A building cost estimation method for inland ships

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ABSTRACT

There is very little publicly available data about the building cost of inland ships, especially for ships that have dimensions that differ significantly from those of common ships. Also, no methods to determine the building cost of inland ships are described in literature. In this paper, a method to estimate the building cost of inland ships is presented. Furthermore, the method is used to develop rules of thumb for the cost of inland ships as a function of their length, beam and draught. All material that is presented in this paper is based on or taken from Hekkenberg [2013].

Key words: inland ships, cost estimation

1. INTRODUCTION

There have been many studies into the economics of inland shipping and the competitiveness of inland shipping compared to road and rail transport. In virtually all studies in which the cost of transport by inland ship plays an important role, only data on ships of common types and sizes are provided. In the few exceptions where the use of non-standard ships is explored, no methods for the estimation of the building cost are provided [Hekkenberg 2013, p 30]. Since building cost is an important element in the total cost of transport by inland ship, this absence of suitable estimation methods makes it hard or impossible to explore the economic performance of non-standard inland ships. This in turn can be considered as an impediment to innovation in the sector. To fill this gap, in this paper a method to estimate the building cost of an inland ship on the basis of its technical specifications is presented as well as several of rules of thumb, derived from this method, that allow estimation of building cost as a function of only length, beam and draught. All material that is presented in this paper is based on or taken from Hekkenberg [2013].

2. LITERATURE SURVEY

From literature, only a partial picture of the relationship between the technical properties of an inland ship and its building cost can be obtained. Several sources list the commercial prices for a number of standard ship types, while others provide estimates for various components of the ship as a function of one or more technical properties.

De Vries [Vries, 2000, p. 148], in a very rough estimate, arrives at a cost of approximately 3.9 million euro for a 110 x 11.45 m ship and 2.2 million euro for a 63 x 7 m ship (2011 values), while research institute VBD [2004], currently known as DST, provides cost data for a number of conventional ship types, as shown in table 1. Indexing the values by VBD [2004] to 2011 values by means of the OECD producers' price index for the EU 27 [OECD, 2012] leads to the following values for the cost of these ships:

Table 1 Building cost of various vessel types. Source: adapted from VBD [2004]

type	Gustav Koenigs	Johann Welker	GMS	Elbeleichter (small)	Elbeleichter (large)	pusher	
L	80	85	110	32.5	65	20	m
B	8.2	9.5	11.4	8.2	8.2	8	m
T	2.5	2.7	3.5	2.32	2.32	1.4	m
P_{inst}	750	900	1100	0	0	800	kW
Hull cost	1.30	1.36	2.00	0.17	0.40	0.69	M €
Propulsion cost	0.58	0.62	0.92	0.00	0.00	0.62	M €
Other equipment cost	0.24	0.25	0.36	0.00	0.00	0.27	M €
Elec., navigation, accomm. cost	0.24	0.25	0.36	0.02	0.02	0.27	M €
Total cost (2011 values)	**2.36**	**2.48**	**3.63**	**0.20**	**0.42**	**1.86**	**M €**

As a further rough but illustrative indication of building cost, Schuttevaer, [2011] quoted "*… In 2008 prices for a new ship were much higher than today. Then a 110 m ship cost 4.5 million Euro, now only 3.3 million Euro*". This provides further confirmation of the values by VBD, but also reveals large fluctuations in commercial prices due to changes in market situation. These fluctuations are also apparent from the different values mentioned by De Vries [2000] and VBD [2004]. In the same article, Schuttevaer [2011] also quotes *"…a small hull costs between 1 and 1.5 million Euro."* (2011 values). This is comparable with the hull cost as stated by VBD [2004] for the Johann Welker and Gustav Koenigs type ships.

EICB [2011] also quotes a number of prices for various inland ships, as shown in table 2:

Table 2 Building price for various ship types. Source: adapted from EICB [2011]

Ship type	Newbuild price (2011 values)
Peniche (350-400 T, 40 x 5 m)	€1.2 million
Kempenaar (650 T 55 x 6.6 m)	€1.6 million
Europa ship (1200-1500 T, 86 x 9.5 m)	€2.5 million
Large ship (3000 T, 110 x 11.45 m)	€3.5 million

When the cost of a ship is broken down into smaller pieces than those presented above, it can be subdivided into the cost of all activities that are performed by the yard and the cost of all activities performed by subcontractors. The yard typically manages the project, designs and engineers the ship and erects the hull, while subcontractors supply and install all equipment. The yard-related cost can be estimated by combining the estimates of Kerlen [1981] and Coenen 2008, p 15]. Kerlen [1981] provides a building cost estimate for the hull as a function of LBD, steel price and labour cost, while Coenen [2008] provides an estimate of the cost of engineering, including procurement and ship management.

