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Modeling and Analysis of Labor Cost Estimation for Shipbuilding: The Case of China Shipbuilding Corporation

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Taiwan's shipbuilding industry confronts serious competition in the international market. Shipyards must acquire market information and give accurate quotations in order to obtain shipbuilding orders. The estimation of labor cost for shipbuilding is very important during the quotation stage. It is the purpose of this paper therefore to investigate the prevailing factors for labor cost and to construct models of man-hour estimation for building new ships for the China Shipbuilding Corporation. According to an empirical analysis, the effects of factors such as hull steel weight, main engine output, compensated gross tonnage, and technological progress on man-hours for construction have been confirmed. Furthermore, the comparison between the actual and estimated values for man-hours of construction shows that the derived models are highly accurate.

Introduction

According to the 1998 statistics of The International Monetary Fund, Taiwan is the 15th largest trading nation in the world. The total amount of import and export trade is 210 billion US dollars annually, for which 90% of the trade depends on sea transportation. Taiwan is an island located at the transportation hub of the Pacific Ocean. Thousands of ships enter and leave Keelung and Kaohsiung harbors annually. Therefore, the shipbuilding industry plays an important role in assisting national defense construction, promoting shipping development, and boosting related industrial development. The shipbuilding industry has experienced very large fluctuations, and is considered a difficult and high-risk industry (Stott 1995). At present, Taiwan's shipbuilding industry confronts serious competition in the international market, especially from Japan, South Korea, and mainland China. Shipyards must possess market information and give accurate quotations in order to obtain shipbuilding orders. The estimation of construction costs is very important during the quotation stage. The cost of shipbuilding includes direct material cost, direct labor cost, direct expense, and indirect expense. The direct material share of the total shipbuilding cost is 55% to 60%. However, most of the direct materials are imported from foreign countries and fluctuation in foreign exchange rates is an uncontrollable factor. On the other hand, direct labor cost and indirect expenses, which can be estimated from direct labor cost, account for 30% to 35% of the total shipbuilding cost. Therefore, direct labor cost plays a significant role in the total cost of shipbuilding.

Previously, labor cost estimation for building new ships at China Shipbuilding was simply calculated as a function of hull steel weight. However, there might be an enormous deviation between the actual labor cost and the estimated labor cost. The most striking instance was the container vessel No. 101 built for a German shipowner where the actual labor cost was about twice as much as the estimated labor cost, thus causing a great financial loss in its construction. The purpose of this study is to investigate the prevailing factors for labor cost by empirical analysis and to construct labor cost estimation models for shipbuilding. Generally, labor cost equals man-hours multiplied by wage rate, so man-hours will be used as a dependent variable instead of labor cost. Furthermore, application of these models will provide more accurate labor cost estimation and allow decisions to be made more rapidly, thus enhancing competitiveness and profitability.

Determinants for labor cost

With respect to the factors affecting labor cost for shipbuilding, most research emphasizes the important role of design character-

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istics. Johnson & Rumble (1964) proposed that factors affecting labor cost for building new ships include hull steel weight, outfitting weight, and main engine output. Benford (1967) also regarded hull steel weight and outfitting weight as important factors. Summers (1973) suggested that factors affecting labor cost for building new ships are any criteria at all denoting size.

Besides the aforementioned factors, there are a few other design characteristics in outline specification which can also be adopted to estimate labor cost for shipbuilding during the quotation stage. Deadweight (tons), which represents the ship's loading capacity, is one of the important design characteristics. The greater the deadweight, the more the labor cost needed for construction. Compensated gross tonnage (CGT) was recommended by the Association of West European Shipbuilders (AWES) and the Shipbuilders' Association of Japan (SAJ) in 1984 as a unit of measurement acting as a common yardstick to reflect the relative output produced by shipbuilding activity in large aggregates. Compensated gross tonnage (CGT) equals gross tonnage multiplied by CGT coefficient, and the relevant CGT coefficients for ships used in this study are presented in Table 1. The bigger the compensated gross tonnage, the more the labor cost needed for construction.

