A SYSTEMATIC APPROACH TO MEASURE SHIPBUILDING PRODUCTIVITY

By

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A Thesis presented to the University of Instituto Superior Técnico
in fulfilment of the thesis requirement for the degree of Master in

Naval Architecture and Ocean Engineering

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Lisbon, November 2019

Art is the elimination of the unnecessary

Pablo Picasso

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Abstract

The present dissertation studies the concept of productivity in shipbuilding, and how it should be measured. The existing metrics, shipbuilding process and shipyard organization were studied in order to propose a methodology that would allow the measuring of a shipyard productivity in a systematic and holistic way.

The proposed methodology allows the shipyard to keep track, and manage, the ongoing constructions and to calculate an average productivity, through different cost centers and ships.

Data for thirty ships built in a European shipyard was gathered and used as a case study. 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 (divided by Structures, Outfitting, Support activities and Project) which were studied along the series and across ship types.

Keywords

Efficiency,

CGT – Compensated Gross Tonnage,

Cost Center,

Group Technology,

Inputs,

Man-Hour.

Outputs,

Productivity,

Series Effect,

Shipyard Learning,

Shipbuilding, WBS – Work Break Down Structure.

Acknowledgements

I would like to acknowledge, the persons which have helped to make this thesis become a reality, to these persons I am deeply grateful for their support.

Firstly, I would like to thank professor Gordo, and the course directors, for accepting and believing on this thesis, and for the support he has provided along the way.

A special acknowledgement is also needed to the shipyard and its workers, for the data provided and important insights they provided on the shipbuilding process and shipyard organization. It is thanks to their help and data that a deeper study on the shipyard productivity was possible.

Lastly, I would like to thank my family and friends, specially David, which always supported and helped along the way.

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Glossary

Beam – The width of the ship at its widest point measured at the waterline.

Compensated Gross Tonnage – An indicator of the amount of work that is necessary to build a ship.

Deadweight – Difference between the displacement and lightship. Measure of the carrying capacity.

Draft – Vertical distance between the waterline and the keel.

Efficiency – Optimization of the productivity while minimizing the waste of resources.

Group technology - “A method to apply mass production techniques to products that vary widely in type and quantity “(Lamb, 1986);

Gross Tonnage – Nonlinear measure of a ship’s internal volume.

Productivity – Ratio of the outputs to inputs of a company or process.

SFI – A widely used coding and classification system created by the Ship Research Institute of Norway

Acronyms

AOR - Auxiliary oiler replenishment vessels:

BIM - Building information model;

CGT - Compensated Gross Tonnage;

DEA - Data Envelope Analysis;

DWT – Deadweight;

ESWBS - Expanded Ship Work Breakdown Structure;

GT – Gross Tonnage;

LPP – Length between perpendiculars;

MEP - Mechanical, electrical, and plumbing;

MH – Man hours;

NSRP - National Ship Research Program;

OECD -Organization for Economic Co-operation and Development;

OPV - Offshore patrol vessel;

OTF – Outfitting;

PIM - Perpetual Inventory Method;

PWBS - Product Work Breakdown System;

SCGT - Metric that accounts for the learning effect when building several ships for the same series;

SNAME - Society of Naval Architects and Marine Engineers;

SWBS - Ship Work Breakdown Structure;

USA - United States of America;

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1. Introduction

1.1 Introduction to shipbuilding productivity and efficiency

In the modern society, full of competitivity and economic pressure, shipyards are forced to constantly evaluate and improve their efficiency and efficacy in order to remain competitive. The first challenge starts with 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. Only then and after choosing econometric indicators related to production, can one 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.

1.2 Motivation

For centuries Europe was the leading shipbuilder, but this scenario has changed, and it now faces difficult times. The leading shipbuilder nation have been constantly changing, for many times it was the United Kingdom, followed by Sweden and Spain. Nowadays shipbuilding is dominated by three Asian nations, Japan, Korea and China. The World Shipyard Monitor (WSM) shows that in 2004 only 15.5% of the Global Orderbook belonged to Europe (see Fig. 1.1). The low wages on China makes it difficult to compete against, and even Japan struggled and tried transferred yards to Brazil to remain competitive. According to OECD (2016), Japanese companies are now shifting shipbuilding to countries in Southeast Asia with cheaper labour, such as Vietnam. But even China is not free of difficulties and many yards have been closed during the periods of low new orders.

Shipbuilding is a particular industry and even though the world's demand could be satisfied by the production of a small number of countries, most coastal nations have a strategical interest in keeping the national shipbuilding capacity. This is usually accomplished by creation of favourable financial policies and by public contracts, which are often seen for naval vessels.

For countries with an elevated man hour cost to be able to keep the shipbuilding industry alive, it is needed more than the favourable financial policies; it is needed to enhance and optimize the shipbuilding productivity. And it was this need to better understand and measure a shipyard productivity that motivated the elaboration of the present thesis.

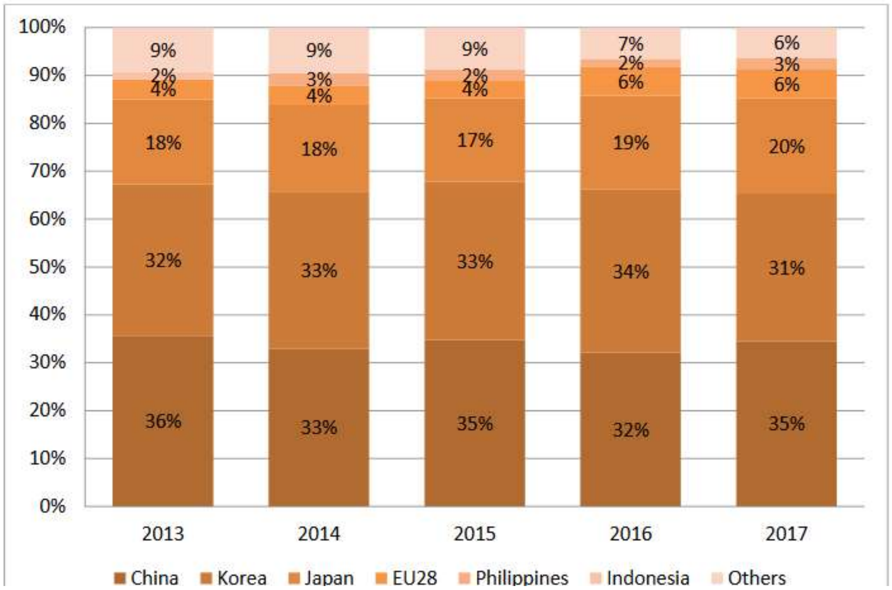


Fig. 1.1 - Market Shares in CGT

In OECD (2018)

1.3 Objectives

The main objective of this thesis is to study a shipbuilding yard productivity and propose a systematic approach able to quantify and monitor the productivity of a yard, which would allow to later build a database able to compare, equally/meaningfully, different yards and benchmark them, while giving the yard a tool that would allow them to organize and keep track of their productivity for both old and new ships, while allowing for an average productivity to be calculated.

The proposed measuring system allows the recording of detailed information along the shipbuilding process, and the correct processing of this information gives the yard a tool to measure their productivity for each ship, for each of those processes. When used correctly, and with the cooperation of a sufficiently large number of yards should provide a benchmark among yards, able to indicate if a shipyard is operating in an acceptable efficiency or if it is relatively inefficient, can also be obtained. The careful analysis of the data will also provide insightful information about a yard's shipbuilding process efficiency and which areas require more development.

