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COST ESTIMATING FOR SHIPS BASED ON STATISTIC METHODS

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Abstract:
The paper proposes to present an approach that estimate the cost of a ship (merchant or warship) according to the actual international practices in this domain. There are presented basis of detailed estimates costs such as structural costs (structural material, structural labour), outfit costs (outfit material merchant ships, outfit material warships, outfit labour costs), machinery costs (machinery material costs - merchant ships, machinery material costs – warships, machinery labor costs).

Key words: structural costs, outfit costs, machinery costs.

1. Introduction

The cost of a ship is the sum needed to pay for all the materials and labor involved in its construction plus the overhead costs incurred. Costs can be divided into two categories - estimated and actual. The estimated cost is that calculated when the shipyard is tendering; the actual cost is that ascertained to have been incurred at the end of the contract. The price is the sum of money which the shipyard quotes to, and eventually receives, from his customer.

The figures in a detailed estimate will come from quotations for materials and detailed work assessment for labor costs, while those in an approximate estimate are generally derived by the use of costs per ton or man-hours per ton from records of recent construction or from figures used in a recent detailed estimate for a similar ship.

Cost estimates for merchant ships are generally made in the first instance on the basis of a single ship against which all the first costs are charged. If more than one ship is to be tendered, a second estimate for a repeat ship, excluding first costs is then made.

Warship builders follow a more logical practice by separating first of class (F.O.C.) costs completely from production costs - a practice merchant shipbuilders could adopt with advantage, even though F.O.C. costs are very much smaller proportionally for merchant ships than they are for warships [1].

F.O.C. costs include design and drawing office costs, mod loft or equivalent costs, tank test and similar costs. Depending on the overhead structure of the firm, they may also include buying department and similar non repeating costs.

2. Material costs, labor costs, overhead costs

As well as the obvious items of steel, outfit and machinery, the materials cost includes the cost of work carried out by subcontractors working on the ship. Electrical and

plumbing work are the two main activities for which some yards have their own departments while others use subcontractors.

Labor costs by definition include the cost of the time charged to the ship contract by the labor force, including contract labor, employed by the shipyard. This includes all the tradesmen, but shipyards differ in their treatment of the cost of foremen and managers. In many cases it difficult to record this, so many shipbuilders let them charge to an overhead number.

Overhead costs include a wide variety of costs incurred in the operation of the shipyard which are not directly chargeable to particular ship contracts. They include such items as interest on bank loans, rates and taxes, insurance, electricity, telephone and postage, salary costs of managers and office staff, etc. It is usual for one standard overhead rate to be applied to all labor costs. An estimate sheet with eight "vertical" sections that can be used for either merchant ship or warship cost estimates is given in Fig. 1 [2]. It will be noted that this estimate sheet uses the unit production cost concept and makes provision for different overheads rates being used for each cost section. Definitions of the items in the warship sections are given in Table 1 [1].

SECTION	1.	2	3.	4.	5.	6.	7.	8	SERVICES & MISC.	TOTAL
WARSHIPS	STRUCTURE	PROPULSION	ELECTRICAL	CONTOL and COMMS.	AUXILIARY SYSTEMS	OUTFIT $ FURNISH	ARMAMENT	VARIABLE LOADS		
	OUTFIT					MACHINERY				
MERCHANT SHIPS	STRUCTURE	STRUCTURE RELATED	ACCOMOD. RELATED	OUTFIT CARGO RELATED	DECK MISC. RELATED	PROPULSION	MACHINERY AUXILIARIES	RELATED		
WEIGHT TONNES										
MATERIAL COST PER TONNE										
MANHOUR PER TONNE										
MANHOURS										
LABOUR RATE PER MANHOUR										
OVERHEADS										
MATERIAL COST										
LABOUR COST										
OVERHEAD COST										
UNIT PROD COST										

