A Measurement of Shipbuilding Productivity

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ABSTRACT: The present work studies the concept of productivity in shipbuilding and how it should be measured. The existing metrics, shipbuilding process and shipyard organization were studies in order to choose the most adequate metrics which would allow the measuring of a shipyard productivity in a systematic and holistic way. This is achieved by gathering the man-hours spent in each ship organized by cost centre and using Compensated Gross Tonnages as the measure of output from the shipyard. Data was gathered for thirty ships built in the same European yard organized by cost centre. From the data collected it was found that the ratio of hours spent in outfitting to the hours spent in structures is proportional to the complexity of the ship. There was also opportunity to study the work reduction resulting from building ships in series and the shares of labour for ships series and across ship types.

Keywords: Shipbuilding; productivity; block's manufacturing; manufacturing cost

1 INTRODUCTION

In the current times shipbuilding faces several challenges, on one hand shipyards must compete in a fierce international market while on the other hand shipyards, which are usually traditional and conservative, must adapt to a quickly changing market and technologies. From the International Maritime Organization (IMO) 2020 sulphur cap and the target to reduce the Green House Gas Emissions by at least 50% by 2050 (compared to 2008), to the Internet of Things, Building Information Modelling (BIM) which allow the yards to optimize and monitor its shipbuilding process in a systematic and automatic way.

This has driven and shaped the shipbuilding market, on one hand we are now seeing shipyards adapting to newer requirements by owners to provide environmentally friendly ships, be it either by using scrubbers, alternate fuels such as LNG or, in some cases by opting for an emission free electric vessel. While on the other hand, yards have to keep up with technological advances and improve their efficiency in order to remain competitive. Some yards have also adapted to newer profitable markets, namely some yards will also produce steel structures for the offshore market, such as the offshore wind. Andritsos et al. (2000), Sharma et al. (2010) and Yoshihiko et al. (2011) are a few examples of the efforts being made to improve and modernize the shipbuilding industry.

For a yard seeking to improve their productivity and efficiency the first challenge is the definition of these two terms in the shipbuilding industry and finding different methods to quantify them.

Independently of the various forms of quantifying a shipyard's efficiency, it is necessary to have a holistic understanding of not only the assets but of all the steps involved in the process of building a ship, the technologies involved and general shipyard organization. When choosing the metrics to use, the facility to obtain the necessary data should also be considered. While thorough data can be used, such as done by Guofu et al. (2017) and Sulaiman et al. (2017), which provide insightful and important information on the shipbuilding process, the metrics chosen should be readily available from the data which is often accounted for by the yard cost centres.

Only then, and after choosing econometric indicators related to production, one can identify possible bottlenecks and indicate a course of action to improve the efficiency.

Inevitably, most indicators end up analysing the selling price and the cost of its produced vessels. The major costs involved in building a ship can be more easily understood once we decompose them in two main partitions which are labour and materials (where materials and intermediate products can represent can to up to 70% of the total ship cost, as seen in Lamb, 2003). While material costs should be similar in every country (not always the case), labour is not, and is where the yard is presented with greater change of improvement.

Lastly the suggested metrics where gathered for a case study consisting of 30 ships built in the same yard.

Which allowed the study of the weight of four main cost centres (Hull, OTF, Support and Project) on different ship types (Container ships and Chemical Tankers) and showed the limitations of the Compensated Gross Tonnage (CGT) system as a measure of output.

2 SHIPYARD ORGANIZATION AND SHIPBUILDING PROCESS

In order to identify the factors that influence the productivity of the yard it is first needed to understand the process of shipbuilding.

2.1 *Shipbuilding process*

The shipbuilding processes a shipyard adopts will be dependent on their production strategy. The shipbuilding industry is very characteristic and most of the shipyards will build several ships at a time with significant variation among them but will try to make use of standardization to implement the gains of mass production. This production strategy is known as Group Technology (Lamb, 1986), as presented in Figure 1.

In this strategy the yard will establish a work breakdown structure for the ships it builds and will group identical products (products which suffer the same processes) into intermediate products families, as in Figure 2. By grouping those intermediate products and fabricating them for several ships at the same time the yard manages to take some of the gains from mass production while allowing for variety among ships.

To allow the grouping of similar products into families a good coding and classification system in essential. Classification separated products through similarities (properties, shape, processes among others) by use of a code system. Lamb (1986) proposed a seventeen-digit shipbuilding classification and coding system. Pal (2015) analysed different work breakdown systems as well as coding systems identifying three as the most relevant: the SWBS (Ship Work Breakdown Structure); PWBS (Product Work Breakdown Structure) and the SFI (Senter for Forskningsdrevet Innovasjon) system. Of those SFI is widely used in both project and shipyards, namely, to assign costs to cost centres, as shown in Table 1.