1.4 Thesis Arrangement

The present thesis was organized sequentially, allowing the reader to obtain a holistic view of a shipyard productivity in a fluent way.

On chapter two the shipbuilding process, shipyard organization and coding systems are briefly studied. Those will later be crucial to correctly define the shipyard cost centers, were all the man hours and expenses associated with the ship are registered, according to their position in the shipbuilding process.

In chapter three it will be studied how can the shipyard productivity be measured. Inputs and outputs are studied separately, and for each a review of the available metrics, and available data sources is made, in the end the most adequate metrics and data sources are proposed.

In chapter four data was gathered for thirty ships, organized by cost centers, and by applying the previously suggested metrics the productivity for each ship is studied. In the end an average shipyard productivity is also calculated.

Lastly, the main conclusions reached throughout this thesis are summarized and recommendations for future studies are left.

2. Shipyard management and productivity

Since the beginning of its activity shipbuilders have used some measure of productivity as a basis for estimating and planning. These metrics are often used to compare their performance with the competition, for tendering and for costs control. The first metrics used were originally measured in the amount of resources used and time spent. Those metrics have constantly evolved, and several metrics are currently available. Some yards will use man-hours, generally man-hour per ton of steel and man-hour per outfit weight. Often countries measure their shipbuilding industry output based on deadweight or gross tonnage. All those metrics share one flaw, which is, they do not account for the difference in complexity nor size between ships. This can lead to misleading results which do not reflect the true built effort of the ship.

In 1977 OECD (Organization for Economic Co-operation and Development) developed the standard CGT (Compensated Gross Tonnage) in order to have a more reliable aggregate metric, which accounted for ship size and complexity, for comparisons of shipbuilding productivity between countries. In 2007 the formula was revised again by OECD providing the system that is still in use today. However, this formula is still not perfect and it has been shown by Lamb *et all* (2001), Craggs *et all* (2004) and Hopman *et all* (2010) that the CGT was far from being a perfect metrics and since its creation it has been continuously developed .

Most of the studies and work done on the shipbuilding process, breakdown structure and group technology were made during the 80’s, mainly by the SNAME (Society of Naval Architects and Marine Engineers), and by the NSRP (National Ship Research Program) both from the USA (United States of America). Both studied intensively the shipbuilding industry, analysing the shipbuilding process and the current best practices, and as result several reports have been issued with information that ranges from very specific technical aspects of the shipbuilding process to the general organization of a shipyard.

The work from the 80’s has been continued and the most recent works done in the area study specific technologies of the shipyard, such as welding, automation and simulation of shipyards to optimize the shipbuilding process and shipyard layout, works such as those done by Andritsos *et al.* (2000), Pires *et al.* (2009), Hopman *et al.* (2010), Krishnan (2012), Pal (2015), Suleiman *et al.* (2017), Guofu *et al.* (2017) and Oliveira (2017).

However, the basis of the current knowledge on the shipyard organization, breakdown structure and production strategy (such as group technology) arouse from the work done on the 80´s and has remained mainly the same.

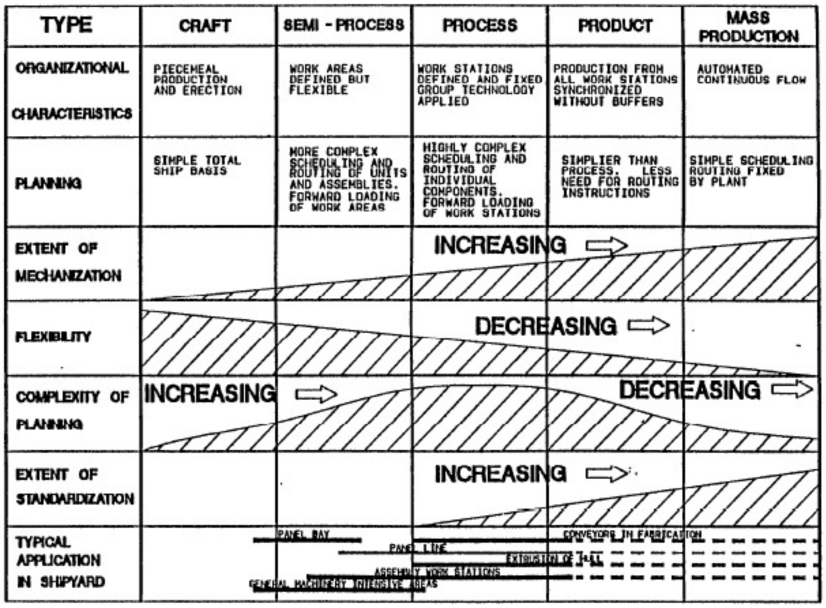
2.1 Shipbuilding Process

In order to identify which factors will influence the efficiency of a shipyard, it is needed first to understand the process or steps involved in shipbuilding.

The process of building a ship is defined by the production strategy of the yard where the construction takes place. A shipyard will decide which strategy is most adequate based on its production volume and the variability of the ships it has scheduled, Lamb (2004). Some yards specialize in building standard ships in high numbers (ships series), while others build only a few highly customized ships. In between there are yards that build several ships at a time, with significant variation between them. Shipbuilding is a peculiar industry, where products are built in small quantity and with high variation among them, which impedes the use of mass production assembly lines as seen in the automotive industry. Even with ship series it is hard to adopt mass production and enjoy its gains, contrarily of most of the modern industries. Nevertheless, efforts have been made to make use of the advantages of mass production strategies and adapt them to shipbuilding, by applying group technology to shipyards, which Lamb (1986) describes as “a method to apply mass production techniques to products that vary widely in type and quantity“.

2.1.1. Production organization

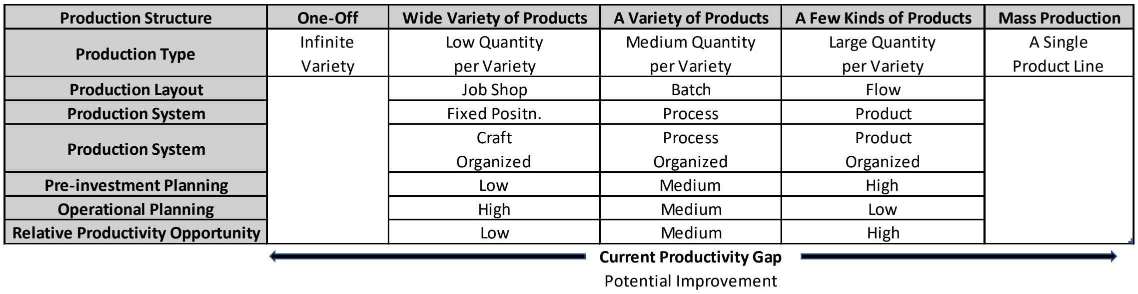
In: “Engineering for ship production”, Lamb (1986) defines five different families of production organizations along with their advantages and disadvantages, and defines the typical application of each type of organization in a shipyard. In Figure 1.2 we can see the characteristics of those five production organizations. On Table 1.1 it is shown the differences between each type of organizations, based on their production structure, where “One-off” is matched with the craft organization and “A Few Kind of Products” to the group organization. It is also shown the productivity gap between one-off and mass production products; group technology manages to increase its productivity compared to craft organization, and while not as productive as mass production it manages to reduce this gap.