For some of the systems that are supplied and installed by subcontractors, cost data are available from various sources, while for several other systems, no reference data is available from literature. For the drive train, Hunt and Butman [1995, 9-2] arrive at a cost estimate as a function of installed power expressed as cost = c x P_{inst}^{n}, while Aalbers [unknown year, 200X] arrives at a similar estimate for the relationship between power and cost of the drive train. However, due to the fact that Aalbers, Hunt and Butman analyse seagoing ships with medium and slow speed engines, running on marine diesel oil and heavy fuel oil, the coefficient of cost that is used is not believed to be representative for high speed inland ship engines that run on gasoil. The power of 0.79-0.82 that Aalbers, Hunt and Butman use, however, is believed to provide an acceptable indication for scale effects.

Stapersma, [2001] provides a more detailed approximation of specific unit purchase cost (supc) of an engine based on the detailed characteristics of the engine. For propellers, shafting and attached hydraulics (if any), lecture material from Delft University of technology [Delft University of Technology, 2009] quotes values for fixed and variable pitch propellers operating at various speeds.

Schneekluth and Bertram [1998, p. 95] provide a trend for the cost of hatch covers: They state that hatch cover price depends linearly on length and to the power 1.6 on width.

Outfitting, which is generally recognized as one of the most difficult and design-specific cost elements to calculate, is determined as a function of outfitting weight to the 2/3 power both by Watson [1998, p. 478] and Hunt & Butman [1995].

From this, it can be concluded that there are several handholds to determine the cost of inland ships, but also that up-to-date cost data are very scarce due to the age of several literature sources. Furthermore, import cost elements such as the cost of the accommodation, wheelhouse, navigation equipment, electrical installation, rudders, bow thrusters, cranes and piping of tankers are still lacking. Therefore, the data from literature will need to be supplemented with recent cost data from actual ships before a proper building cost model for inland ships can be assembled. The way in which this is done is presented in the following section.

3. BUILDING COST ESTIMATION METHOD

For the cost estimation method, the cost of the ship is broken down into 12 categories:

1. General object cost
2. Hull
3. Propulsion & manoeuvring
4. Electrical system
5. Bilge & ballast systems

6. Cargo pumps & piping for tankers
7. Accommodation
8. Mooring gear
9. Hatch covers
10. Outfitting
11. Miscellaneous equipment
12. margin

Below, it is explained how the costs for each category are determined, followed by a final overview of the formulas that are used in the model. All costs are expressed in 2011 values; they are derived on the basis of scaling rules from literature and reference cost data from quotations from 2011.

General object cost

General object costs include acquisition, overhead and engineering. Coenen [2008, p. 15] states that in shipbuilding the cost of engineering, including procurement and ship management equals roughly 20-35% of a shipyard's labour hours. What is included in the yard's labour varies from yard to yard, as is also discussed by amongst others Stopford [2009, p. 646], but in the case of the yard at which Coenen did her PhD work, the yard's labour costs typically consist of the building of the steel hull, including small steelwork & installation of the main piping and project management. Other tasks, such as painting, installation of the major mechanical and electrical systems and the propulsion units are subcontracted.

Here, we need to take into account that the yard Coenen performed her research at builds complex one-off vessels (i.e. dredgers), while inland ships are vastly simpler and highly standardized. At the same time, it is important to note that the engineers and project managers that are paid for through the general object costs are better paid than yard workers that build the vessel's steel structure. As a result, a value of 15% of the labour cost for the building of the ship's hull is estimated as typical cost of cost category 'general object costs'.

Hull

The cost of the ship's hull can be estimated in various ways. Commonly accepted values[1] are in the range of 2.5 to 3 €/kg of steel weight. This claim can further be substantiated by research by Kerlen [1981, p 104]. Kerlen quotes the required number of man-hours per ton of steel (for general cargo, bulk and tank vessels (between 20.000 m^3 and 100.000 m^3 LBD) as:

$$k_{fr} = 45.36\left(\frac{LBD}{1000}\right)^{-0.115} \cdot \frac{0.866}{\sqrt[3]{C_B}} + x_{II}\,, \qquad (1)$$

where x_{II} represents a compensation for yard-specific variations, which for the purpose of this method is left out of the equation.