Fig. 1. Cost estimate summary sheet for both merchant ships and warships

1 HULL	2 PROPULSION	3 ELECTRICAL	4 C^{4}I
10 Hull structure	20 Nuclear propulsion	30 Power generation	40 Navigation systems
11 Superstructure	21 Non-nuclear propulsion	31 Dystribution equipment	41 Internal communication
12 Structural bulheads 13 Structural decks	22 Propulsion units 23 Condenser and air ejectors	32 Dystribution cabling 32 Lighting systems	42 Ship and mechanical control 43 Weapon control
14 Doors, hatches and scuttles	24 Shafting and propulsion		44 Ship protective systems
15 Seats, masts and supports	25 Exhaust and air supply system		45 External communication
16 Control surfaces	26 Steam systems		
17 Structural castings 18 Buoyancy and ballast 19 Fastenings	27 Water cooling systems 28 Fuel service systems 29 Lub oil systems		
5 AUXILIARY	**6 OUTFITTING**	**7 ARMAMENT**	**8 VARIABLE LOAD**
50 Air condition and ventilation	60 Hull systems	70 Surface to air	80 Officers, crew and effects
51 Fuel systems	61 Boats and life saving equipment	71 Surface to surface	81 Ammunition
52 Sea and fresh water systems	62 Minor hull bulkheads	72 Surface to subsurface	82 Aircraft
53 Air and gas systems	63 Storeroom furnishing	73 Sublaunched antisurface/subsurface	83 Military vehicles
54 Hydraulic systems	64 Living space furnishing	74 Sublaunched antiair	84 Victualing stores
55 Aircraft systems	65 Office furnishing	75 Air launched armament	85 Naval stores and spare gear
56 Waste disposal systems 57 Aux. steam systems	66 Galley/workshop equipment 67 Superstructure partitions	76 Mine warfare equipment 77 Small arms and rocktes	86 Weapon stores 87 Operational fluids
58 Lubricating oil systems	68 Portable firefighting equipment		88 Stowed liquids
	69 Echipament de manevră a încărcăturilor		89 Cargo

Table 1 Warship weight and cost groups

3. Structural costs

3.1 Structural material

Methods of calculating the net structural weight have been used according to Watson-Practical ship design [2]. The cost of welding rods and gases is normally added to the structural material cost as a percentage of this based on an analysis of completed ships.

3.2 Structural labor

The structural labor cost is the product of the man-hours required multiplied by the labor cost per man-hour.

If sufficient structural drawings are available the estimate can be made by detailed work assessment, which may be broken down into shop man-hours; berth man-hours and afloat man-hours. When only a total steel weight is available, the estimate must be made by the use of a plot of man-hours derived from completed ships against the total steel weight as shown in Fig. 2 or of man-hours per ton as shown in Fig. 3. Both plots have advantages but that of man-hours per ton is the more usual [1].

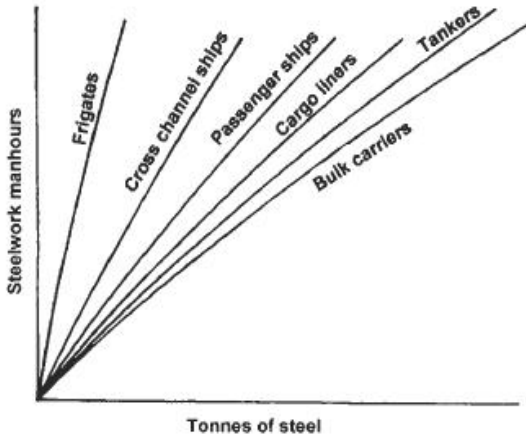

Fig. 2 Steelwork man-hours versus steel weight

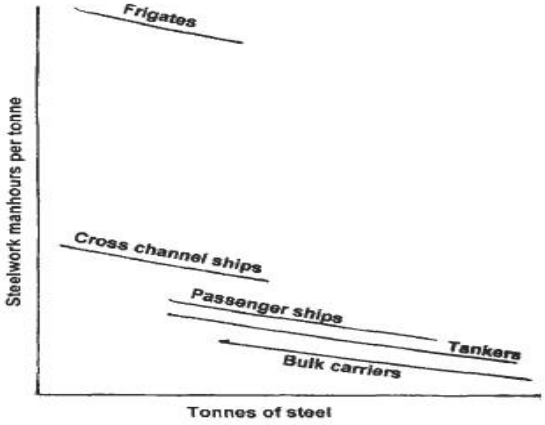

Fig. 3 Man-hours per ton versus steel weight.