The generator provides electric power while the boiler provides hot water and steam for the whole ship. The bigger the capacity (kW) of the generator or the greater the evaporation capacity (ton/hr), the more the labor cost needed for construction.

Superstructure is the space for crew accommodation and navigation control. Since there is a lack of data for the superstructure space in the outline specification during the quotation stage, ship's complement is used instead of superstructure space. With progress in technology, the degree of automation in ship control has become much more advanced. The higher the degree of automation in ship control, the more complex the construction is and the more the labor cost needed for construction. The degree of automation is classified by whether the ship applies the automatic control system certified for unattended engine room (ACCU) as specified by the American Bureau of Shipping (ABS) or its equivalent. The number of TEUs (twenty-foot equivalent units) measures the loading capacity of a container vessel. The more the number TEUs, the more the labor cost needed for construction.

High variety and low volume are two characteristics of the shipbuilding industry. Labor cost for ship construction will show a learning effect; therefore, it is assumed that the labor cost for construction of a follow-on ship will decrease due to technology accumulation which can be measured by shipbuilding sequence.

As for outfitting weight, it can be expressed by subdivision such as main engine output, generator capacity, and boiler evaporation capacity, and therefore will not be considered in this study.

Model construction

Forecasting is used to calculate and predict future events or conditions. Its purpose is to offer the best available basis for the management to predict the future and understand the implications for alternative courses of action (Milne 1975). Chambers et al (1971) proposed that there are three types of forecasting methods, namely, qualitative techniques, time series analysis and projection, and causal models. Qualitative techniques use qualitative data (expert opinion, for example) and information about special events, and may or may not take the past into consideration. On the other hand, time series analysis and projection focuses entirely on pattern change, and thus relies entirely on historical data. Causal models use highly refined and specific information about relations between system elements, and are powerful enough to take special events formally into account. As with time series analysis and projection techniques, the past is important to causal models. Techniques vary in their costs as well as in their scope and accuracy. Management must determine the level of inaccuracy which can be tolerated and trade off cost against the value of accuracy in choosing a technique.

Most of the conventional methods for labor cost estimation for building new ships are time series, e.g., finding shipbuilding cost savings from a learning curve and developing a comparison formula for cost and quantity (Couch 1963, Sverdrup 1985), or deriving experience formula for shipbuilding by the trial-and-error method (Barton & Cole 1994, Benford 1967). Johnson & Rumble (1964) presented the comparison graph of displacement and cost for tankers and dry cargo ships based on a parametric analysis of weight and cost data of existing ships. Landsburg et al (1988) showed graphically the variations in cost and selling prices for 90 000 dwt tankers built in Japan. Summers (1973) noted that the processes by which labor cost is estimated are indeed numerous, including operational analysis, craft analysis, the use of cost returns, unit labor rates, and the empirical formula method. As to the type of ship investigated, most studies of labor cost estimation for shipbuilding focus solely on tankers and general cargo vessels (Benford 1967, Johnson & Rumble 1964, Landsburg et al 1988).

Since labor cost for shipbuilding may be affected by the factors

Table 1 CGT coefficient list

<table>
<tr><th></th><th colspan="9">Deadweight</th></tr>
<tr><th>Ship Type</th><th>Above 100 GT to 4000</th><th>4000 to 10 000</th><th>10 000 to 20 000</th><th>20 000 to 30 000</th><th>30 000 to 50 000</th><th>50 000 to 80 000</th><th>80 000 to 160 000</th><th>160 000 to 250 000</th><th>Above 250 000</th></tr>
<tr><td>Oil tanker</td><td>1.7</td><td>1.15</td><td colspan="2">0.75</td><td>0.60</td><td>0.50</td><td>0.40</td><td>0.30</td><td>0.25</td></tr>
<tr><td>Bulk carrier</td><td>1.5</td><td>1.10</td><td colspan="2">0.70</td><td>0.60</td><td>0.50</td><td>0.40</td><td colspan="2">0.30</td></tr>
<tr><td>Multipurpose cargo ship</td><td>1.85</td><td>1.35</td><td>1.00</td><td>0.85</td><td>0.70</td><td>0.55</td><td>0.45</td><td colspan="2">0.35</td></tr>
<tr><td>Container vessel</td><td>1.85</td><td>1.20</td><td>0.90</td><td>0.80</td><td>0.75</td><td>0.65</td><td>0.45</td><td colspan="2">0.35</td></tr>
<tr><td>Customs patrol vessel</td><td>5.00</td><td>3.20</td><td>2.00</td><td>1.50</td><td colspan="5">1.50</td></tr>
</table>

