10^{-5} \cdot \text{TEU}^2 \quad (4)$$

where:
 P – price of a container ship in USD;
 TEU – number of containers;
 DWT – deadweight capacity [t].

- Equation (4) is characterized by:
- correlation coefficient $R^2 = 0.73$;
 - standard error $\sigma = \$ 16.8$ million.

Figure 3 shows the prediction of the price of a container ship based on the carrying capacity and

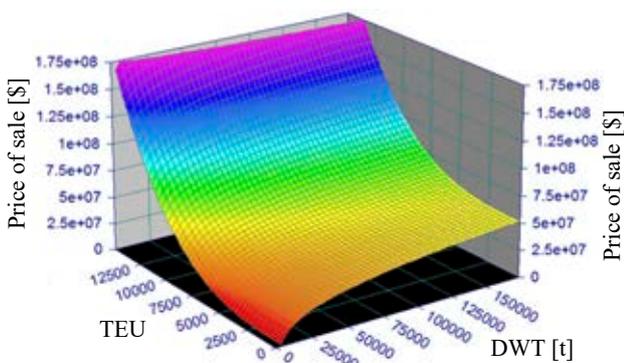


Figure 3. Projecting the price of a container ship depending on the DWT capacity and TEU capacity according to formula (4)

the number of 20-foot containers according to formula (4).

Use of artificial neural networks for container ship price approximation

In many scientific works on hydromechanics and ship design, the application of the theory of artificial neural networks to make approximations brought to good solutions. In the publications of Abramowski (2008; 2013) the author used the theory of artificial neural networks to build approximating functions, while Chądzyński (2001) shows the possibility of using an analysis of neural network sensitivity to a dependent variable for the selection of independent variables.

Equation (4) presented in the previous section has a slightly higher accuracy than equations (2) and (3). It means that this relationship is of little practical use, because it does not enable more accurate approximations than equations (2) and (3). On the other hand, the use of the theory of artificial neural networks for approximating the sale price depending on the TEU capacity produced more accurate solutions.

The artificial neural network was applied to determine a function approximating the sale of vessels. In this research, the following types of networks were tested:

- Multilayer Perceptron (MLP) of a sigmoidal activation function;
- Generalized Regression Neural Network (GRNN) – a regression network;
- Radial Basic Function Network (RBF).

The search for the most appropriate network was carried out through the following steps:

1. description of the best network structure by means of genetic algorithms;
2. learning a network (usually by using the back-propagation method);
3. testing a network;
4. assessment of approximation accuracy obtainable within a network on the basis of the testing data.

The MLP network of the structure: 2 (inputs) × 3 (hidden neurons) × 1 (output), appeared to be the most accurate (Figure 4). The network can be represented by this mathematical relationship:

$$P = \frac{\left(\frac{1}{1 + e^{-((DWT, TEU) \times S + P) \times A - B}} \right) \times C + 0.211}{5.99 \cdot 10^{-9}} + 2.4 \cdot 10^{-2} \tag{5}$$

where:

P – price of a container ship in USD;

DWT – deadweight capacity [t];

TEU – number of containers;

A – matrix of weight values:

$$\begin{bmatrix} .6549 & .7148 & .6021 \\ 1.6543 & .4188 & -1.1279 \end{bmatrix};$$

S – matrix of coefficients:

$$\begin{bmatrix} 6.45E-06 & 0 \\ 0 & 7.67E-05 \end{bmatrix};$$

B – threshold vector

$$[3.1783 \ 1.1353 \ -0.5476];$$

C – column vector of weights:

$$[2.4972 \ 0.7511];$$

P – vector of offset values:

$$[-6.84E-02 \ 2.35E-02].$$

Equation 5 allows the approximation of the price, P , based on deadweight capacity, DWT , and number of containers, TEU , using the matrix calculation method. The matrix and column vectors were described above.

The artificial neural network described by equation (5), compared to relations (2)–(4), is characterized by:

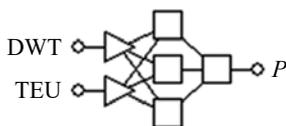


Figure 4. The structure of artificial neural network for the approximation of container ship price P according to equation (5), where: DWT – deadweight capacity, TEU – number of twenty-foot containers

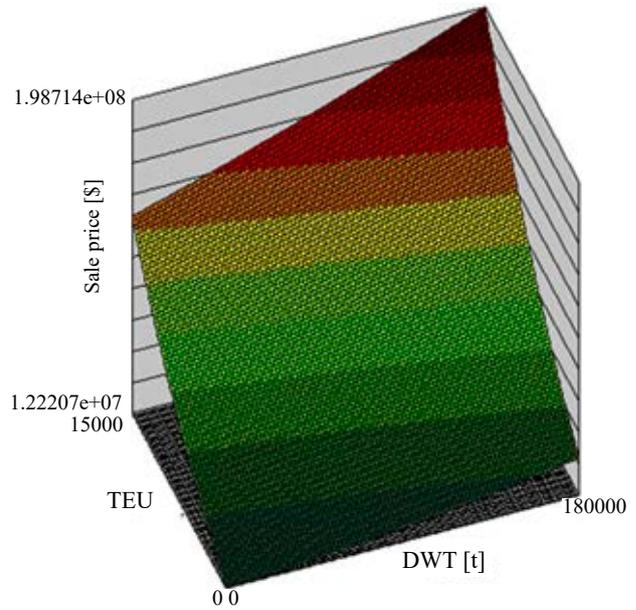


Figure 5. Projecting the price of a container ship depending on the DWT capacity and TEU capacity according to the formula (5)

- the highest value of the correlation coefficient, $R^2 = 0.86$;
- the lowest standard error, $\sigma = \$ 13.0$ million.

Figure 5 presents container ship price prediction based on the DWT capacity and TEU capacity resulting from equation (5).

Conclusions

The study shows that the price estimate of a new container ship is influenced mainly by the TEU capacity and DWT capacity. The article presents a series of mathematical formulas that allow forecasting the price of a container based on these quantities. The relations have been developed from data on sale prices of 241 container ships built in 2005–2015.

Formulas (2) and (3) may be used interchangeably as the ship’s carrying capacity depends mainly on the number of containers. Formula (4), which takes into account both DWT capacity and $TEUs$, is characterized by an accuracy that is only slightly higher than the one of formulas (2) and (3). Therefore, the practical value of this formula is low. Formula (5), on the other hand, includes the same independent variables, i.e. DWT capacity and TEU capacity, yet it is characterized by the highest accuracy and lowest error of the developed formulas.

It follows from the above that the use of artificial neural networks to predict the price of a container ship brings more accurate solutions than linear regressions.

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