Estimation of ship production man-hours

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The estimation of labor man-hours for ship production is considered an important item during the early stage of negotiation before signing the contract. With few information about the ship during the preliminary design stage, it is necessary to apply a good prediction method for estimating the ship production man-hours. In this paper, the previous works for estimating the shipyard labor man-hours, based on hull steel and outfit weights as shipyard output measure, are presented and their limitation is discussed. Add to that, the yardstick productivity measure for shipbuilding yards, man-hours per compensated gross tonnage, is presented. Based on this productivity measure, a method is proposed to predict the ship production man-hours and its effectiveness is examined. In addition, the influence of any improvements in ship production activities on the prediction approach is investigated.

يعتبر تقدير عدد ساعات العمالة لإنتاج السفينة جزء مهم أثناء المراحل الأولي من تصميم السفينة. باستخدام معلومات قليلة عن السفينة خلال مرحلة التصميم المبدئي للسفينة، من الضروري استخدام وسيلة تنبأ مناسبة لتقدير ساعات عمل بناء السفينة. في هذا البحث تم عرض الأعمال السابقة لتقدير ساعات العمل لإنتاج السفينة، والمبنية علي أساس وزن بدن السفينة ووزن تجهيزات السفينة كمقياس لإنتاجية الترسانة، وشرح القيود علي هذه الطرق. بالإضافة إلي هذا، تم شرح مقياس إنتاجية الترسانات المعياري، ساعات عمل إنتاج السفينة/الحمولة الكلية المعادلة. وعلي أساس مقياس إنتاجية الترسانات المعياري، تم اقتراح طريقة لتقدير ساعات عمل إنتاج السفينة وتم اختبار فاعلية هذه الطريقة. بالإضافة إلي ذلك، تم مناقشة تأثير التحديث التكنولوجي بالترسانة علي الطريقة المقترحة وإمكانية حساب تأثيره.

Keywords: Ship production man-hours, Hull steel weight, Productivity measure, Compensated gross tonnage CGT, Ship production activities

1. Introduction

In recent years, there is severe competition in the shipbuilding industry due to the increased shipbuilding capacity compared with demand. The shipbuilding yard has to deal with a highly variable product that makes bidding on contracts very difficult. The pricing for new shipbuilding could have a high risk especially with minimal profit margins and precious little time available. To reduce such risk in estimation, there should be a quick and accurate means to accomplish reasonable and reliable cost estimate method.

The estimation of labor man-hours necessary for ship production, as a part of shipbuilding cost, has usually evolved at two stages of detail. The early stage provides only a preliminary estimate before any details of ship design and production processes are considered. Such preliminary estimates is made usually using empirical equations based on the ship weight, size and other general design parameters [1-4]. A more detailed man-hours estimate starts after signing the contract, as the information of the project increases parallel with detail ship design, so as to make suitable planning and scheduling for shipbuilding process [5].

The previous approach for estimating the ship production man-hours suffers from two main disadvantages. The first one is that the shipyard must establish an equation for each ship type based on its past production data. The second is that these equations do not reflect the impact of any progress and development in the ship production process on the predicted man-hours. In this paper, a method is proposed to predict the ship production man-hours during the preliminary design stage. The productivity metric, man-hours per compensated gross tonnage, is used as a unified parameter for predicting the ship production man-hours. Using this productivity measure, the ship production man-hours can be predicted for any ship type even if the shipyard did not have any historical data in building such type of ship. The approach is examined for certain Egyptian shipyard and it has proved to be effective in the estimation process. In addition, the impact of development in the shipyard on the production man-hours is explained through study of the sharing percent of different shipbuilding activities with respect to the total ship production man-hours.