[1] Obtained through private conversations with shipyards and owners

When this equation is used, costs per ton of steel are in the same range as the abovementioned 2.5 to 3 €/kg.

The second main aspect of the cost of the hull, being the cost of the purchased materials, is directly related to the amount of steel that is used to build the hull structure. Estimates for the steel weight of inland ships may be found in Hekkenberg [2013]. Multiplying this weight with the steel price per ton will result in an acceptable first estimate of the material cost of the hull.

Tuning the above equation with a man-hour cost of 45 €/h, and a steel price of 950 €/ton results in costs for the hull of a typical inland ship that closely match the quoted cost of 2.5 to 3 €/kg. It should be noted that the mentioned man-hour costs not only include the direct labour cost, but also includes indirect cost.

Propulsion & manoeuvring

For the determination of the cost of the propulsion system several rules of thumb exist. Aalbers [unknown year, 200X] arrives at cost of the entire drive train of $\$4700 \cdot P_{prop}^{0.79}$, with P, the installed power in kW, while Hunt and Butman [1995, 9-2] use $K_3 * P_{prop}^{0.82}$. Due to the fact that Aalbers, Hunt and Butman look at seagoing ships with medium and slow speed engines, running on MDO and HFO, the coefficient of 4700 is not believed to be representative for high speed inland ship engines that run on gasoil. The power of 0.79-0.82, however, is believed to provide an acceptable indication for scale effects.

In absolute cost for the main engine, Aalbers quotes a value of \$200 to \$300 per kW (values from unknown year). Based on quotations for modern inland ship engines of 330 to 500 kW of rated power, a price of roughly 220 €/kW (2011 values) is found. However, there is a large spread in prices. Stapersma [2001] arrives at a more physically correct approximation of specific unit purchase cost (supc) of an engine (2001 values) as follows.

$$\sup c = \frac{upc}{P_b} = 270 \cdot \left(\frac{c_m}{9.5} \cdot \frac{1.25}{\lambda_S} \cdot \frac{10}{n} \right)^{0.7} \qquad (2)$$

Where:
upc = unit purchase cost (k€)
P_b = brake engine power (kW)
C_m = piston speed (m/s)
λ_s = stroke/bore ratio

Although the approach by Stapersma provides the most well-founded comparison between engines with different specifications, it requires quite detailed knowledge about the engine. Within this cost estimation method, the more simple approximation of 220 €/kW is used.

For propellers, shafting and attached hydraulics (if any), lecture material from Delft University of technology [2009] quotes 55 €/kW for a fixed pitch propeller at 100 rpm and 65 €/kW for a fixed pitch propeller at 250 rpm. For the gear box, values are not quoted in terms of €/kW, but as 15-25 €/kg of gearbox weight. When a weight 2 kg/kW is assumed as a standard gearbox weight [Hekkenberg, 2013, p 222], this brings cost of the gearbox to roughly 40 €/kW.

As a result of the above, the cost of a complete drive train is estimated at around 325 Euro per kW. There are, however, scale effects in drive train cost. Using a cost of 330 €/kW for a drive train with a 750 kW engine and a power of 0.82 to relate cost to engine power, this results in a cost of $C = N*1086\ P^{0.82}$,with N as the number of propellers and P as the installed power per propeller. For bow thrusters and their engine, the same formula is used. Per propeller, € 50.000 is added for rudders and steering machines, based on an actual quotation.

Electrical system

The cost of electrical system is hard to estimate, especially since it interacts with virtually all other systems and is, therefore, very ship-specific. Based on a quotation for a number of actual ships, generator sets are cost is estimated at 175 €/kW, while the cost of the total electrical system (including gensets) is estimated at 500 €/kVA.

Bilge and ballast systems

Bilge & ballast systems are related to vessel length and are estimated to cost € 450 per meter of ship length, based on several quotations.

Cargo pumps and piping (tank ships only)

In a similar approach, a value of 145 €/m^3 of LBD is used for cargo pumps and pipes for tank ships, although it should be noted that this is a rudimentary approximation, since the system is significantly influenced by the number of different parcels and the size of the tanks.