TYPE	CRAFT	SEMI - PROCESS	PROCESS	PRODUCT	MASS PRODUCTION
ORGANIZATIONAL CHARACTERISTICS	PIECEMEAL PRODUCTION AND ERECTION	WORK AREAS DEFINED BUT FLEXIBLE	WORK STATIONS DEFINED AND FIXED GROUP TECHNOLOGY APPLIED	PRODUCTION FROM ALL WORK STATIONS SYNCHRONIZED WITHOUT BUFFERS	AUTOMATED CONTINUOUS FLOW
PLANNING	SIMPLE TOTAL SHIP BASIS	MORE COMPLEX SCHEDULING AND ROUTING OF UNITS AND ASSEMBLIES. FORWARD LOADING OF WORK AREAS	HIGHLY COMPLEX SCHEDULING AND ROUTING OF INDIVIDUAL COMPONENTS. FORWARD LOADING OF WORK STATIONS	SIMPLIER THAN PROCESS. LESS NEED FOR ROUTING INSTRUCTIONS	SIMPLE SCHEDULING ROUTING FIXED BY PLANT

Fig. 1.2 - Characteristics of the five main production systems

In: Lamb (1986)



Production Structure	One-Off	Wide Variety of Products	A Variety of Products	A Few Kinds of Products	Mass Production
Production Type	Infinite Variety	Low Quantity per Variety	Medium Quantity per Variety	Large Quantity per Variety	A Single Product Line
Production Layout		Job Shop	Batch	Flow	
Production System		Fixed Positn.	Process	Product	
Production System		Craft Organized	Process Organized	Product Organized	
Pre-investment Planning		Low	Medium	High	
Operational Planning		High	Medium	Low	
Relative Productivity Opportunity		Low	Medium	High	

Tab. 1.1 - Characteristics of the five main production types

Adapted from*:* Lamb (1986)

Lamb (1986) defines the following organizations:

1- Craft Organization (Job Shop)

Organization using well trained and experienced workers to perform many activities in one or a few locations. Most production decisions are left to the craftsman, who may approach each job in a different way. Required engineering data are minimum in scope and can be lacking in accuracy. Craft organizations are difficult to schedule and control.

2- Semi-Process Organization

Organization utilizing well trained and experienced workers but attempting better planning and control by muting similar work processes to specific work areas. Requires more planning effort but scheduling and some control is attainable. Engineering has to be more detailed to enable planning to break down the work into task packaged.

3- Process Organization (Batch)

This is the complete use of specific work areas to perform specialized activities. This enables workers to be trained only in the special activity they are selected to perform. Planning becomes more complex regarding scheduling and material control engineering is prepared for specialized process rather than total product.

4- Product or Group Organization

This type of organization focuses on a type of product, such as flat panels, and links all the processes together to complete the product. It then combines a number of products to make a new larger product, such as an erection module and ultimately the ship’s hull. Planning is simpler as it follows a logical sequence of events. Again, the extent of worker training is limited to those processes utilized in a given workstations. Engineering is prepared to show the product to be processes at a given workstation. Control can be precise due to the many available data points.

5- Mass Production Organization

This type of organization maximizes the use of mechanization, continuous flow lines, and specialization of activities at sequential workstations. Material handling is decided at the time of the facility design. Engineering is more involved in machine instructions, jig and tooling, and quality control data.

2.1.2. Coding and Classification Systems

In group technology, similar products are grouped into families, and the families manufactured in groups of associated workstations. Therefore, a good coding and classification system is essential to identify and group those similar products and processes.

Classification separates product data through similarities into groups or classes, while coding is the system which enables storing and retrieving the classified data so it can be organized, analysed and used for specific purposes. Lamb (1986) proposes a seventeen-digit shipbuilding classification and coding system, where the first ten digits are used for the design classification and the remaining seven for processing classification. This coding system can be consulted on Annex A.

Pal (2015) analysed different work breakdown structures along the entire ship lifecycle, from concept to operation. And also studied the coding systems used in shipyards identifying three as the most relevant: the SWBS (Ship Work Breakdown Structure); SFI (Senter for Forskningsdrevet Innovasjon) group system and PWBS (Product Work Breakdown Structure).

ESWBS Group	Description
000	General Guidance and Administration
100	Hull Structure
200	Propulsion Plant
300	Electric Plant
400	Command and Surveillance
500	Auxiliary Systems
600	Outfit and Furnishings
700	Armament
800	Integration/Engineering
900	Ship Assembly and Support Services

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)

Tab. 1.2 - ESWBS and SFI Groups

In: Pal (2015)

The PWBS is the system produced by Thomas Lamb (1986), which was seen previously, and can be consulted in Annex A.

The SWBS is a system-oriented breakdown used by the U.S. Navy also called ESWBS (Expanded Ship Work Breakdown Structure) and is used to organize and correlate elements for cost, weight, specifications, system function and effectiveness, design, production, and maintenance studies.

The SFI group system was developed at the Norwegian Ship Research Institute and was first released in 1972. The SFI group system is an international standard which is used for a functional breakdown of technical and economic information of ships and offshore units and is currently widely used. It structures and systemizes all the ship's different systems and components through a 3-digit coding structure. This system is also used as a cost work breakdown structure in cost management.

On the SFI system the ship is divided into 10 main groups, from 0 to 9, where 0 and 9 are to be used for costs related to the ship that do not fit into the other main groups. The main groups are divided into 2-digit groups which are sub divided into 3-digit subgroups.

2.1.3. Work Breakdown Structure

In order to identify the groups or classes, so that the coding and classification system can be employed, one must first analyse and break down the shipbuilding process. This is called WBS (Work Breakdown Structure).

In the report 'Product Work Breakdown Structure', by the NSRP (1980), a WBS for shipbuilding is performed, based on the one used by Ishikawajima-Harima Heavy Industries (IHI), which makes use of group technology.

In shipbuilding technology PWBS (Product Work Breakdown System) classifies components to be purchased, parts to be fabricated and plans subassemblies in order to achieve uniform and coordinated workflows. The product-oriented work breakdown structure conforms with the way a ship is built.

The PWBS first divides the shipbuilding process into three basic types of work: Hull constructions, Outfitting and Painting. (Those three types of work are often also adopted as cost centers).

In 1980 the NSRP divided the work process by four aspects:

1- System

A structural function or an operational function of a product, i.e., longitudinal bulkhead, transverse bulkhead, mooring system, fuel-oil service system, lighting system, etc.

2- Zone

An objective of production which is any geographical division of a product, cargo hold, superstructure, engine room, etc., and their sub-divisions or combinations (a structural block or outfit units, a subassembly of either and ultimately a part or component).

3- Area

A division of the production process intro similar types of work problems which can be by:

- Feature (curved vs. flat blocks, steel vs. aluminium structure, small diameter vs. large diameter pipe, pipe material)
- Quantity (job-by-job vs. flow lane, volume of on-block outfitting machinery space vs. volume of on-block outfitting for other than machinery space.)
- Quality (grade of workers required; grade of facilities required.)
- Kind of work (marking, cutting, bending, welding, blasting, bolting, painting, testing, cleaning.)
- Anything else that creates a manifestly different work problem

4- Stage

A division of the production process by sequences, such as, sub-steps of fabrication, sub-assembly, assembly, erection, outfitting on-unit, outfitting on block and outfitting onboard.

In Figure 1.3 a generic work breakdown structure that encompasses the entire lifecycle of the ship, from Inquiry to in-service support, passing through design and production is shown. Different breakdown structures are used for each phase of the ship but are associated throughout all phases. The blue arrows shown in the Figure indicate the associative between the items throughout the ship design phases; those breakdowns will also be used latter for maintenance and service support. Although not shown in the Figure, each work breakdown structure will also have associated a coding, and it will also need to exist associativity between items coding through all phases, so that the item can be traced back to all phases.