NOTE: CGT coefficient was recommended by the Association of West European Shipbuilders (AWES) and the Shipbuilders' Association of Japan (SAJ) in 1984.

as mentioned above, there is a causal relationship between them, and hence multiple regression can be used to construct a labor cost estimation model. Furthermore, since labor cost ($) equals man-hours (man-days) multiplied by wage rate ($/man-day), man-hours will be used as a dependent variable instead of labor cost.

The model is constructed as follows. First, the independent variables that affect man-hours for shipbuilding are selected. Then, the relevant data for the dependent and independent variables are collected. Finally, the multiple regression model is constructed and the parameters are estimated. The regression equation is constructed for estimating the quantitative relations between man-hours and other independent variables. On the other hand, the researcher can specify one or more particular variables to be included in the model. This decision can be made based on theoretical or practical considerations (Younger 1983).

The Ordinary Least Squares (OLS) approach is used in the regression analysis, and the software STATGRAPHICS version 5 is adopted. If the model passes the test and meets the practical considerations, then it is adopted. A flow chart for the model construction is presented in Fig. 1 and the regression model is as follows.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + E \quad (1)$$

where

Y = man-hours for building new ship (man-day)
X_1 = deadweight (tons)
X_2 = compensated mass tonnage (tons)
X_3 = hull steel weight (tons)
X_4 = main engine output (PS)
X_5 = generator capacity (kW)
X_6 = boiler evaporation capacity (ton/hr)
X_7 = complement (No.)

$$X_8 = \text{automation} = \begin{cases} 1, & \text{if ACCU or equivalent is applied} \\ 0, & \text{otherwise} \end{cases}$$

X_9 = technological progress (building sequence)
X_{10} = number of containers (TEU)
E = error team

The data for this study came from the official documents of the China Shipbuilding Corporation in Taiwan. The documents include:

1. Final construction reports for each ship: for variables Y, X_1, X_2, X_3, X_4, X_5, X_7, and X_9.
2. Document for ship delivery: for variables X_6, X_8, and X_{10}.

Owing to the high variety and low volume characteristics of the shipbuilding industry, the observation data for each type of ship are quite different. From 1980 to 1996, there are 16 sets for the bulk carrier, 14 sets for the oil tanker, 15 sets for the container vessel, 7 sets for the multipurpose cargo ship, and 7 sets for the customs patrol ship. In order to carry out posterior forecasting and to compare between different estimation models before and after modification, the data are to be separated into two parts. For instance, the 16 sets of ship (N1179-N1381) are used to select the model for the bulk carrier and the latest one delivered (N1520) is used to evaluate its accuracy for posterior forecasting.

Regarding the oil tanker, the 13 sets of ship (N023-N1321) are used to select the model and the latest one delivered (N1342) is used to evaluate its accuracy for posterior forecasting. The regression model is constructed in a similar way for the container vessel, the multipurpose cargo vessel and the customs patrol ship.

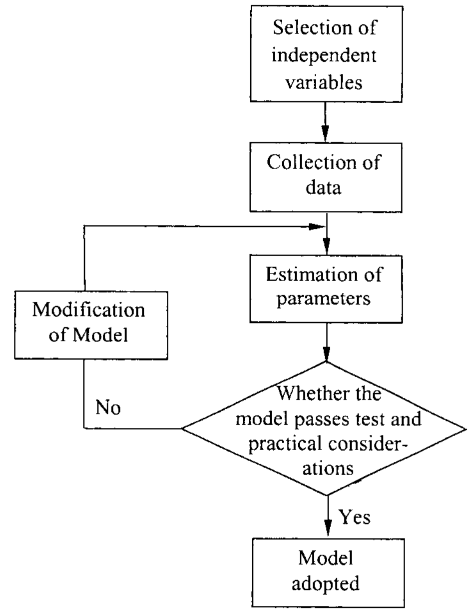

Fig. 1 Flow-chart for model construction

Empirical results and analysis

Equation (1) was estimated by OLS, and STATGRAPHICS version 5 was used. The results of the regressions are presented in Table 2.