There are also concurrent activities which, while not contributing directly to production, are essential for a proper organization and operation of a yard.

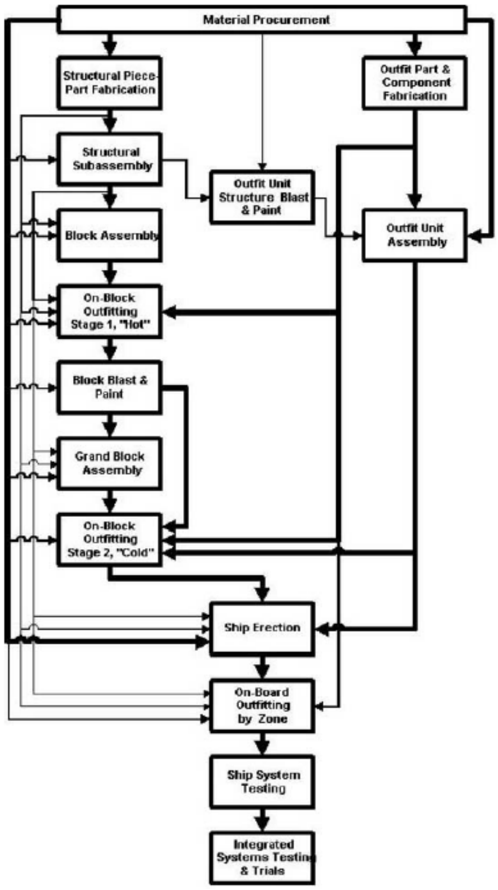

Figure 1. Shipyard Material and Workflow for a shipyard employing Group Technology (Lamb, 2004).

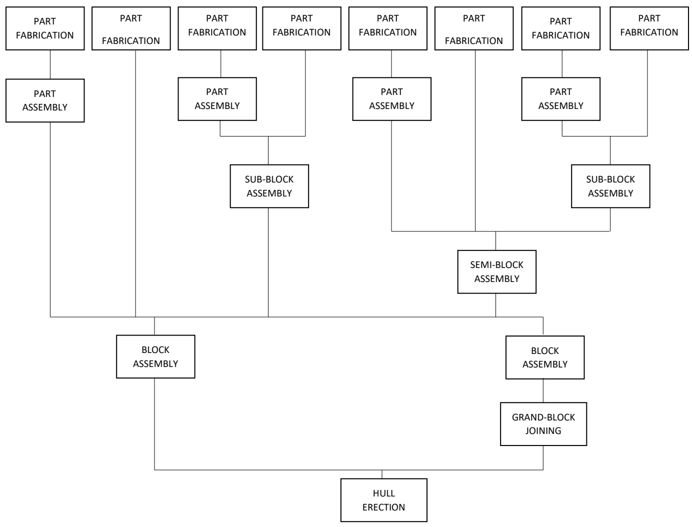

Figure 2. Manufacturing levels for the hull construction method.

The activities involved in the process of building a ship can be divided in production activities, support activities and engineering, production activities includes hull work (steelwork), outfitting (which includes piping, electrical and HVAC) and painting, while support activities are not directly involved in production but are still essential to support and provide the information needed to produce the ship, as systematised in Figure 3. Associated with each of those activities there will also be a cost centre, where the hours and resources spent for that activity are registered.

Table 1. SFI system main groups (Pal, 2015)

SFI Group	Description
000	(reserved)
100	Ship General
200	Hull
300	Equipment for Cargo
400	Ship Equipment
500	Equipment for Crew and Passengers
600	Machinery Main Components
700	Systems for Machinery Main Components
800	Ship Common Systems
900	(reserved)

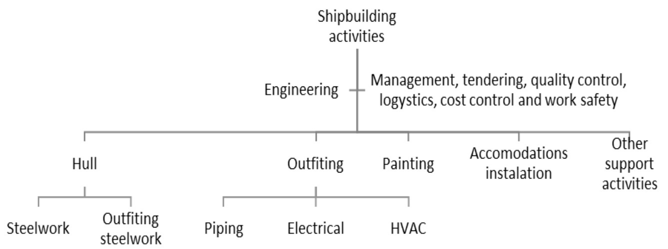

Figure 3. Shipbuilding activities

2.2 *Measuring shipbuilding productivity*

Productivity is defined as a measure of the efficiency of converting inputs into outputs. In shipbuilding there are several metrics used to measure a shipyard productivity, the choice of the metric to use will depend on its purpose.

Krishnan (2012) analyses the productivity measurement system for shipbuilding, mentioning the difficulty of calculating total productivity and defines some of the usages of productivity as being benchmark performance, value of comparison, measurement of production capacity, resource utilization and measure profitability. The intention of this work is to study a shipyard productivity in order to provide a benchmark performance value, hence, the choice of the metrics should reflect this.