From the construction perspective the PWBS would be the most relevant and is often the breakdown structure the yards use building ships, and in cost centers. The PWBS can be consulted in greater detail in Lamb (1986).

2.1.1. Shipbuilding intermediate products

Lamb (2004), decomposes and lists the product families present on a ship into intermediate products, which are divided into two main groups: structural parts and outfitting parts. Painting is usually dealt separately from structures and outfitting but is also essential during the construction, and its planning needs to be coordinated with the steel structures assembly. The intermediate products can be joined into larger assemblies, which are the building blocks of a modern ship, once several of those blocks are joined together the final ship is obtained.

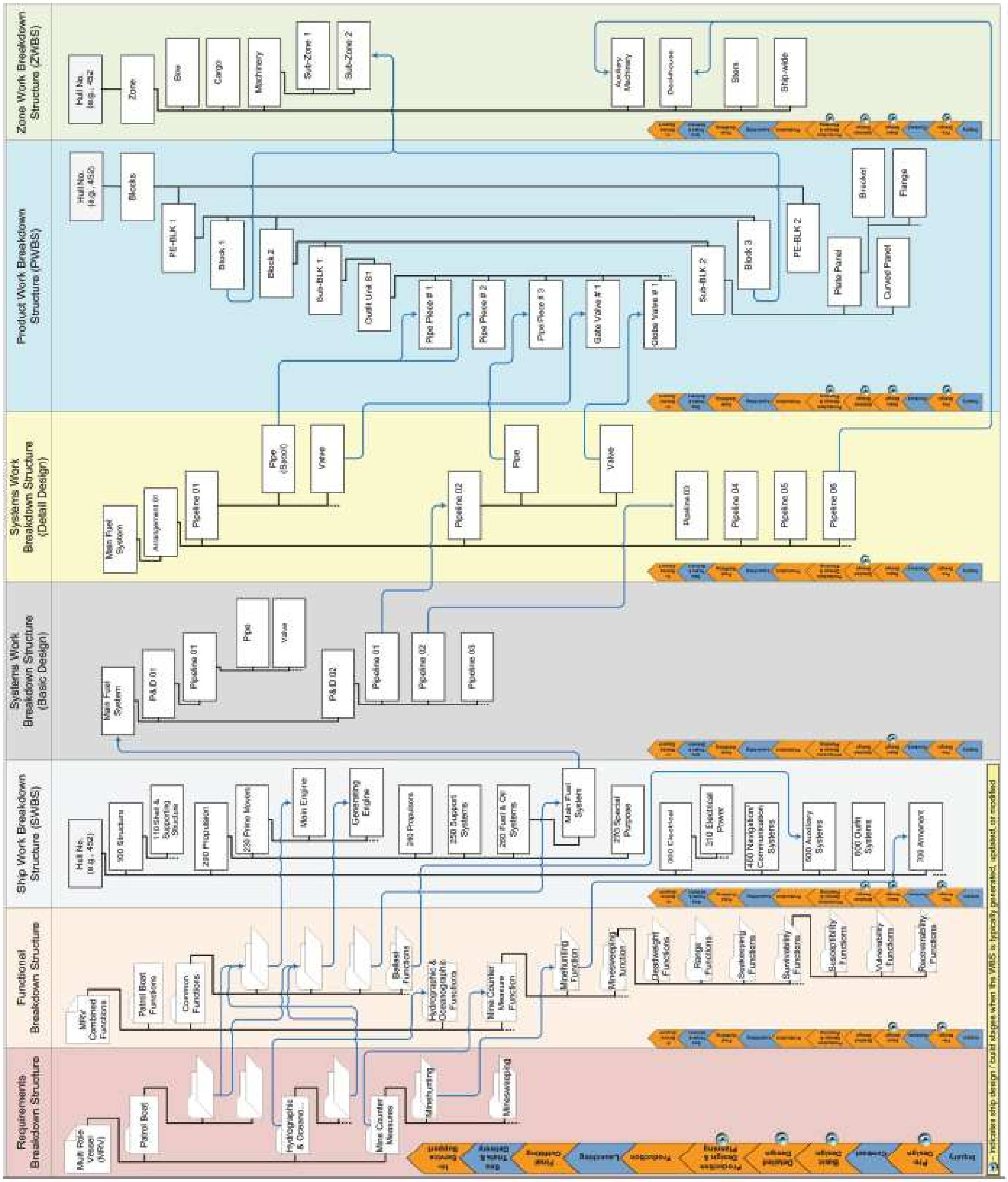


Fig. 1.3 - Generic work breakdown system

In: Pal (2015)

2.1.1.1. Structural parts

Structural parts are comprised of plates (which can be curved or flat) and stiffeners. Those structural parts are joined together to form subassemblies, sub-blocks (i.e. stiffened panels, bulkheads, double bottom), those subassemblies can include outfitting steelwork, such as foundations, supports and ladders. In turn several subassemblies can be joined to form a block, structural unit or module. In Figure 1.4 a generic assembly process, comprised of several intermediate products, for the hull is shown. Oliveira (2017) also studied the fabrication process of ships using blocks and intermediate assemblies.

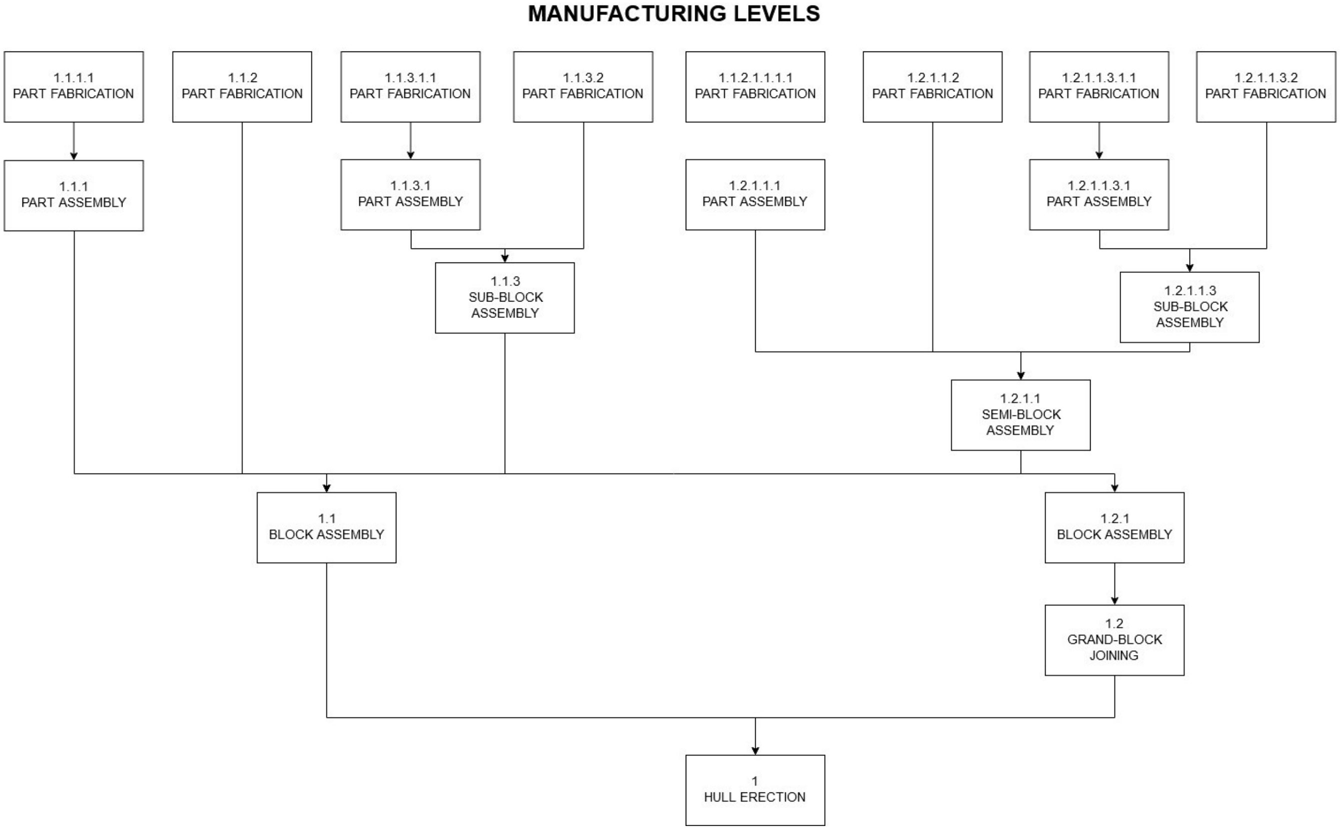


Fig. 1.4 - Manufacturing levels for the block construction method

Adapted from: Lamb (1980)