2. Labor man-hours

The labor man-hours necessary for producing a ship comprises all labours' activities man-hours employed in building that ship. These activities include the different phases starting from the contract signing time until delivery. The labours employed in shipbuilding process can be divided into [7]:

- Direct and indirect shipbuilding labours,
- Direct and indirect shipbuilding subcontractors,

The definition of direct and indirect labors and subcontractors varies with countries and with shipyards within country, so some adjustments to the supplied figures may be necessary. Whatever the subdivisions used the total number of employees involved in shipbuilding is given by the sum of the direct workers and indirect workers including the relevant subcontractors.

3. Previous work

Empirical equations that can be used to estimate the ship production man-hours in the preliminary design stage depend generally on two types of data; the basic information available about the ship and the condition of the shipbuilding yard. Traditional information about the ship during the preliminary design stage is the ship size that can be represented by the hull steel and outfit weights. On the other hand, the data about shipyard condition represents its ability for building such ships that can be determined from past shipyard production data. Generally, the ship production man-hour was derived mainly for shipbuilding cost estimation and usually was divided into hull steel, outfit and propulsion machinery installation man-hours. Carreyette [1] and Benford [2] proposed different empirical equations based on the above principle. For example, Carreyette [1] proposed an equation for estimating steel work man-hours, for merchant ships, as follows:

$$MH_S = C\frac{W_S^{2/3}L^{1/3}}{C_b}, \qquad (1)$$

where,

MH_S is the man-hours for steel work,
C is the coefficients depend on the shipyard condition ≈ 227,
W_S is the net steel weight in tones,
L is the length between perpendiculars (LBP), meters, and
C_b is the block coefficient of ship.

Carreyette [1] did not give any equation for either the outfit or the propulsion machinery labor man-hours. It can be seen that Carreyette's equation may describe the effect of ship size on the hull steel work man-hours without any consideration for the ship complexity. As a matter of fact, the ship production man-hour rate depends not only on ship size, represented by steel weight, but also on ship type which reflects the complexity of construction which is not clearly defined by the previous researchers. The steel weight does not reflect the effect of complex work content because there is a wide range of vessels varying in both size and complexity of construction produced by shipyards. Consequently, an equation must be derived for each ship type for a shipyard as shown in fig. 1 [3]. These relationships, between the man-hours per steel or outfit weight and hull steel weight, are established based on past production data for the specific shipbuilding yard. Subsequently, the shipbuilding yard will face a problem in predicting the necessary man-hour to make bidding for any new ship type without past experience. In addition, since the coefficient of the shipyard condition is included in the previous empirical equation based on past applied methods and performance of the shipyard, therefore the affect of any improvement that may occur in the production process on the man-hours rate will not appear. Thus, the previous approach does not account for the man-hours changes resulting from newly

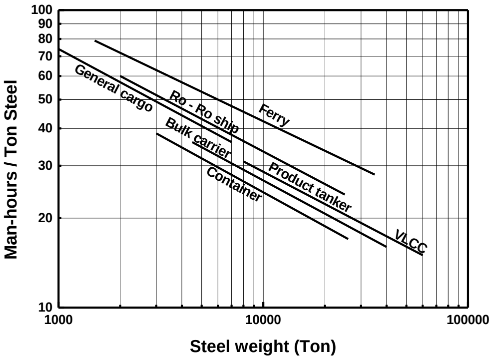

Fig. 1. Steel weight productivity measure for certain shipyard [4].

adopted and developed shipbuilding technologies.

Chou and Chang [4] proposed another empirical equations to estimate the ship production man-hours for five different ship types for China shipbuilding cooperation. They selected the independent variables that affect the man-hours for shipbuilding and collecting relevant data for them. Afterwards, they construct multiple regression model and the parameters are estimated. The limitation in their approach is the same as stated previously.