2.2.1 *Inputs for productivity measurement*

Krishnan (2012) focuses on inputs such as labour, ship launching, shop floor area and total shipyard area. Pires *et al.* (2009) also present production cost, building time and quality as basic criteria to evaluate the performance of a shipyard from the competitiveness point of view, while capacity (total area, erection area, capacity for moving blocks), industrial environment and technology as indicators and influencing factors.

Inputs are often divided into five main types (Coelli *et al.* 2005): energy, Material, Purchased Services, Capital and Labour. The first three types are often aggregated into one single input.

2.2.1.1 Labour inputs

Labour inputs are one of the major input categories and measures the human work employed to produce the output.

Some of the most common ways to measure labour are the number of employed persons, the number of hours of labour (MH – man hours), and number of full-time equivalent employees.

Worked hours is the preferred metric (OECD, 2001), since it does account for hours paid by not worked, due to illness, leave among others. An well-organized yard will keep a registry of MH per cost centre for each ship, this is the ideal source of labour as it is the most complete and detailed, it allows not only to calculate the yard productivity but also allows to study the results from each cost centre.

2.2.1.2 Capital inputs

The capital of a shipyard is comprised of all the assets it owns. On a shipyard the most relevant capital would be those which contribute for production, productive assets. In these categories we will find the heavy and machinery of each workshop as the principal productive assets, as well as the area of the yard (Pires *et al.* 2009).

Ideally capital would be measured using the PIM (Perpetual Inventory Method). However, for this method requires the time series of investment expenditures on the yard assets, which might not always be available. Coelli *et al.* (2005) presents the following alternative measures of capital:

- Replacement value
- Sale price
- Physical measure
- Depreciated capital stock

From the alternative measures of capital two option stand out as the ones for which information is more readily available. Those are; physical measures and the depreciated capital stock.

For the physical measures it would be required to make an inventory of the main machinery used in the yard (heavy machinery) and the area of the yard. The differences between machinery quality and category should be accounted; the main equipment's could be categorized depending on their capabilities, however this would lead either to only a few categories being used, to maintain a simple approach, which would lead to a significant decrease in differentiation, or too many categories being considered which would lead to an exhaustive list of equipment's being created which, due to the variability among yards, would lead to results difficult to compare.

For these reasons the depreciated capital stock of the yard is a preferable method, since the majority of yards will either publish annual financial reports or keep track of their depreciated capital stock for finances purposes.

2.2.1.3 Energy, materials and purchased services

Materials and equipment's can account for most of the cost of a ship (up to 70% of the total ship cost, Jiang *et al.* 2011).

However, in this study there was no opportunity to develop the study of the materials cost which *per se* would be worthy of an individual study. The price of steel depends on the location of the yard, transport costs and, when applicable, import taxes. Yards in China and Europe will purchase steel at different prices, which can make the yard which buys steel cheaper appear more efficient, while it might only be more competitive, but not necessarily more efficient.

The services of painting, interiors, insulation, cleaning, HVAC, Scaffolding and others which include both labour and materials should also be considered in this category (energy, materials and purchased services inputs). The remaining subcontracted labour, which does not include materials, should be included as labour. In the cases where no man hours are known for that service, then the price must be converted to man hours worked by using the maritime industry worker average hour price.

2.2.2 *Outputs*

The output of a shipyard are the ships it produces, however the number of ships produced, by itself, is not an adequate metric as it does not account neither for the complexity nor size of each ship. Compensated Gross Tonnage (CGT) is the recommended measure of output of a shipyard as it accounts for the complexity and size of the ship. This metric has been used in OECD studies as well as by Lamb *et al.* (2001), Pires *et al.* (2009) and Krishnan (2012), among others.

Initially super yachts and naval vessels were not included in the original CGT coefficients; however, recent works have been done to include them. Hopman *et al.* (2010) proposed a factor A=278 and B=0.58 for super yachts and Craggs *et al.* (2004) presents a formula to calculate the CGT of naval vessels by calculating a base CGT coefficient, dependent on the outfit weight to lightship ratio and a customer factor which represent the extra work required for naval vessels.

The formula for calculating the CGT can be seen in Eq. 1, while the corresponding coefficients are shown on Table 2.

$$cgt = A * gt^B \tag{1}$$

To calculate the CGT of a naval vessel Eq. 2 should be used instead, where the base CGT coefficient is calculated using Eq. 3 and the client factor is obtained from Table 3.

$$cgt = gt * BC * CF \tag{2}$$

where *gt* is the gross tonnage; *BC* is the base CGT coefficient for naval vessels; *CF* is the customer factor, as presented in Table 3 according to Craggs *et al.* (2004). The base CGT coefficient is given by:

$$BC = 44.65x(\text{Outfit weight/Lightship})^{3.19} \tag{3}$$

Table 2. CGT coefficients (OECD, 2007; Hopman *et al.*, 2010)

Ship Type	A	B
Oil tankers (double hull)	48	0.57
Chemical tankers	84	0.55
Bulk carriers	29	0.61
Combined Carriers	33	0.62
General cargo ships	27	0.64
Reefers	27	0.68
Full container	19	0.68
Ro ro vessels	32	0.63
Car carriers	15	0.7
LPG carriers	62	0.57
LNG carriers	32	0.68
Ferries	20	0.71
Passenger ships	49	0.67
Fishing vessels	24	0.71
NCCV	46	0.62
Mega Yacht	278	0.58

Table 3. Customer factor.