From the results presented above, the values of R^2 for bulk carrier, oil tanker, and multipurpose cargo ship indicate that the regression line fits the observation quite well. The forecasting accuracy of the model is good.

The main factors affecting man-hours for building the bulk carrier include compensated gross tonnage, hull steel weight, and technological progress. The main factors affecting man-hours for building the oil tanker include hull steel weight, main engine output, and technological progress. The main factors affecting man-hours for building the multipurpose cargo ship include compensated gross tonnage and technological progress.

Although the values of R^2 also indicate that the sample regression lines for the container vessel and the customs patrol ship fit the data well, the factor of technological progress is not included in the models. This causes a problem since the container vessel is highly technological intensive and the man-hours for building the container vessel will decrease due to technology accumulation. Therefore, it is appropriate to take technological progress into consideration. The results of the modified model are presented in Table 3. From Table 3, it is worth noting that the man-hours for building all ships are influenced negatively by the degree of technological progress.

Furthermore, other independent variables that are important for estimating the man-hours for building new ships are compensated gross tonnage (X_2), hull steel weight (X_3), main engine output (X_4), and technological progress (X_9). The independent variable, hull

Table 2 Man-hour estimation model for shipbuilding

Item	Type	Estimation Parameter for Model	R^2	F*
1.	Bulk carrier	$Y = 25247.663 + 1.607X_2 + 2.413X_3 - 1526.17X_9$	0.9476	153.782 (3,12)**
2.	Oil tanker	$Y = 89398.875 + 4.469X_3 + 2.276X_4 - 4874.081X_9$	0.9858	208.298 (3,9)**
3.	Container vessel	$Y = 93730.876 - 5.3948X_3 + 5.6022X_4 - 2255.1962X_7$	0.9827	56.857 (3,11)**
4.	Multipurpose cargo ship	$Y = 69408.091 + 2.423X_2 - 3984.537X_9$	0.8978	17.585 (2,4)**
5.	Customs patrol vessel	$Y = 3391.321 + 36.126X_3 + 0.717X_4$	0.9825	112.926 (2,4)**

*All are significant at $\alpha = 0.05$.
**Values in parentheses are degrees of freedom.

Table 3 Modified man-hour estimation model for shipbuilding

Item	Type	Estimation Parameter for Model	R^2	F*
1.	Bulk carrier	$Y = 25247.663 + 1.607X_2 + 2.413X_3 - 1526.17X_9$	0.9476	153.782 (3,12)**
2.	Oil tanker	$Y = 89398.875 + 4.469X_3 + 2.276X_4 - 4874.081X_9$	0.9858	208.298 (3,9)**
3.	Container vessel	$Y = 52188.529 + 3.551X_2 - 2845.5872X_9$	0.9223	77.229 (2,12)**
4.	Multipurpose cargo ship	$Y = 69408.091 + 2.423X_2 - 3984.537X_9$	0.8978	17.585 (2,4)**
5.	Customs patrol vessel	$Y = 4808.193 + 31.492X_3 + 1.348X_4 - 802.343X_9$	0.9908	108.522 (3,3)**

*All are significant at $\alpha = 0.05$.
**Values in parentheses are degrees of freedom.

steel weight, is included in the model of three types of ship, namely, the bulk carrier, oil tanker, and customs patrol ship, while main engine output is included in the model of two types of ship—the oil tanker and customs patrol ship. These agreed with the results obtained by Benford (1967), Johnson & Rumble (1964), and Summers (1973). Technological progress is an important independent variable in the model of all ships. The China Shipbuilding Corporation has a long history and has expanded its shipyard capacity a few times. Its facility has been renewed and its shipbuilding method has been improved. The negative value of the parameter for technological progress agrees with expectations. The relationship between man-hours and compensated gross tonnage is positive and significant at a level of 5% in the models for the bulk carrier, container vessel and multipurpose cargo vessel. The positive value of the parameter shows that the bigger the compensated gross tonnage, the more the man-hours needed for construction. It matches the purpose of compensated gross tonnage recommended by the Association of West European Shipbuilders and the Shipbuilders' Association of Japan.