4. Man-hour per compensated gross tonnage

The Compensated Gross Tonnage, CGT, is considered as a worldwide yardstick for shipyard output in commercial shipbuilding replacing the traditional measures, man-hours/tonne steel weight, and this concept have been developed from 1960s [6-13]. Experts from the Association of West European Shipbuilders (AWES) and the Shipbuilding Association of Japan (SAJ) formulated a joint proposal for the CGT system. The proposed factors of compensated gross tonnage were published and adopted by the Organization of Economic Co-operation and Development (OECD) in 1984 as a parameter on which to base national shipbuilding output comparisons. The compensation factors for the gross tonnage, C_{CGT}, have been developed for all types of commercial ships, as given in table 1, through negotiation between major shipbuilding countries over many years. This coefficient reflects the amount of work necessary to produce that particular type and size of ship. The Compensated Gross Tonnage, *CGT*, can be determined for any ship by multiplying its gross tonnage, *GT*, by the proper compensation factor, C_{CGT}, corresponding to its deadweight or gross tonnage as follows:

$$CGT = GT \times C_{CGT}. \quad (2)$$

The Compensated Gross Tonnage *CGT* has been used as a productivity metric in the form of Man-Hours per compensated gross tonnage, MH/*CGT*. This measure means that for different ship types and sizes constructed in the same shipyard, the man hours per *CGT* would be the same. The effectiveness of the *CGT* approach can be drawn from table 2 that presents a comparison between man-hours/ton of steel and man-hours/*CGT* [10]. It is clear from table 2 that there is a significant improvement by using the *CGT* approach although there is a slight difference between different ship types compared with the steel weight measure. Thus, the shipbuilding productivity measure, based on the compensated cross tonnage parameter, can be used to estimate the shipbuilding man-hours for any ship type and size even if there is no past production data for all ship types.

5. Proposed method

Instead of using steel weight and/or outfit weight as shipyard output measure to calculate the ship production man-hours, the compensated gross tonnage can be used as a unified measure for shipyard output. The evaluation of the compensated gross tonnage is described in the previous section. However, the compensation factor for each ship, given in table 2, was intended mainly to measure the relative output of large groups of shipyards and it should be modified slightly for application to small groups or individual shipyards. These factors cover bands of sizes, using step function, within the different ship types. The step function representation can cause anomalies when ships have only slightly different deadweights and could have factors with significantly different values applied. Thus, it is proposed that the compensation factor can be represented for each range by

Table 1
Gross tonnage compensation factors (C_{CGT})

Ship type	DWT < 4000	4000 < DWT < 10000	10000 < DWT < 20000	20000 < DWT < 30000	10000 < DWT < 30000	30000 < DWT < 50000	50000 < DWT <80000	80000 < DWT < 160000	160000 < DWT < 250000	250000 < DWT
Crude oil tankers (single hull) [DWT]	1.7	1.15	-	-	0.75	0.6	0.5	0.4	0.3	0.25
Crude oil tankers (double hull) [DWT]	1.85	1.3	-	-	0.85	0.7	0.55	0.45	0.35	0.3
product and chemical carriers [DWT]	2.3	1.6	-	-	1.05	0.8	0.6	0.55		
Bulk carriers [DWT]	1.6	1.1	-	-	0.7	0.6	0.5	0.4	0.3	
Combined carriers [DWT]	1.6	1.1	-	-	0.9	0.75	0.6	0.5	0.4	
General cargo ships [DWT]	1.85	1.35	1	0.85	-	0.75	0.6	0.5	0.4	
Container ship [DWT]	1.85	1.2	0.9	0.8	-	0.75	0.65			
Ro-Ro ships [DWT]	1.5	1.05	0.8	0.7	-	0.65				
Car carriers [DWT]	1.1	0.75	0.65	0.55	-	0.45				
LPG carriers [DWT]	2.05	1.6	1.15	0.9	-	0.8	0.7			
LNG carries [DWT]	2.05	1.6	1.25	1.15	-	1	0.75			
Reefers [DWT]	2.05	1.5	1.25							
	GT < 1000	1000 < *GT* < 3000	3000< *GT* <10000	10000 < *GT* < 20000	20000 < *GT* < 40000	40000 < *GT* < 60000	60000 < *GT*			
Ferries [*GT*]	3	2.25	1.65	1.15	0.9					
Passenger ship [*GT*]	6	4	3	2	1.6	1.4	1.25			
Fishing vessels [*GT*]	4	3	2							
Other non-cargo vessels [*GT*]	5	3.2	2	1.5						

two lines connecting the mid-point of that range and the average factor value of the previous and subsequent ranges in conjunction with that range. Fig. 2 shows the line representation of the compensation factors for general cargo ships as an example.