Customer Factor	Characteristic
1.00	Normal commercial contract
1.06	Naval auxiliaries for Ministry of Defence and typical export combatants
1.12	Combatants built for Ministry of Defence and demanding export customer

3 CASE STUDY

For this case study data was gathered for thirty ships, thirteen chemical tankers and seventeen containerships, built in the same European shipyard. The ships where built in five distinct series. Series A, B and C comprised of eight, three and two chemical tankers, respectfully, while series D and E comprised of thirteen and four containerships respectfully. The series A ships had stainless steel cargo hold, series B had painted holds and series C had icebreaking capacity.

3.1 *Data Collected*

The data gathered consists on the man hours registered in the yards custom cost centres for each ship, as well as each ship GT and type.

The cost centres are organized into four main groups: Structures, Outfitting, Support and Project. Structures included the hours spent on fabricating, (cutting, welding) and assembly of the ship structures plus steel outfitting. Outfitting included piping, mechanical works, electricity, on board outfitting and insulation. Support included painting, cleaning, interiors, scaffolding, transportation, quality and others support activities. Project included the hours spent in engineering for each ship.

Table 4 compares each ship to the most expensive one in terms of man-hours for every main cost centre.

Table 4. Man-hours in % to maximum MH by cost centre.

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ID [Series/Nº]	Man hours / maximum MH in the series for the group (%)					
	Hull	OTF	Support	Project	T. Prod.	Total
SERIES A - CHEMICAL TANKERS (SS TANKS)						
A1	100%	100%	100%	100%	100%	100%
A2	96%	84%	80%	8%	90%	75%
A3	88%	76%	76%	11%	82%	70%
A4	84%	71%	70%	3%	78%	65%
A5	82%	67%	71%	4%	75%	63%
A6	78%	67%	74%	2%	73%	60%
A7	72%	64%	71%	2%	69%	57%
A8	71%	62%	73%	1%	68%	56%
SERIES B - CHEMICAL TANKERS (PAINTED TANKS)						
B1	98%	97%	100%	100%	98%	100%
B2	94%	90%	83%	14%	92%	78%
B3	100%	100%	98%	23%	100%	87%
SERIES C - CHEMICAL TANKERS (ICEBREAKERS)						
C1	100%	100%	100%	100%	100%	100%
C2	98%	88%	86%	8%	94%	82%
SERIES D - CONTAINERSHIP (HEAVY LIFT)						
D1	100%	100%	72%	100%	100%	100%
D2	91%	81%	68%	18%	88%	77%
D3	87%	79%	61%	8%	84%	73%
D4	87%	78%	66%	7%	85%	73%
D5	85%	76%	66%	11%	83%	72%
D6	83%	72%	57%	6%	79%	68%
D7	86%	73%	59%	7%	82%	71%
D8	85%	88%	100%	56%	89%	84%
D9	77%	83%	91%	8%	82%	70%
D10	75%	76%	82%	7%	78%	67%
D11	75%	70%	83%	3%	76%	65%
D12	79%	71%	74%	14%	78%	68%
D13	78%	69%	74%	2%	77%	66%
SERIES E - CONTAINERSHIP						
E1	95%	95%	100%	100%	95%	100%
E2	98%	90%	93%	17%	96%	89%
E3	96%	89%	95%	6%	94%	87%
E4	100%	100%	100%	6%	100%	92%

Table 5 presents the composition of every main cost centre in percentage of the total cost in MH for each ship.

3.2 *Subcontracted Services*

On the data gathered from the yard there where man-hours from subcontracted services included. Some of those services included both the labour and materials necessary for the service, those services where Interiors, insulation, painting, cleaning, scaffolding and HVAC, for those the shipyard estimated the man-hours spent, however, due to the uncertainties regarding those estimations those hours where excluded in this study, except for the final shipyard productivity calculation, where their exclusion would show an erroneous higher productivity.

The share of subcontracted labour was, nevertheless, studied for all series, except series D, whose data was not trustworthy. In Table 6 it is shown the ratio average value to maximum value in series and the coefficient of variation (COV) for each series.