Accommodation

For the accommodation, an estimated price of €600 per square meter of floor space is used, based on several quotations.

Mooring gear

The cost of mooring gear is estimated at 13 €/m^3 of LBT, based on a quotation and the reasoning that L, B and T of the vessel all affect the forces on the anchors.

Hatch covers

Schneekluth and Bertram [1998, p 95] provide a trend for hatch covers: They state that hatch cover price depends linearly on length and to the power 1.6 on width. As a result the cost of hatch covers is estimated at € 24 * L_{hold} * B_{hold}^1.6 of the vessel, again based on the same quotations that were used above.

Outfitting

Outfitting cost, being generally recognized as one of the most difficult and design-specific factors to calculate, is determined as a function of outfitting weight to the 2/3 power both by Watson [1998, p 478] and Hunt & Butman [1995]. Again based on a reference vessel, the cost of outfitting is estimated at € 40000 * $W^{2/3}$, with W, expressed in tons, subdivided in weight in the fore and aft part of the ship. The coefficient of 40000 is again arrived at by analysis of a quotation for a ship.

Miscellaneous equipment

Cost for miscellaneous non-ship size related equipment (wheelhouse, navigation masts etc.) may vary from case to case but is hardly dependent on ship size, apart from anchor winches. For the analysis made here, these items are grouped together with class cost, cost of required software etcetera and estimated at € 100.000,- In case the wheelhouse is raisable, another € 65.000 is added to this, although commercial prices show that this is strongly dependent on the raising height.

Risk margin

Since the price for which a ship owner buys a ship will include a risk margin for the yard, a 5% margin for the yard is included in the cost of the ship.

All cost elements discussed above are summarized in table 3 below.

Table 3 Overview of the elements of the building cost estimation method

Element		Value
General object cost		15% of labour cost of ship hull
Hull	labour	$45 \cdot 45.36\left(\frac{LBD}{1000}\right)^{-0.115} \cdot \frac{0.866}{\sqrt[3]{C_B}}$
	material	€ 950,- per ton
Propulsion & maneuvering	Drive train	€ N*1086 P^0.82 with N as the number of propellers and P as the installed power per propeller
	Bow steering	€ N*1086 P^0.82 with N as the number of propellers and P as the installed power per propeller
	Rudders + actuator	€ 50.000,- per propeller
Electrical system		500 €/kVA (incl. gensets)
Bilge & ballast systems		€ 450 per m of LOA
Cargo pumps & piping		145 €/m^3 of LBD
Accommodation		600 €/m^2
Mooring gear		13 €/m3 of LBT
Hatch covers		at € 24 * Lhold * $\text{Bhold}^{1.6}$
Outfitting		€40.000 * $W^{2/3}$, calculated separately for fore and aft ship
Miscellaneous	Various items	€100.000,-
	Raisable wheelhouse	€65.000,-
Risk margin		5%

4. METHOD VALIDATION

To validate the method that was presented in the previous section, the cost of a number of common ships, as calculated using the cost estimation method, are compared to previously discussed building cost as stated by VBD [2004], EICB [2011] and Schuttevaer [2011]. Results from the estimation method are as follows: The Gustav Koenigs class vessel costs 2.02 million Euros, the Johann Welker/Europa ship class costs 2.30 million Euro and the GMS costs 3.28 million Euros. The cost breakdown for these vessels is as shown below, in figure 1.