5.1. Validation proposed method

The proposed method is examined using collected data for certain Egyptian shipyard which can be considered as a small shipyard that can build general cargo ships, small bulk carriers, etc and competes within the country domain. The ship production man-hours for three different ship types, bulk carrier (38391 DWT), RO/RO ship (3000 DWT), mini bulk carrier (6500 DWT) and multipurpose cargo ship (5800 DWT), arranged sequentially based on production dates, are collected with their compensated gross tonnage during period of same level of shipbuilding technology. The

Table 2
Comparison between productivity measures [10]

Ship type	MH/TON OF ST. WT	MH/*CGT*
VLCC	16	32
SUEZMAX	19	22
Product carrier	27	20
Chemical carrier	46	36
Bulk carrier	19	20
Container ship (4,400)	19	22
Container ship (1,880)	28	22
Reefer	43	34
Ferry	51	39
General cargo	56	29
Ocean tug	105	31

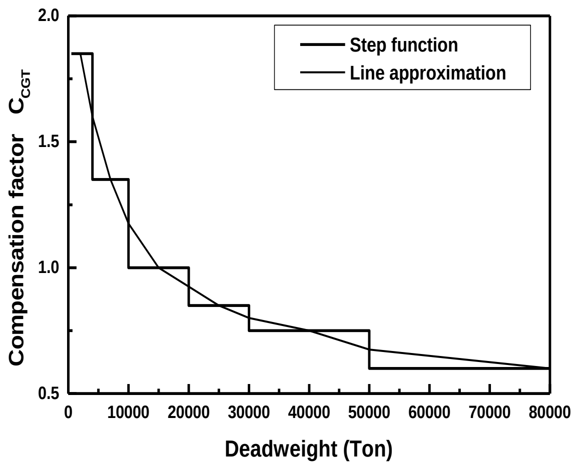

Fig. 2. Compensation factor step function representation and line approximation for general cargo ships.

magnitudes of the calculated MH/*CGT* for each of the previous ships are shown in tables 3 and 4. The average MH/*CGT* for the bulk carrier and the Ro-Ro ship, equals 101 MH/*CGT* as given in table 3, is used as a basic shipyard productivity value. The MH/*CGT* for the other ships are used to examine the accuracy of the proposed method as they were built later. It should be noted that the MH/*CGT* is used here to examine the accuracy of the approach, since it reflects the accuracy in predicting the ship production man-hours. Table 4 shows the error of predicted MH/*CGT* for the mini-bulk carrier and multi-purposes cargo ship. It can be seen from tables 3 and 4 that the magnitude of the MH/*CGT* for the two different sizes of bulk carriers is almost the same which indicates the effectiveness of the MH/*CGT* measure in predicting the ship production man-hours. In addition, the maximum error in predicting the MH/*CGT* for mini bulk carrier and cargo ship is 8% which can be considered satisfactory during the early stage of ship design. Thus, the proposed method can be used to estimate the ship production man-hours with reasonable accuracy.

5.2. Productivity improvement effect

The shipyard productivity depends on different parameters such as design and production techniques and tools, management, work organization, work practice, and worker skill and motivation. There is no direct relationship between these parameters and the shipyard productivity.

Table 3
Average shipyard productivity measure using MH/*CGT* for bulk carrier and Ro-Ro ship

+Ship type	MH/*CGT*	Average
Bulk carrier (38391 DWT)	96	101
Ro-Ro ship (3000 DWT)	105	

Table 4
Error of predicted MH/*CGT* based on average productivity measure (101 MH/*CGT*)

Ship type	MH/*CGT*	Error %
Mini bulk carrier (6500 DWT)	94	-7%
Multipurpose cargo ship (5800 DWT)	109	8%

However, another parameter, based on the previous variables together, is called the best practice rate is used to evaluate their effect on shipyard productivity [12-15]. The best practice rate is mainly used for the purpose of comparison between different shipyards in the world.