It was found that the values for subcontracted serviced remained fairly constant along the series, with an average relative standard deviation of 10%.

Table 5. Man-hours in % to total production MH in series by cost centre.

ID [Series/Nº]	Man hours / total production MH for the ship (%)					
	Hull	OTF	Support	Project	T. Prod.	Total
SERIES A - CHEMICAL TANKERS (SS TANKS)						
A1	52%	42%	6%	21%	100%	121%
A2	56%	39%	5%	2%	100%	102%
A3	56%	39%	5%	3%	100%	103%
A4	56%	38%	5%	1%	100%	101%
A5	57%	38%	5%	1%	100%	101%
A6	56%	38%	6%	0%	100%	100%
A7	55%	39%	6%	0%	100%	100%
A8	55%	39%	6%	0%	100%	100%
SERIES B - CHEMICAL TANKERS (PAINTED TANKS)						
B1	63%	30%	7%	25%	100%	125%
B2	64%	29%	6%	4%	100%	104%
B3	63%	30%	7%	6%	100%	106%
SERIES C - CHEMICAL TANKERS (ICEBREAKERS)						
C1	61%	32%	7%	17%	100%	117%
C2	63%	30%	6%	1%	100%	101%
SERIES D - CONTAINERSHIP (HEAVY LIFT)						
D1	66%	29%	6%	18%	100%	118%
D2	68%	26%	6%	4%	100%	104%
D3	68%	27%	6%	2%	100%	102%
D4	68%	26%	6%	1%	100%	101%
D5	68%	26%	6%	2%	100%	102%
D6	69%	26%	6%	1%	100%	101%
D7	69%	25%	6%	2%	100%	102%
D8	63%	28%	9%	11%	100%	111%
D9	62%	29%	9%	2%	100%	102%
D10	64%	28%	8%	2%	100%	102%
D11	65%	26%	8%	1%	100%	101%
D12	67%	26%	7%	3%	100%	103%
D13	67%	25%	7%	1%	100%	101%
SERIES E - CONTAINERSHIP						
E1	69%	24%	7%	16%	100%	116%
E2	71%	23%	7%	3%	100%	103%
E3	70%	23%	7%	1%	100%	101%
E4	69%	24%	7%	1%	100%	101%
Average value in series						
A	55%	39%	6%	4%	100%	104%
B	63%	30%	7%	11%	100%	111%
C	66%	27%	7%	4%	100%	104%
D	70%	23%	7%	5%	100%	105%
E	70%	23%	7%	5%	100%	105%

Table 6. Man-hours subcontracted in % to total production MH by ship

Series	Type	AVG [%]	σ	RSD [%]
A	CT	16	0.01	7
B	CT	17	0.01	9
C	CT	20	0.01	5
E	C	2	0.00	5

3.3 *Total production man-hours*

By plotting the total man-hours per ship along the series, it becomes evident that series A and D have a steady increase in efficiency until a limit efficiency is reached, Figure 4. Series A peak efficiency is reached on the 8th ship while series D construction in series was interrupted on the 8th ship due to changes in that ship project. For series B, C and E, in Figure 5, the number of ships built were not enough to notice improvements in building ships in series.

The improvement seen follows a logarithmic decrease in total production man-hours. The regression obtained for series A and D are shown in Table 7 and compared with the regression shown on OECD (2007).

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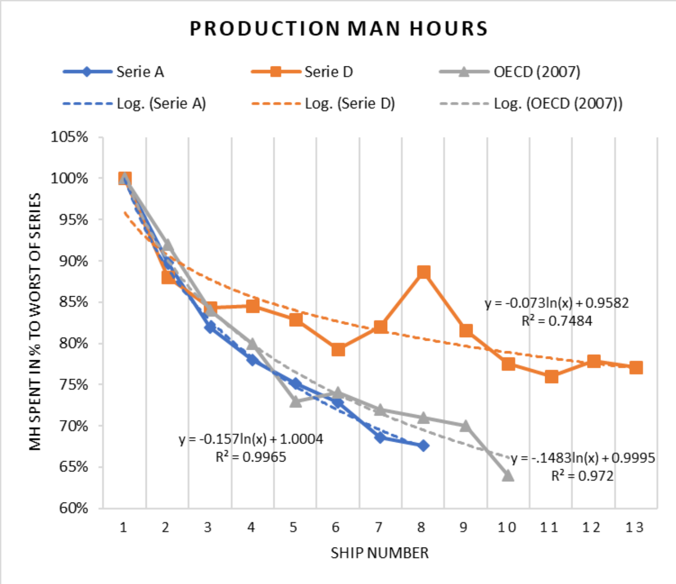

Figure 4. Evolution of man-hours required per ship in series A series D and OECD (2007).