To make use of group technology and optimize the use of resources and materials to allow the build of several ships simultaneously the intermediate products are grouped into families. The intermediate products are grouped according to the processes they require to go through, so that products which go through the same processes are grouped into the same family and are dealt with together, even if they belong to different blocks, or even ships. This allows yards to approximate the fabrication of those products to that of a production line, and work for several projects at the same workstations, thus optimizing its resources and materials. In Figure 1.5 an example of such a grouping, with intermediate products numbered from one to twenty (which might be plates, curved plates, stiffeners among others), and a total of seven processes (A to G, which can be cutting, marking, bending among others).

Intermediate Products

Intermediate Product	Process A	Process B	Process C	Process D	Process E	Process F	Process G
1	x		x	x			
2		x		x		x	
3	x				x		
4		x				x	
5				x		x	
6	x		x	x			
7		x				x	
8	x				x		x
9	x		x				
10		x		x			
11	x				x		
12	x		x	x			
13		x		x		x	
14	x						x
15			x	x			
16		x				x	
17	x				x		x
18	x		x				
19					x		x
20		x		x		x	

Intermediate Products Families

Intermediate Product	Process A	Process B	Process C	Process D	Process E	Process F	Process G
1	x		x	x			
6	x		x	x			
9	x		x				
12	x		x	x			
15			x	x			
18	x		x				
3	x				x		
8	x				x		x
11	x				x		
14	x						x
17	x				x		x
19					x		x
2		x		x		x	
4		x				x	
5				x		x	
7		x				x	
10		x		x			
13		x		x		x	
16		x				x	
20		x		x		x	

Fig. 1.5 - Intermediate products, product families and association between intermediate products

In: Lamb, 2004

2.1.1.2. Outfitting parts

Outfitting parts comprise of pipe spools (which are classified based on their attributes such as material, surface preparation, bends type among others), HVAC ducts, electrical cables, machined components and assemblies, pipe hangers, wireway hangers and joinery. Those components are joined to form outfit units, assemblies or modules, divided by class, pipe, electrical, accommodation or machinery. There is also distinction among outfitting based on its stage, if it is mounted before or after block assembly.

2.1.1.3. Shipbuilding process

The complete list of intermediate products, for a Group Technology based shipbuilding approach, as proposed by Lamb (2004) can be consulted in Annex B. In Figure 1.6 we can see the workflow for a shipyard using the Group Technology approach.

Recently there have also been additional works done on this area, Bruce *et al.* (2012) presents the historical background, evolution and a simplified shipbuilding process, which is shown on Figure 1.7.

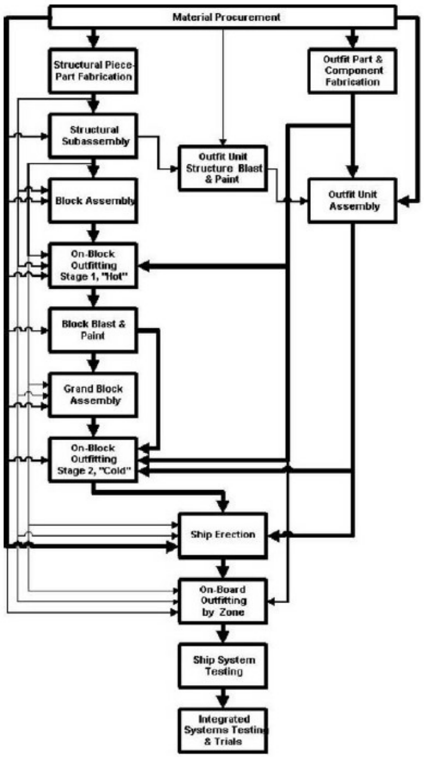


Fig. 1.6 - Shipyard Material and Workflow, for a shipyard employing Group Technology

In: Lamb (2004)

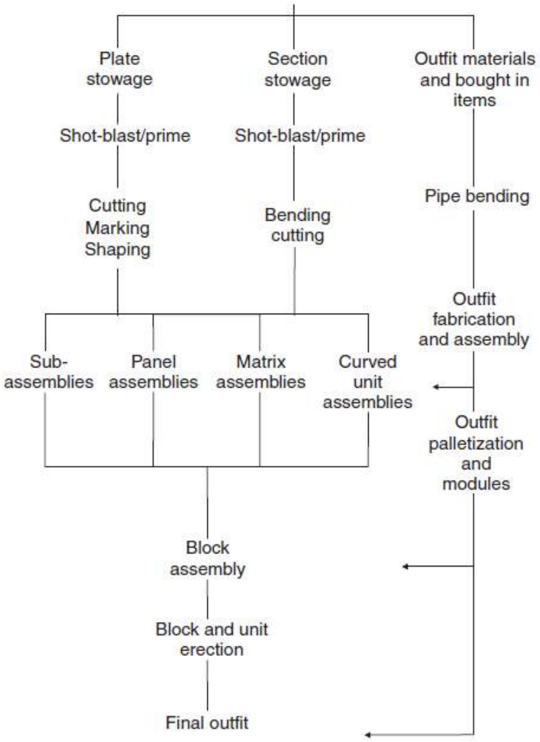


Fig. 1.7 - Shipbuilding process

In: Bruce *et al.* (2012)

A more thorough work was done by Andritsos *et al.* (2000). In their work a breakdown of the generic shipbuilding process is made and can be consulted in Fig 1.8. This breakdown will be applicable to the majority of yards and constructions, with exception of very specialized constructions.