Finally, the regression models in Table 3 are used to estimate the latest ship built to test their practicality. Validation tests are performed on five ships built outside the regression model data range. Table 4 shows the data for determinants (including deadweight, CGT, hull steel weight, main engine output, generator capacity, boiler evaporation capacity, complement, automation, technological progress/delivery year, number of containers), estimated value and actual value of man-hours for building a new ship, and the error between those two values. Table 4 also shows that there is only a slight difference between the estimated and actual value for building a new ship, indicating the potential usefulness of the models.

Conclusion

This research has identified the important factors affecting man-hours and has formulated models used to estimate man-hour cost for building new ships for the China Shipbuilding Corporation Keelung Shipyard. The comparison between the actual and estimated value for man-hours of construction shows that the model has high accuracy. The result of the estimated value of man-hours for building a new ship multiplied by wage rate will be the estimated labor cost for construction during the quotation stage. Owing to the effectiveness of the application, China Shipbuilding Corporation Keelung Shipyard has assisted Kaohsiung Shipyard in building the estimation model for man-hours for construction. With regard to the maintenance of the model, it is necessary to update the data for newly built ships and to use the analysis method mentioned above to keep it practical.

There are close relationships between man-hours for new ship construction and design characteristics for the hull and outfitting parts. The effects of factors such as hull steel weight, main engine output, compensated gross tonnage, and technological progress on man-hours for construction have been confirmed. However, the effects vary depending on the type of ship.

Table 4 Data and results of regression model tests

Type	Determinant X_i: X_1 Deadweight (tons)	X_2 CGT (tons)	X_3 Hull Steel Weight (tons)	X_4 Main Engine Output (PS)	X_5 Generator Capacity (kW)	X_6 Boiler Evaporation (tons/hr)	X_7 Complement (no.)	X_8 Automation *1	X_9 Technical Progress (Building Sequence /Delivery Year)	X_{10} Number of Containers (TEU)	(A) Estimated Value (man-days)	(B) Actual Value (man-days)	(C) Error (%) *2
Bulk carrier N1520	149 000	30 838	18 687	16 900	1520	1.5	32	1	17/1996	0	93 952	93 378	3.86
Oil tanker N1342	103 000	23 957	13 235	16 690	3000	55	40	0	14/1993	0	119 526	122 279	2.25
Container vessel N1516	20 000	15 300	5370	13 500	2520	2.0	34	1	16/1996	1100	60 989	57 305	6.42
Multipurpose cargo ship N1272	22 500	12 413	5300	9300	1200	1.6	31	0	8/1988	782	67 608	63 438	6.57
Customs patrol ship N1510	1975	9755	648	13 184	1150	0	82	0	8/1996	0	36 568	34 373	6.38

*1: $X_8 = 1$, if automation level for ship is ACCU or equivalent.
$X_8 = 0$, otherwise.
*2: (C) = | 1-(A)/(B) |

According to the empirical analysis presented above, the independent variable, hull steel weight, is included in the model of three types of ship—bulk carrier, oil tanker, and customs patrol ship. Another important independent variable, main engine output, is included in the model of two types of ship—the oil tanker and customs patrol ship. These agreed with the results obtained by Benford (1967), Johnson & Rumble (1964), and Summers (1973). Technological progress is an important independent variable in the model of all ships. The compensated gross tonnage is to provide a common yardstick to compare the relative output produced by shipbuilding activity in large aggregates. This research investigated compensated gross tonnage as a factor affecting man-hours for construction and showed that it plays an important role in man-hour estimation.

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