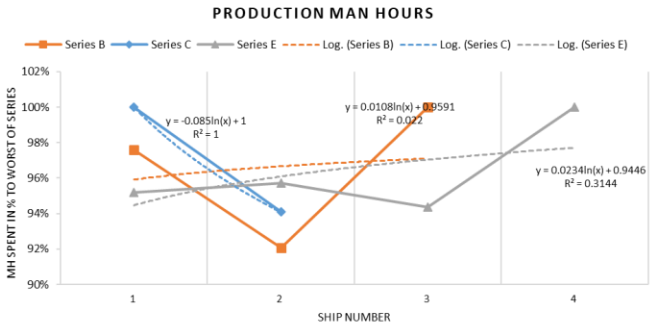

Figure 5. Evolution of man-hours required per ship in series B, C and E.

Table 7. Efficiency in a shipbuilding series

Series	f(x)	R^2
A	$f(x) = -0.1571 * \ln x + 1.000$	0.996
OECD (2007)	$f(x) = -0.1483 * \ln x + 0.972$	0.972
D	$f(x) = -0.073 * \ln x + 0.958$	0.748
D1-D6	$f(x) = -0.104 * \ln x + 0.921$	0.921
D8-D13	$f(x) = -0.066 * \ln x + 0.873$	0.844

Series A gives a regression very close to the one suggested on OECD (2007), with an R^2 of 0.996. The division of series D into two subseries, D1-6 and D8-13, yields better results, obtaining a regression with R^2 0.921 and 0.844 respectfully.

From the decomposition of hours spent in each ship by cost centre the following conclusion were reached: the share of each cost centre is maintained virtually the same along the series, showing that the decrease in man-hours has affected all cost centres proportionately, as presented from Figure 7 to Figure 11.

It was also found that the ratio of OTF to Hull was identical between ship types, 0.55 for chemical tankers and 0.37 for containerships, those two also represented the majority of the hours spent per ship, composing 85-90% of the total production man-hours. An higher ratio of OTF to Hull appear to represent a more complex ship, as chemical tankers are more complex ships than containerships they have an higher ratio (this is also reflected on the CGT coefficients, that are higher for chemical tankers), this also goes in accordance to Craggs *et al.* (2004) which uses this ratio to obtain the base CGT coefficient for naval vessels, and as seen in equation 3 the higher this ratio the higher the base CGT coefficient and thus the higher is the ship complexity.

Support activities share is constant and independent of ship type, ranging from 5% to 7%. Project man-hours ranged from 3% to 10% of the total hours spent. This share remained fairly constant at 3-4% with the exception of series B and C, as in Figure 6.

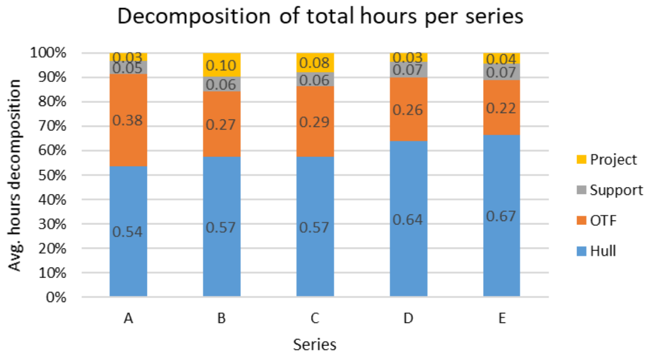

Figure 6. Average share of the 4 main areas in the total hours spent, by ship series