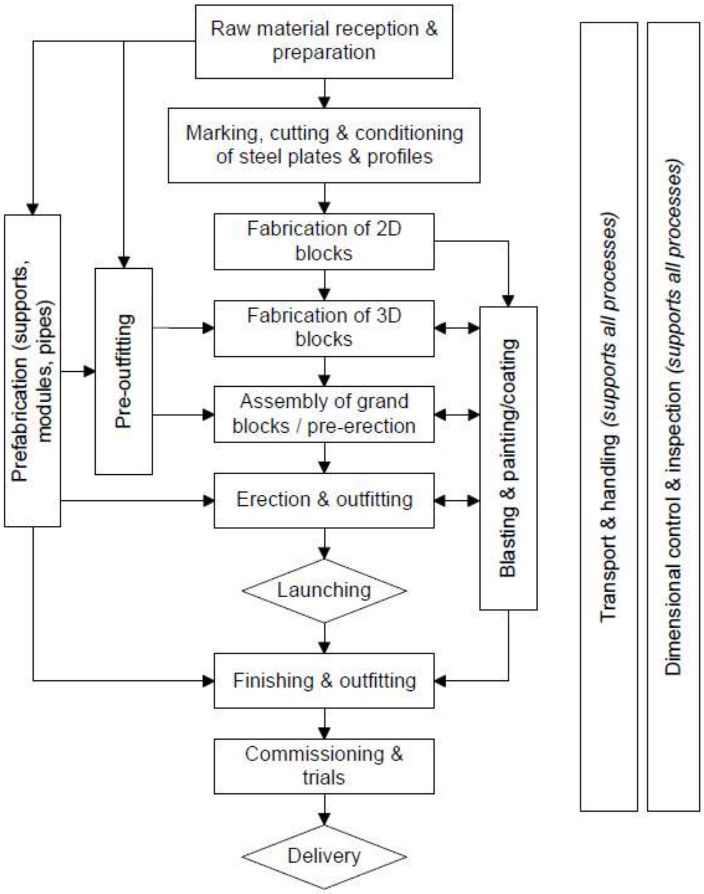


Fig. 1.8 - Shipbuilding production process flow

In: Andritsos *et al.* (2000)

All of the shipbuilding processes shown have as their basis three main areas: structure fabrication, outfitting fabrication and painting. Structural parts are assembled to form bigger assemblies, culminating in blocks that are assembled to obtain the hull. Those structural assemblies, blocks, define the zones of the ship and in parallel to those assemblies (that begin to define the final ship shape and zones) painting and outfitting is carried. Those two activities are concurrent to assemblies, since the earlier the outfitting is fitted on the block, and the block is painted, the easier will be the access and installation of those. Thus, the more percentage of painting and outfitting is made early on, before block assembly the more efficient will be the construction of the ship.

2.1.2. Shipyard Layout

Having made the breakdown of the shipbuilding process it is also possible to derive the shipyard layout most adequate to the shipbuilding process. The ideal yard layout will follow the work and material flow and minimize the distance a part must travel before arriving to its assembly point. This is done by positioning workshops along the assembly zones, depending on the phase in which it is assembled. Parts to be assembled early on are nearer the unit assembly areas while parts to be assembled in a later phase are nearer the berth.

The assembly of the ship is divided into zones that, as seen in the previous chapter, are created by structural parts assemblies and, as with the breakdown structure, the layout of the yard will be built along the structural assembly.

Therefore, the structural fabrication and assembly can be seen as the main line of production. It will start with a store yard where plates and stiffeners are stored, those parts will then have a preparation before being cut and machined. The machined parts will then be assembled into larger parts, which in turn are joined together to form larger blocks. Finally, those blocks will be joined together to obtain the hull. Parallel to the steel production line we will have the outfitting workshops. Those workshops will be placed nearer to the block assembly workshops or dock depending if those parts are to be assembled during the early fabrication of blocks or only after the ship is afloat. This minimizes the travel distance of each outfitting part.

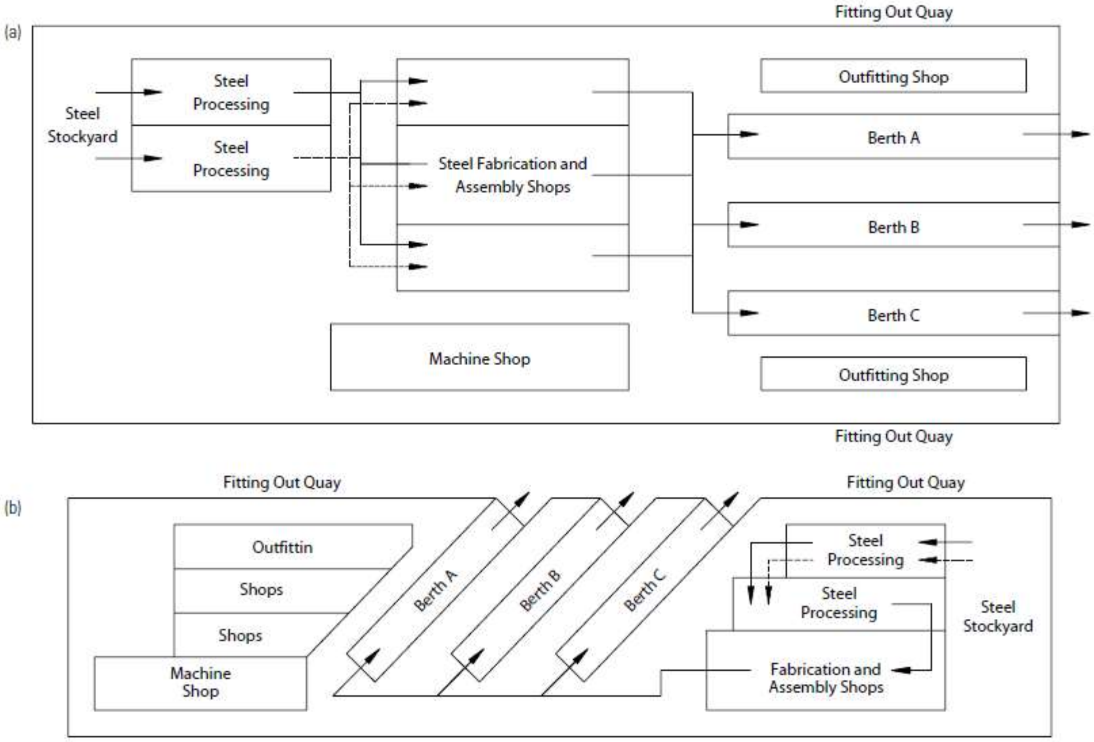


Fig. 1.9 - Basic Shipyard Layouts

In: Lamb 2004

Each yard will seek a layout which is most adequate for its production strategy, which might be a configuration in L, U, linear or parallel, among others. Figure 1.9 shows two basic shipyards layouts, (a) having a straight-line flow arrangement and (b) having a lateral flow arrangement. At all-time the shipyard layout will be constrained by the physical space available, which is linked with the productivity, and shipyards which are unable to employ an optimized layout due to lack of space, will have their productivity negatively affected. Having covered working areas is also relevant when working in regions with adverse climacteric conditions, such as rain, cold or snow, if the working area is exposed to the elements then during periods of worse weather the productivity can be greatly affected.

In Figure 1.10, an Idealized layout for a new shipyard, with no space constraints, is shown. This layout is appropriate for a smaller yard specializing in a few standard type ships with a high throughput.