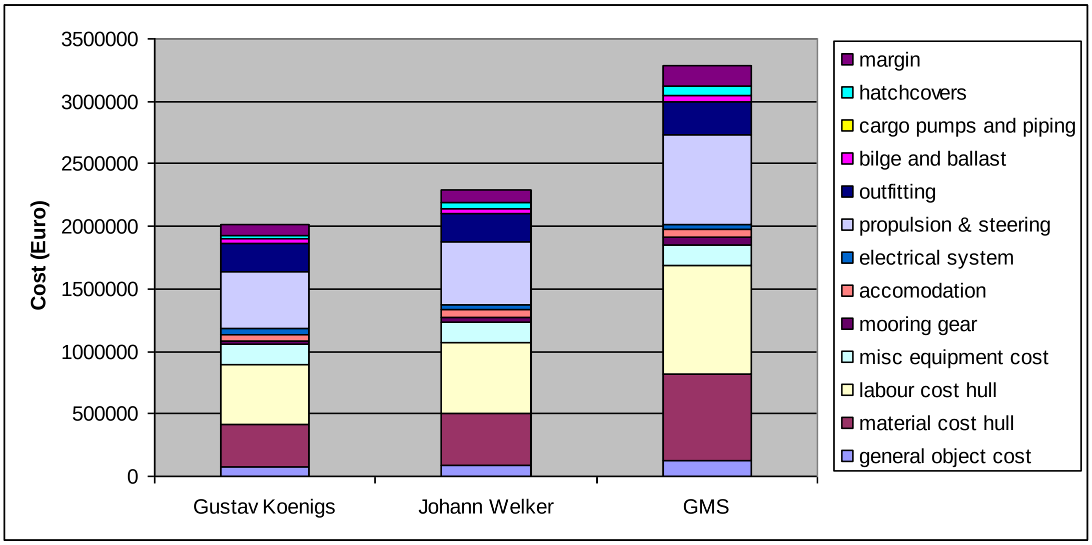

Fig. 1 Cost breakdown of three vessels

The values presented in figure 1 are slightly lower than the previously discussed values by VBD [2004] and EICB [2011]. For the GMS (i.e. a 110 m ship) the calculated cost almost exactly match those quoted by Schuttevaer [2011] and the prices of the hulls for the smaller ships are also in the range mentioned by that magazine for 2011. Differences may be explained by difference in specifications such as accommodation size, installed power, level of finishing and so on, but probably also by the effects of economic factors like inflation, wages, material prices and profit margins.

5. RULES OF THUMB

The method that was presented above yields acceptable results, but requires quite a significant amount of detailed knowledge about the technical specifications of the ship for which a cost estimate is required. In order to arrive at a more easy-to-use method to estimate the cost of an inland ship, rules of thumb are developed that only use length, beam and design draught as variables. To achieve this goal, the cost estimation method is applied to a large set of computer generated ship designs for inland dry bulk, container and tank ships with draughts between 1.5 and 4.5 meters, beams between 5 and 25 meters, lengths between 40 and 185 meters and L/B ratios between 4 and 20. For dry bulk and container vessels, longitudinally and transversely framed designs are explored, while for tank ships, only longitudinal framing is applied. This dataset is elaborately discussed in Hekkenberg [2013].

From this dataset two separate sets of rules of thumb are derived:

1) **Simple rules of thumb** in the form of 2^{nd} order polynomial trend lines for building cost as a function of LBT with different coefficients for various draughts. These trend lines are valid for ships with a length up to 135 m and L/B values between 6 and 12, i.e. lengths and L/B values that are common for existing European inland ships. Due to the limited scatter that occurs for ships that meet these boundary conditions, it is not necessary to model L, B and T_{design} as independent variables and the rule of thumb can be kept simple.

2) **Advanced rules of thumb** for each vessel type and framing system. In this case L, B and T_{design} are independent variables in a single formula that covers the entire investigated range of L/B values and lengths, i.e. L/B values between 4 and 20 and lengths up to 185 m.

5.1 Simple rules of thumb

Simple rules of thumb all have the form of equation 3:

$$C_{ship} = c_1 \cdot (LBT)^2 + c_2 \cdot LBT + c_3 \tag{3}$$

In table 4, the coefficients and R^2 values are given for dry bulk ships. The high R^2 values indicate that the trend line provides a good approximation of the original data.

Table 4: Building cost - coefficients for dry bulk ships

Transverse framing

T	C1	c2	c3	r2
1.5	-2.36E-02	1.39E+03	3.54E+05	0.984
2	-1.20E-03	9.67E+02	4.54E+05	0.994
2.5	1.50E-02	6.97E+02	5.56E+05	0.988
3	8.00E-04	6.41E+02	5.65E+05	0.993
3.5	-1.30E-03	5.82E+02	5.85E+05	0.993
4	3.50E-03	5.06E+02	6.78E+05	0.992
4.5	1.90E-03	4.81E+02	7.06E+05	0.992

Longitudinal framing

T	c1	c2	c3	R^2
1.5	6.14E-02	1.18E+03	4.91E+05	0.988
2	3.81E-02	8.79E+02	5.22E+05	0.991
2.5	3.24E-02	6.55E+02	6.14E+05	0.993
3	1.83E-02	5.83E+02	6.29E+05	0.993
3.5	2.46E-03	6.03E+02	5.62E+05	0.992
4	1.34E-04	5.67E+02	5.75E+05	0.993
4.5	-1.79E-03	5.38E+02	6.06E+05	0.993

For container ships, the rule of thumb has the same form as for dry bulk ships, but coefficients are different. This difference is caused by different demands on the stability of container ships and, therefore, on the higher depth at equal design draught. Coefficients for container ships are shown in table 5.