A disadvantage of both these plots is the fact that they fail to distinguish between two ships of the same steel weight, one of which is smaller but heavily constructed and the other larger but with lighter scantlings. Fig. 4 fails to show a proper allowance for the steel weight and a plot of man hours per ton may be better against this base. An approach about the problems posed by these alternatives offer a plot of man-hours against the total area of plate used as shown in Fig. 5 [1]. Remarkably, this was found to give a straight line relationship irrespective of ship type, suggesting that area rather than weight was the best criterion for labor man-hours.

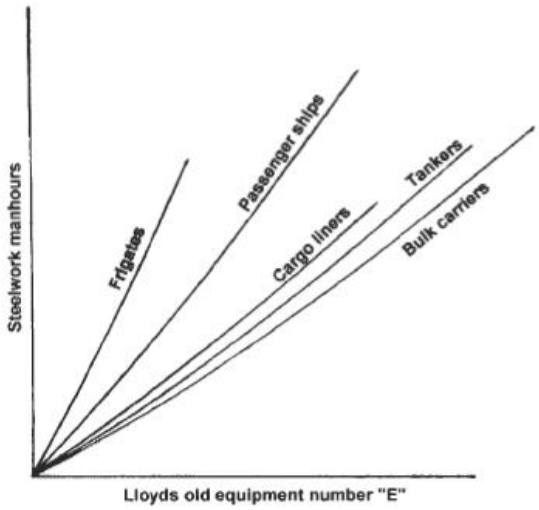

Fig. 4 Steelwork man-hours versus ship size.

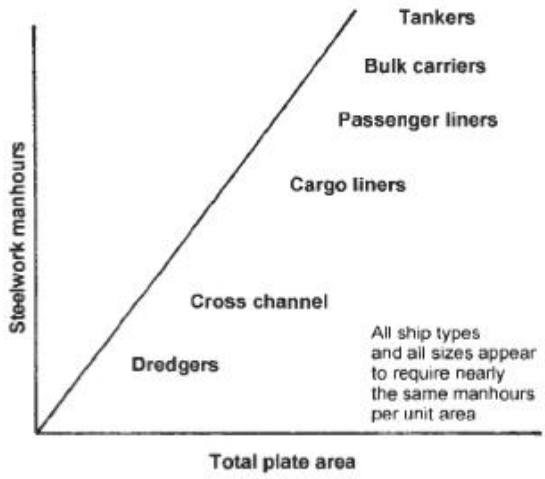

Fig. 5 Steelwork man-hours versus total plate area.

3.Outfit costs

The following groupings for weight estimation seem to meet this criterion reasonably [1]:

Group 2. Structure related (steel weight): structural castings or fabrications (rudder and stern frame), small castings (bollards, fairleads etc.), steel hatch covers, W.T. (water tight) doors;

Group 3. Cargo related (cargo capacity or ship size): cargo space insulation and refrigeration machinery, cargo ventilation, firefighting, paint, 3(a) -plumber work;

Group 4. Accommodation related: joiner work, upholstery, deck coverings, sidelights and windows, galley gear, lifts, HVAC-(Heating, Ventilating, and Air Conditioning), LSA- (Life-saving appliances and arrangements), nautical instruments, stores and sundries, 4(a)- electrical work;

Group 5. Deck machinery related (by units or by ship type x size): steering gear, bow and stem thrusters, stabilizers, anchoring and mooring M/C- (Machine (mechanical engineering), anchors, cables and mooring ropes, cargo winches, derricks and rigging, cranes.

Outfit labor costs can be calculated in two ways, both of which require an assessment of the man-hours and the multiplication of this by an average wage rate per man-hour. The most accurate method is based on detailed work assessment for each of the trades, work areas or systems involved.