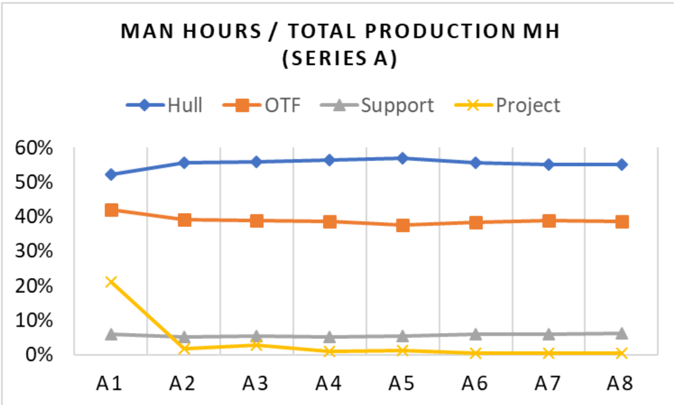

Figure 7. Evolution of MH/TP(MH) in series A

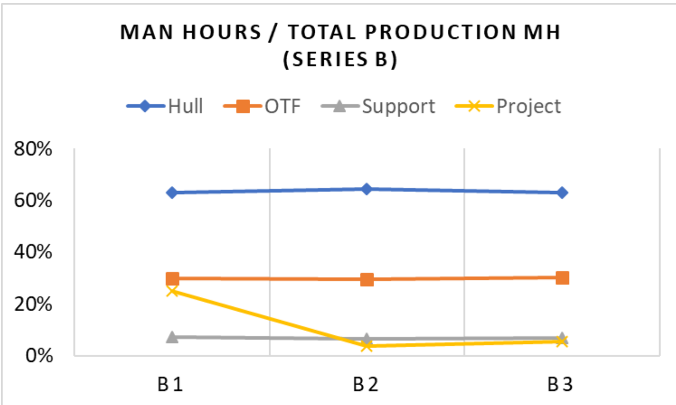

Figure 8. Evolution of MH/TP(MH) in series B

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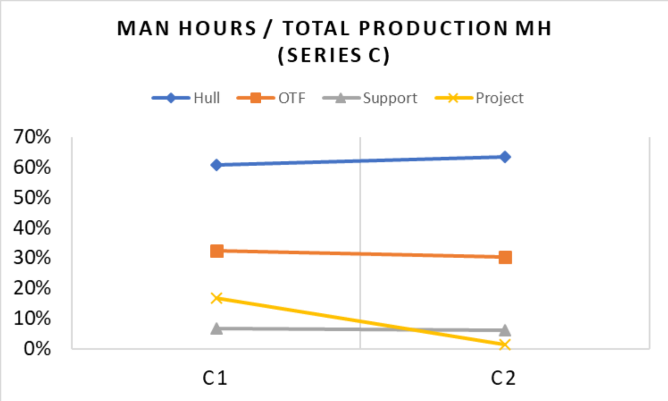

Figure 9. Evolution of MH/TP(MH) in series C

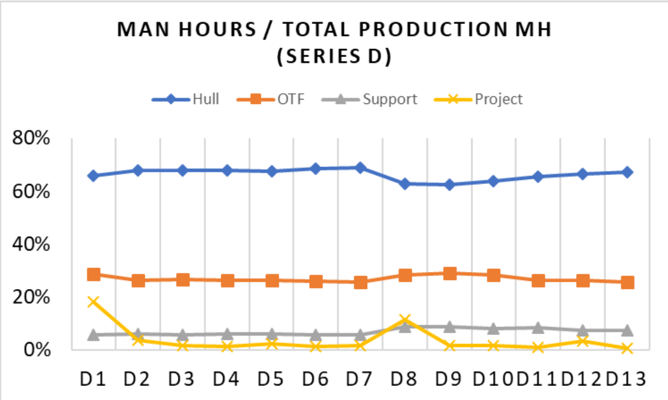

Figure 10. Evolution of MH/TP(MH) in series D

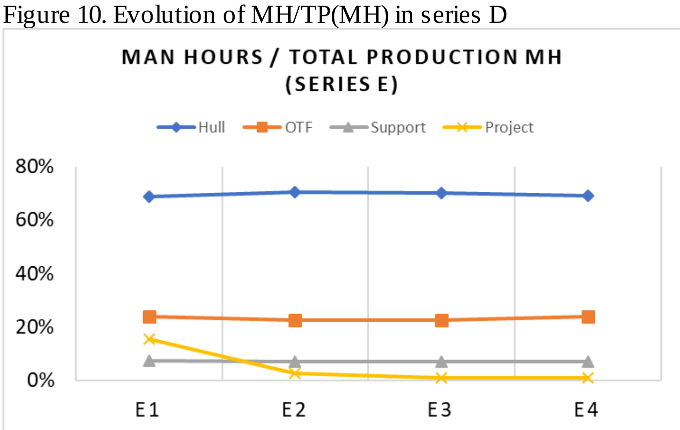

Figure 11. Evolution of MH/TP(MH) in series E

Contrary to the other cost centres, project man-hours decrease along the series is not constant, a steep decrease is noted from the first to the second ship, showing an average decrease of 86%, after which will remain relatively constant and at a residual value of 2.1%, on average, of the total project man-hours spent on the first ship, as may be estimated from Table 8 and Table 9.

3.4 *Shipyard's productivity*

Using Eq. 1 and the factors in Tab. 2 the CGT of each ship was found. The inverse of the productivity was calculated by the ratio MH/CGT for each ship. This provides the average amount of MH spent to produce one unit of CGT, which can be later be used for productivity control and for tendering. To avoid getting a mistakenly low value the estimated MH spent in subcontracted services were included. If the average price of MH (in €/MH) was known, as well as the depreciated capital stock it would also be possible to calculate the average cost to produce one unit of CGT (excluding materials costs).

Table 8. Project hours in % to total production hours.