Table 5: Building cost - coefficients for container ships

Transverse framing

T (m)	c1	c2	c3	R^2
1.5	6.55E-01	1.29E+03	4.82E+05	0.986
2	2.36E-02	1.02E+03	4.67E+05	0.988
2.5	2.13E-02	7.65E+02	5.69E+05	0.991
3	1.47E-02	6.51E+02	6.12E+05	0.991
3.5	2.61E-03	6.35E+02	5.84E+05	0.991
4	4.80E-03	5.60E+02	6.57E+05	0.992
4.5	7.48E-03	4.92E+02	7.52E+05	0.992

Longitudinal framing

T (m)	c1	c2	c3	R^2
1.5	8.20E-02	1.18E+03	5.06E+05	0.987
2	4.49E-02	9.06E+02	5.08E+05	0.991
2.5	3.55E-02	6.69E+02	6.08E+05	0.992
3	2.30E-02	5.89E+02	6.23E+05	0.993
3.5	7.30E-03	5.92E+02	5.78E+05	0.992
4	3.72E-04	5.87E+02	5.49E+05	0.993
4.5	-1.06E-03	5.47E+02	5.96E+05	0.993

Finally, for tank ships, coefficients are presented in table 6. Tank ships are significantly more expensive than dry bulk or container ships due to their higher steel weight and the loading and unloading systems for the cargo.

Table 6: Building cost - coefficients for tank ships

T (m)	c1	c2	c3	R^2
1.5	-4.89E-03	1.41E+03	5.30E+05	0.996
2	-8.90E-03	1.12E+03	5.85E+05	0.996
2.5	3.60E-03	8.70E+02	7.52E+05	0.994
3	-4.05E-03	8.29E+02	7.77E+05	0.995
3.5	-8.20E-03	8.01E+02	8.12E+05	0.996
4	-8.96E-03	7.59E+02	8.91E+05	0.995
4.5	-7.51E-03	7.12E+02	9.54E+05	0.995

5.2 Advanced rules of thumb

In the previous section, simple rules of thumb in the form of 2nd order polynomials were presented. These polynomials, however, only cover a limited range of vessels. For the more ‘exotic’ vessels, these polynomials can no longer be used, since individual values of length, beam and design draught play a large role in the overall cost. Therefore, in order to also provide a building cost estimate for such ships, a more elaborate set of rules of thumb is developed, using an OLS regression analysis. Since especially the machinery and accommodation of inland ships vary strongly from ship to ship and are subject to owner preferences, the rules of thumb are split in two parts for each ship. This allows users to tune values more easily, depending on any additional information they might have. These parts are yard cost and non-yard cost. Yard cost covers the cost of erection of the hull and project management, while non-yard cost covers all other items on board that are typically supplied and installed by subcontractors. These rules of thumb, presented in table 7 to 9, cover the entire range of vessels in the previously discussed dataset. In the majority of case, values obtained using these rule of thumb differ less than 10% from the values belonging to the individual data points that were used for the regression, while differences hardly ever exceed 20%. A more detailed statistical analysis of the regression may be found in appendix E of Hekkenberg [2013].

Table 7: advanced rules of thumb for dry bulk ships

- Yard cost	
Transverse framing	$= 5.956 \cdot 10^4 + 771.7 \cdot LB - 136.7 \cdot (L^2 T)^{0.7} + 62.41 \cdot LBT$ $+ 1.926 \cdot 10^{-3} \cdot L^{3.5} B + 3.244 \cdot 10^3 \cdot \frac{L^{1.3} T^{0.7}}{B}$
Longitudinal framing	$= 1.632 \cdot 10^5 + 782.6 \cdot LB + 185.8 \cdot (L^2 T)^{0.7} - 11.06 \cdot LBT$ $+ 2.413 \cdot 10^{-3} \cdot L^{3.5} B - 438.5 \cdot \frac{L^{1.3} T^{0.7}}{B}$
- Non-yard cost	
	$= 6.075 \cdot 10^5 + 400.8 \cdot \frac{L^{1.5}}{B} + 49.05 \cdot LBT + 474.2 \cdot LB - 2.081 \cdot 10^7 \cdot \frac{1}{LT}$