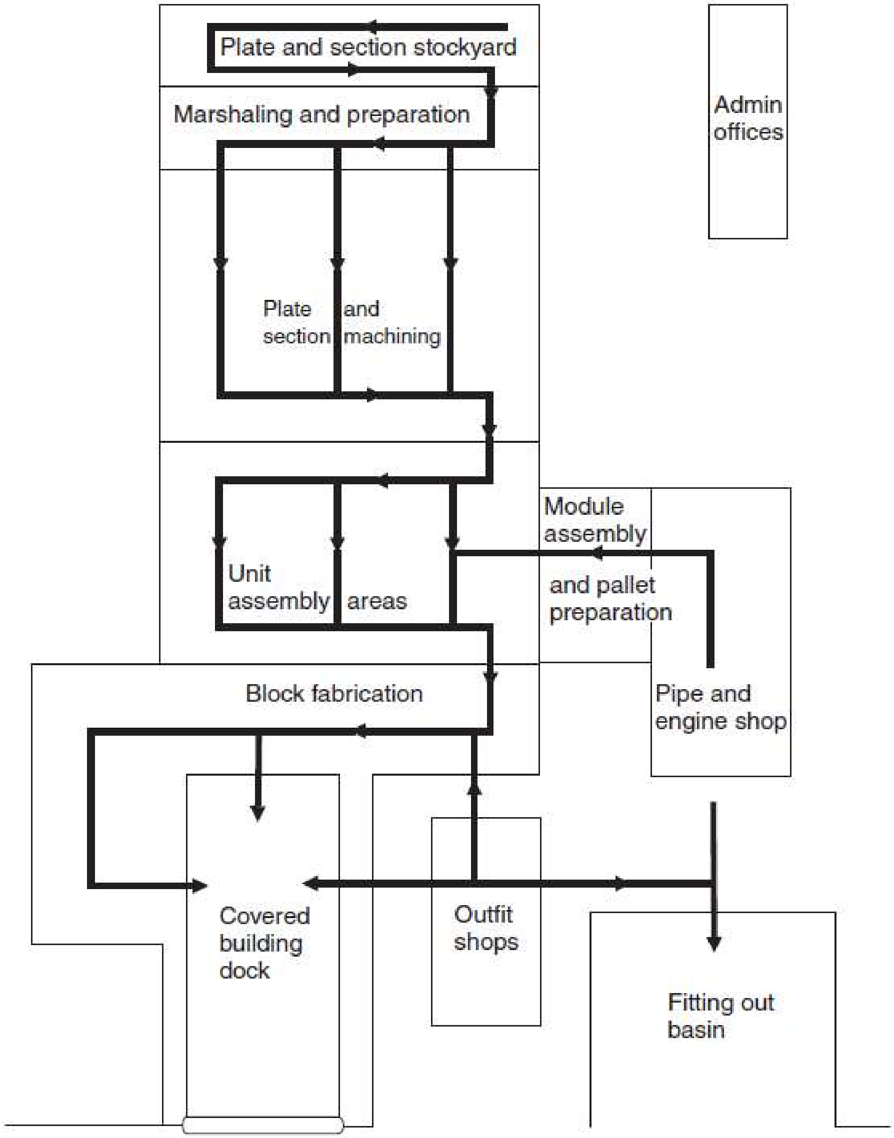


Fig. 1.10 - Shipyard layout

In: Bruce *et al.* (2012)

2.2 Production activities

We have seen the building process of a ship and how coding is used to classify the different components of a ship, but there are more activities associated with shipbuilding, that while not contributing directly to the ship production, are nevertheless essential for a proper organization and operation of a yard. The activities involved in the process of building a ship can be divided in production activities, support activities and engineering, Fig 1.11 shows a simplified organization of the main shipbuilding activities. Production activities includes Hull work (steelwork), outfitting (which includes piping, electrical and HVAC), painting and mechanical works. While support activities are not directly involved but are still essential to support and provide the information needed to produce the ship.

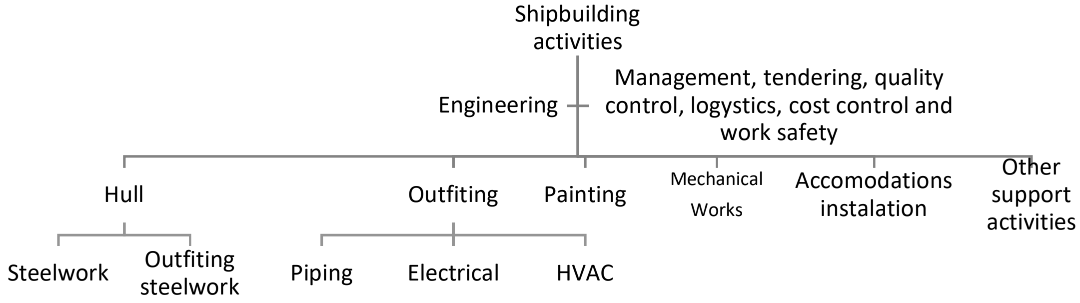


Fig. 1.11 - Shipbuilding activities

Following we elaborate on each of the activities.

Hull:

Hull comprises all the works related to steelwork and outfitting steelwork.

Steelwork includes all major steelwork done in the shipyard, ranging from the marking, cutting of plates and profiles to the fabrication and assembly of those into blocks.

Outfitting steelwork includes all steelwork which is not ship structure, such as seats and walkways. When possible, those outfitting items will be installed on the block during the block fabrication (pre outfitting), which reduces the amount of work to be done after the ship is assembled, which positively affects efficiency. This is only possible when the ship systems project is already at an advanced stage that allows the installation of equipment’s, HVAC and pipes with confidence. When the project is still not developed enough these works will be done after blocks assembly or when the ship is afloat.

Outfitting:

Outfitting is divided into 3 subcategories, Piping, Electrical and HVAC.

Electrical Works:

Includes all the electrical installation on board of the ship, every more often ships have increasing control systems and as such there is an increase on the number of electrical and control components aboard a ship, these works are made by either by a specialized workshop or ever more often subcontracted.

Piping:

Piping comprises the fabrication and installation of all the ship systems on board. Each system is divided in spools, which are then produced individually in the workshop and assembled in the ship. Piping is typically done inhouse on specialized workshops. In some cases, subcontractors may be used.

HVAC:

HVAC comprises of all the ventilation, heating and air conditioning ducts and necessary equipment's. Both HVAC project and construction are often subcontracted to specialized companies or are made by a specialized workshop in the shipyard.

Painting:

Painting includes all the paintwork done in the ship, from the primary, anti-fouling and external coats.

While painting might be sometimes overlooked it is essential that a good paint plan is elaborated. A good paint plan will seek to maximize the amount of structure that is painted before block assembly, while access to tanks and structure is better. This is only possible through good planning that accounts for the steelwork, outfitting and tank testing required in each block.

A well-made paint plan will minimize recoating and will seek to maximize the amount of painting done while the area in question can still be easily accessed.

Accommodations installation:

There's also another important activity on shipbuilding, mainly for passenger and cruise ships, that is one of the final stages and comprises the accommodations installation. Once it was common for shipyards to have carpenters which would do this step, nowadays, however, common practice is to have this activity subcontracted to specialized companies.

Engineering:

Engineering includes all the work spent on project and generating the required production documentation. A good project and design for production are essential and can result in significant costs savings, improve ship quality and contribute to an overall higher efficiency. While shipyards previously would make all the engineering work in house. Nowadays the majority of the project is subcontracted while shipyards maintain only a fix smaller engineering team.

Support:

Support activities are all the activities which do not contribute directly to the production of the ship but are rather activities that serve to support the productive ones. Some of the most significant support activities are scaffolding, transport and cleaning, which can be subcontracted.

There are also other essential activities within the shipyards, such as Management, logistics, tendering, quality control, cost control and work safety are also essential. Which are fundamental for the operation of the yard and have some indirect effect on the production of the ship. Take for example the planning and production engineering work: if done correctly they will reduce the labour required to build the ship.

In this thesis the focus was the areas directly engaged with the ship construction. In future studies it would be relevant to also include the remaining areas and how much of an effect they have on the shipyard efficiency.

2.3 A brief word on project, software and technology

One step easily overlooked is the ship project, the ship design, which was traditionally done in yard but is ever more often being subcontracted, and the production project which is done by the yard and prepares the necessary information to produce the ship, such as drawings, nesting and all other required documentation. The extra hours invested on improving the production project on an early stage can very easily spare great expenses and problems later during the construction of the ship, as well as savings in material and a better build quality.

Even though some components of the ship are following the technology advances, like electronics and automation systems, the general technology involved in constructing the Hull and the ship itself hasn’t evolved much over time.