	Project MH / Production MH (%)		
Series	1st project	2nd project	Avg. rest
Comparison by ship series			
A (CT)	21.1	1.8	1.1
B (CT)	25.0	3.8	5.5
C (CT)	16.7	1.3	-
D (C)	18.2	3.8	2.6
E (C)	15.5	2.6	0.9
Avg.	19.3	2.7	2.5
Comparison by ship type			
Chemical tanker	20.89	2.30	3.30
Containership	16.85	3.18	1.77
Dif. CT to C [%]	+19%	-38%	+46%

Table 9. Drop in project hours, from 1st to 2nd ship

Series	Ship Type	Drop 1st to 2nd (%)	Avg. after second ship (%)
A	CT	91.4	1.1
B	CT	85.0	4.6
C	CT	92.0	1.3
D	C	79.2	1.8
E	C	83.4	1.5
	Avg.	86.2	2.1

In Figure 12 the inverse of the productivity was plotted for each ship. The three lowest points shown correspond to the chemical tankers with painted tanks, which presented, in average, a 46% lower MH/CGT ratio when compared with the tankers with stainless steel tanks. This shows a fragility of the CGT system, that it does not account for difference in complexity inside the same category. Chemical tankers achieved an average productivity of 40.3 MH/CGT, while containerships required a lower 33.9 MH/CGT, thus giving the shipyard an average productivity of 37.7 MH/CGT. In theory, by using the appropriate CGT coefficients the productivity should be identical across ship types, however as shown this was not the case.

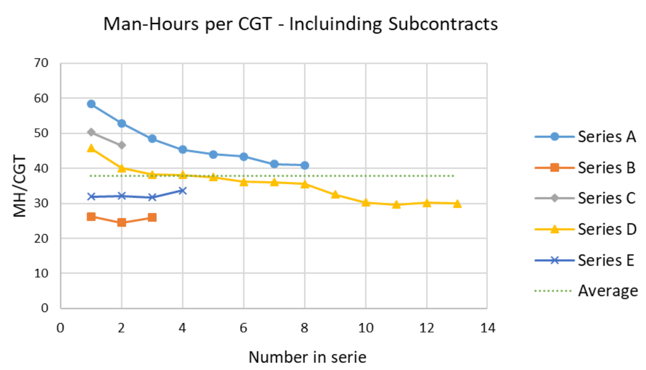

Figure 12. Case study of shipyard productivity in MH/CGT

4 CONCLUSIONS

By realizing this work, it was possible to conclude that the CGT coefficients still do not account for the differences in complexity for ships of the same type. In this study it was observed that chemical tankers with painted holds required 46% less MH/CGT than tankers with stainless steel holds, but it still would have the same CGT factors for being the same ship type.

The average productivity obtained for the chemical tankers and for the containerships was also different, of 40.3 and 33.9 MH/CGT respectfully, with containerships requiring approximately 15% less man-hours to produce one CGT. This shows that the CGT system still does not provide ideal coefficients for use in micro-economic analysis, for macro-economic analysis (which were the intended analysis when the CGT was created) this effect should be diluted due to the vast amount of ships being built, and it would be expectable to obtain a more similar result.

Subcontracted labour accounted for 7.6% to 10.1% of the total MH spent and were found to remain moderately the same along the series.

Structures and outfitting were found to represent the greatest amount of work, with structures ranging from 54% to 67% and outfitting from 22% to 38%, it is was also found that a higher ratio of outfitting to structure represents a more complex ship (chemical tankers obtained a ratio of 0.55 while containerships obtained a ratio of 0.37). Support hours remained virtually constant among the series ranging from 5% to 7%.

Project man-hours represented 3% to 10% of the total man-hours, in average, however, were found to be reduced 82% to 92% from the 1st to the 2nd ship, after which would remain a relatively small portion of the total man-hours showing only slight gains along the series.

4.1 *Further work*

Despite not being included in this study it is becoming increasingly frequent for yards to produce other steel structures other than ships, namely it is becoming more frequent for yards to also build offshore wind contractions, such as transition pillars. The offshore wind market is highly competitive and provides great opportunities to yards. In the offshore wind market, it is also essential for a yard to be highly productive, so that it can complete a project as fast as possible, while maintaining the strict quality required in this market.

As a continuation of this work data from more yards should be gathered, with man-hours divided by Structures, Outfitting, Support and Project cost centres. To account for different production departments and rationalization in the different yards, CGT (output) of the yard would be a function of the labour (MH) as well as the depreciated capital stock (€) and purchased services (€). The inclusion of those three inputs should address the mentioned issues, as a yard with higher automation would require less MH/CGT but would have a significantly bigger depreciated capital stock. With enough data points it would also become possible to establish production frontier using either data envelope analysis or stochastic analysis.

With data for more ships gathered from more yards it would also be interesting to further study the CGT system, the variation found among ships of the same type and study a solution to this issue.

In further works it would also be interesting to study yards involved in the offshore wind and compare its profitability of this market against the shipbuilding one as well as the compatibility and challenges to a yard organization engaged both in offshore wind and shipbuilding.

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