When making a calculation by this method it is vitally important to check that the demarcation between work carried out by the shipyard and that subcontracted is to be the same on the ship for which the estimate is being made as it was on the ship used as the basis;

4. Machinery costs

Machinery material costs are obtained mainly from subcontractor's quotations but partly by costing items either on unit, unit power or unit weight basis. Where greater accuracy is required more subcontractor's prices should be used, but where speed is essential the cost per ton basis is necessarily used for most items.

For merchant ships a split into three groups seems to provide a way of bringing together items whose costs per unit weight are fairly similar and which can be related to an easily assessed parameter.

The groups, according to [1], are:

Group 6. Propulsion: main engine(s), gearbox, shafting, propeller(s), main engine controls;

Group 7. Auxiliary machinery: generators and switchboard, pumps, compressors, etc.

Group 8. Structure related: funnel and uptakes, ladders and gratings, pipe work and ventilation trunking within engine room.

Machinery labor costs are estimated as the product of the man-hours required and the average wage rate applicable. The man-hours can be obtained either by a detailed work assessment - the most accurate way but a lengthy process - or for approximate estimates by proportioning from available data on the man-hours and total machinery power (P) of a suitable reference ship using this in the ratio (P) to the power 0.82, commonly used [1].

5. Approximate structural cost

The use of a total cost per ton method for structural costs is made difficult by the large differences that exist in the labor man-hours required for structural work of different types and sizes of ships. At one extreme a small fine lined specialist ship constructed of

light plating may require something of the order of 130 man-hours per gross ton while at the other extreme a large full lined tanker constructed of heavy plating may be constructed at about 25 man-hours per gross ton. The costs per ton quoted are based on net steel weights but the basic material costs allow for the gross steel ordered and it was noted that the scrap percentages which the different yards regard as normal also differed quite widely.

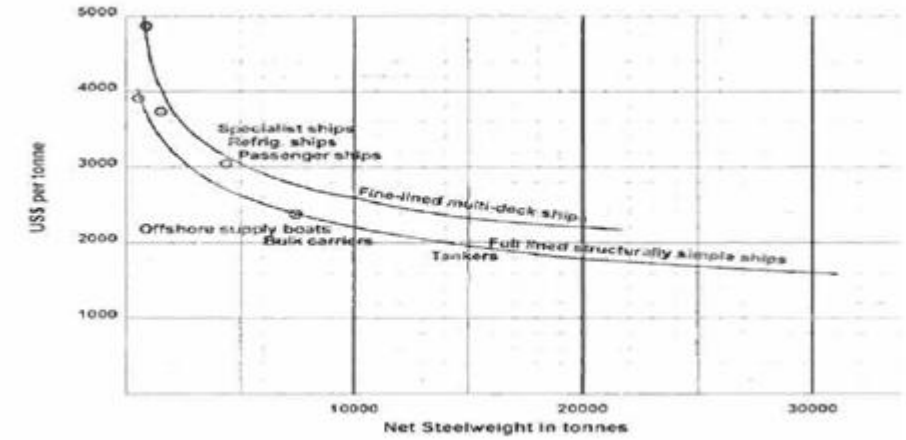

Fig. 9. Approximate costs for structural steelwork per ton.
Costs are on a 1993 basis and include materials, labor and overheads.

Finally, an additional sum was added to the steel material cost to allow for the cost of electrodes and miscellaneous steelworkers stores.

The resulting costs in US dollars per ton of net steel are shown in Fig. 9 [2].

6.Outfit costs

While the costs per ton of different items of outfit were found, as expected, to differ quite widely, the costs per ton of the total outfit were found to be much closer even though the ships were of quite different types and sizes (Fig. 10).