Table 8: advanced rules of thumb for container ships

- Yard cost	
Transverse framing	$= 6.88 \cdot 10^4 + 920.8 \cdot LB - 91.32 \cdot (L^2 T)^{0.7} + 50.22 \cdot LBT$ $+ 2.668 \cdot 10^{-3} \cdot L^{3.5} B + 2651 \cdot \frac{L^{1.3} T^{0.7}}{B}$
Longitudinal framing	$= 1.646 \cdot 10^5 + 842.2 \cdot LB + 193.1 \cdot (L^2 T)^{0.7} - 27.14 \cdot LBT$ $+ 2.774 \cdot 10^{-3} \cdot L^{3.5} B - 509.3 \cdot \frac{L^{1.3} T^{0.7}}{B}$
- Non-yard cost	
	$= 6.075 \cdot 10^5 + 400.8 \cdot \frac{L^{1.5}}{B} + 49.05 \cdot LBT + 474.2 \cdot LB - 2.081 \cdot 10^7 \cdot \frac{1}{LT}$

Table 9: advanced rules of thumb for tank ships

- Yard cost	
	$= 1.514 \cdot 10^{6} + 1.437 \cdot 10^{2} \cdot LBT + 3.204 \cdot 10^{-3} \cdot L^{3.5} B - 2.829 \cdot 10^{7} \cdot \frac{1}{(LBT)^{0.5}}$
- Non-yard cost	
	$= 9.608 \cdot 10^{5} + 84.75 \cdot \frac{L^{1.5}}{B} + 244.4 \cdot LBT + 312.9 \cdot LB - 4.116 \cdot 10^{7} \cdot \frac{1}{LT}$

6. CONCLUSIONS AND RECOMMENDATIONS

In this paper, a method to estimate the building cost of inland ships was presented. Furthermore, this method was used to derive easier-to-use rules of thumb for the cost of inland ships for which only length, beam and design draught are known. The method has been validated for a number of ships with common main dimensions. There is however still significant room for improvement in the underlying data of the model and its validation. It is, therefore, recommended to continue to gather information on the building cost of inland ships and to use this information for further fine-tuning and validation of the method.

LITERATURE

Aalbers, A.: *Evaluation of ship design options*, Delft University of Technology, unpublished, unknown year

Coenen, J.M.G.: *Controlling Engineering-to-Order Processes in Shipbuilding. A Model-Based Approach*, ISBN 90-902-3079-5, 2008

Delft University of Technology: *Project MTP103 Machine Installatie A*, 2009

EICB: *Plan van Aanpak Klein Schip, Hoofdrapport*, 2011

Hekkenberg, R.G.: *Inland Ships for Efficient Transport Chains*, TU Delft Library, ISBN 978-94-6186-099-6, 2013

Hunt, E.C. and B.S. Butman: *Marine engineering Economics and cost analysis*, Cornell Maritime Press, ISBN 0-87033-458-1, 1995

Kerlen, H.: *Über den Einfluss der Völligkeit auf die Rumpfstahlkosten von Frachtschiffen*, Dissertation TH Aachen, 1981

OECD: http://stats.oecd.org/Index.aspx?DataSetCode=MEI_PRICES_PPI#, accessed March 2012

Schneekluth, H., and V. Bertram: Ship design for efficiency and economy, 2nd edition, Butterworth-Heinemann, ISBN 0750641339, 1998

Schuttevaer: *onafgebouwde binnenvaartcasco's blijven nog jaren in de hoek liggen*, edition August 27th, 2011

Stapersma, D.: *Prime movers in an AES power plant: number of units, size and cost, the case of an all electric hopper dredger fitted with diesel generators*, 2001

Stopford, M.: *Maritime Economics, 3rd edition,* Routledge, ISBN 0-415-27557-1, 2009

VBD: *Technische und Wirtschaftliche Konzepte für Flußangepaßte Binnenschiffe*, Auftrag 2317, Bericht 1701, 2004

Vries, C.J. de: *Goederenvervoer over water,* Van Gorcum & Comp. B.V. , ISBN 9023235495, 2000

Watson, D.G.M.: *Practical ship design*, Elsevier Science Ltd., ISBN 0080440541, 1998