To evaluate the effect of any production activity improvement upon the productivity measure, the sharing percent of the different production activities with respect to the total ship production man-hours can be used for this purpose. The sharing percent of the different production activities, for the same Egyptian shipyard, was collected over about 25 years. The activities are divided into ten activities namely: prefabrication, forming and cutting, subassembly and assembly, erection, steel outfit, mechanical installation, pipe work, electrical work, painting, wood wok and the remainder activities are stated here as others. The average sharing percent of these activities with respect to the total ship production man-hours is shown in fig. 3. The deviation of the sharing percent value for each activity from its average is given in table 5. It is clear from table 5 that the maximum absolute error between each activity and its average does not exceed 14%. Thus, the average sharing percent of shipyard activities can be used to evaluate the effect of activity improvement on the total shipbuilding man-hours.
By evaluating the difference between the sharing percent for previous and current situations of any activity due to any improvement, the effect of such development on the total shipyard productivity can be calculated from the direct relationship such as:

Table 5
Absolute error between ship production activities and their average during 25 years.

Shipbuilding activity	Absolute error percent from average value
Prefabrication, cutting and forming	13.3 %
Subassembly and assembly	13.4 %
Erection	11.1 %
Steel outfit	6.3 %
Mechanical installation	10.5 %
Pipe work	11.7 %
Painting	10.1 %
Electrical work	5.2 %
Woodwork	5.2 %

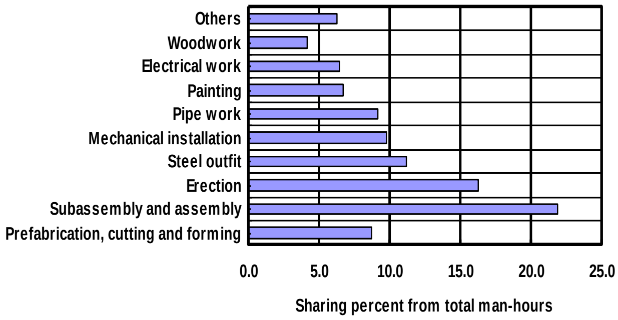

Fig. 3. Average sharing percent of the different activities with respect to the total shipbuilding man-hours.

$$(\frac{MH}{CGT})_{New} = (\frac{MH}{CGT})_{Old} \times (1 - \sum D) \ , \qquad (3)$$

where,
$(MH/CGT)_{New}$ is the new value of productivity measure due to applying any development,
$(MH/CGT)_{Old}$ is the old value of productivity measure before applying that development, and
D is the difference between sharing percent for the previous and the current situations for any activity due to any development.

Using eq. (3), the influence of any development on the shipyard productivity can be estimated. Subsequently, the impact of any development on the ship production man-hours can be evaluated based on evaluation of the difference between sharing percent of previous and new situations of activity.

6. Conclusions

From the present study, the following conclusions can be drawn:
1. A method for estimating the ship production man-hours, during the preliminary design stage, is proposed based on the unified shipbuilding productivity metric MH/*CGT*.
2. Although the proposed MH/*CGT* parameter have been evaluated using past data for certain bulk carrier and Ro/Ro ships, it can be used for estimating the shipbuilding man-hours for other types of ship even if the shipyard has not any historical data for those ship type.

3. Examination of the proposed method shows that the accuracy of prediction is considered satisfactory.
4. The influence of any improvement in ship production activity on the MH/*CGT* can be considered by evaluating the difference of the sharing percent of that activity between the previous and current situations.
5. The proposed method for estimating the ship production man-hours can be extended to predict the construction budget and cost of shipbuilding.

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