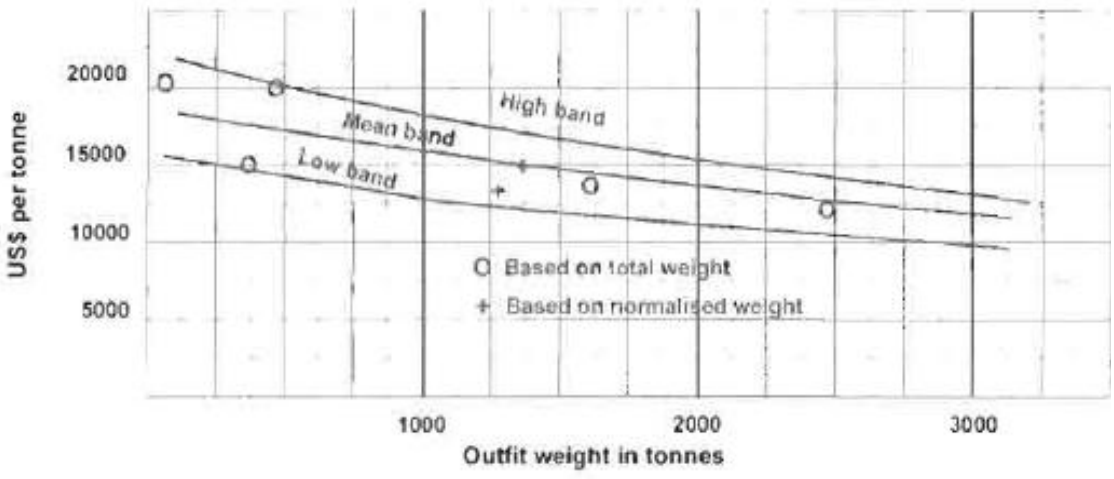

Fig. 10. Approx. costs of outfit per ton. Costs are on a 1993
basis include materials, labor and overheads.

After some experiments it was found that a closer convergence of the data could be obtained if the cost per ton was calculated for a "normalized" outfit which excluded any items which would have a major influence on the average cost per ton either because it had a very high or a very low cost per unit weight -combined in the latter case with a sufficiently large weight to make its influence felt.

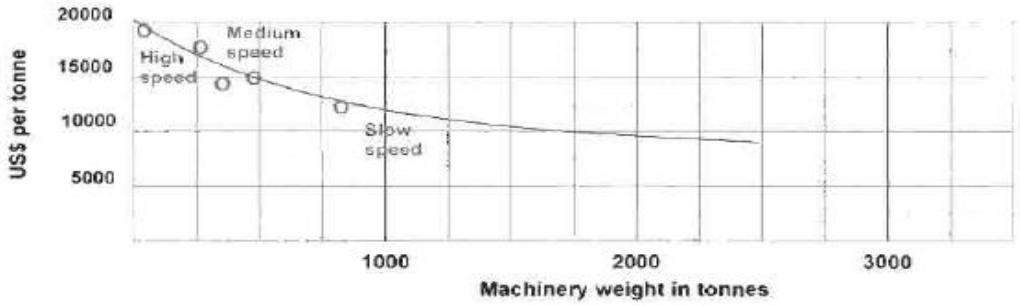

Fig. 11. Approximate costs of machinery per ton. Costs are on a 1993 basis and includee ude ma labor and overheads.

7. Machinery costs

Fig.11 shows a graph of the cost per ton of machinery against the total machinery weight. The trend towards reduced specific cost as the weight increases with a flattening out to a figure of just under $10000 per ton at machinery weights in excess of 1500 tons may be noted [1].

8. Conclusion

The current cost estimating methods are mostly weight based models. Weight is the most commonly used parameter and has been shown in the past to provide good estimates. Nevertheless the weight based model does not reflect or incorporate the effects of productivity changes or the process by which the vessel is built. An example is increasing the “shape” of a hull form by reducing the amount of parallel midbody. The change in actual steel structure weight may be insignificant in terms of the cost estimating relationships, resulting in no change in estimated cost.

It needs that industry to evolve its ship cost estimating capabilities in order to incorporate non weight based parameters into their forecasts

References:

[1] Watson, D.G.M., *Practical Ship Design*, Elsevier Ocean Engineering Book Series, 1998, p. 465-489;

[2] Watson, D.G.M., *Practical Ship Design*, Elsevier Ocean Engineering Book Series, 1998, p. 81-131;