The software involved in project management and cost control have suffered some improvements over time. One good improvement that is yet to be implemented in many shipyards uses is the identification of each production part through barcodes that allows quick and cheap updates of production control and stock inventory.

The software used for the ship design and shipbuilding project development has recently suffered good improvements, both regarding the mathematical, and FEA (Finite Element Analysis), models to simulate the structural and hydrodynamic design, and by the employment of integrated and BIM (Building information model) software.

Integrated design software, such as ShipConstructor and NUPAS, among others contributes to an overall increase in efficiency because integrating all specialties in one it allows a holistic view of the project, which helps avoiding collisions and conflicts during construction. It allows a more production friendly design with overall lower work content, less resources needed, minimizing reworks and allowing for corrective actions to be taken before production starts, thus providing better quality and reducing the amount of reworks. Finally, BIM software such as REVIT MEP (Mechanical, electrical, and plumbing) is a special type of integrated design that allows easy changes to the designs because it automatically produces the updated drawings, scheduling and quantity estimates.

2.4 Summary

For a yard to prosper it is essential to identify the production strategy most adequate to its business model. Often Group Technology will be the most adequate, allowing for variation between ships while making use of some of the advantages of mass production.

Also fundamental for the modern yard is the use of a coding system and work breakdown structure. The work breakdown will be dependent on the production strategy adopted by the yard and allows the yard to keep a systematic approach to shipbuilding. The use of a coding system allows the yard to manage and keep track, in an organized way, of the large amount of data for each project.

The employment of both work breakdown structure and coding system allows the yard to keep track of all the data for all the projects, and keep it organized. This is vital to allow for knowledge to be kept between projects (by keeping information of previous projects easily accessible the yard will be able to use the solutions used on previous projects to tackle new problems), and to keep an accurate registry of resources spent, which is essential for the cost centers and to keep a track of the shipyard efficiency.

It then becomes possible to measure the current efficiency and identify the bottleneck/limiting factors on the yard. Based on this information, and on the current industry wise best practices it becomes possible to identify the areas which improved would yield the biggest increase and efficiency, create and implement a plan to develop those areas.

Regarding how to measure the shipyard productivity, currently the most employed metric is Man Hour spent per CGT, which manages to account for the differences in ships size and complexity.

CGT is not without its flaws, but recent efforts have been to find the CGT coefficients for naval vessels and super yachts.

3. Measuring Shipbuilding productivity

While the studies shown on the previous chapter focuses more on the working and organization of shipyards, there have also been studies that focus mainly in comparing shipyards, generally countrywide comparisons, and compare them with the current international best practices, using the results to advise course of actions in order to improve national shipyards.

Some of the best documented available studies have been made by NSRP for America, there have also been some good works done by OECD and European Commission. In these studies, the Asian yards (Japan and South Korea) are generally the top-ranking yards that set the best practices ranking, requiring fewer manhours per CGT. Figure 1.12 shows a study from 1992 where Japan and South Korea score the best results in best practice rating.

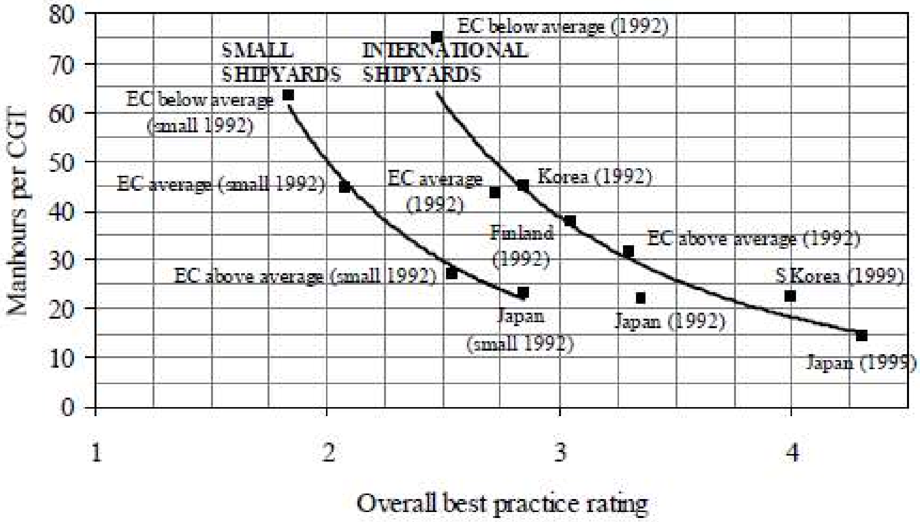


Fig. 1.12 - International competitive performance
In: NSRP (2001)

3.1 Concept of productivity

Productivity is by definition the capacity of producing something. Depending on the finality of the productivity evaluation, the way to measure it may vary. For some, productivity would be the capacity to produce big quantities (how many production units the shipyard can produce in a determined amount of time. For others, productivity would be the capacity of producing using a reduced amount of resources (spent resources per produced unit). Another way to define or measure productivity, from an economic point of view, would be the capacity to produce in a profitable way (profit obtained per produced unit).

So far, there still isn't a universal standard definition and measuring system for shipbuilding productivity measurement. In "A Scientific Approach to Measure Shipbuilding Productivity" commander Krishnan (2012) analyses the productivity measurement system for shipbuilding, mentioning the difficulty of calculating total productivity and explores the use of multifactor efficiency and the use of DEA (Data Envelope Analysis), proposing a scientific method for measuring shipbuilding productivity. The definition and quantification of productivity may have different goals or uses, and each will generally use different metrics. Krishnan (2012) defines some of the usages of productivity measurement as being benchmark performance, value of comparison, measurement of production capacity, resource utilization and measure profitability, detailed below:

Benchmark performance:

In benchmark performance, the numerical value of productivity is used as a benchmark by a shipyard to evaluate its own production and performance. If the productivity were to be defined as the value of CGT/Manhour, in 2009 the average CGT/Manhour for Japanese shipyards was 0.121 (Jiang *et al.*, 2011), one of the goals for a Japanese yard could be to increase the CGT/Manhour to 0.142 in a period of five years.

Value for comparison:

Value for comparison can be used to compare shipyards or shipbuilding countries based on the value of its production in a determined amount of time. For example, if the productivity were to be defined as the production value per worker in year X, then one could compare production values for China ($9.000/worker), Japan ($550/worker) and South Korea ($480/worker), (Collins *et al.,* 2008).

Measurement of production capacity:

The production capacity of a yard or a nation is a more strategic and less economic measurement that focuses on the capacity to produce in quantity. It is often measured in DWT and GT; however recent OECD studies have started adopting CGT as well. For example, in 2011 Japan produced a record of 31 410 459 DWT (OECD, 2016).

Resource utilization:

The resource utilization productivity evaluation focuses on the efficiency of various resources usage in shipbuilding. Examples of this are “tons of steel fabricated/number of employees” or “annual CGT/shop area”. This gives an index of how resources such as labour, and shop area are utilized by a shipyard.

Measure profitability:

Profitability is a relation between of the production cost of a ship and the price at which it is sold that focuses uniquely on the profits of the production. If the selling price is considered as output and the production cost as input, then the ratio sold price / production price can be seen as a productivity unit or measurement. This unit of measure is not commonly used because shipyards do not share cost data.

Table 1.3 shows some productivity evaluations for Europe, Japan, Korea and China in 2007: CGT/employee (Benchmark performance), man hours/CGT (Benchmark performance), Steel tonnes/worker (benchmark performance), Steel tonnes/shop area (Resource utilization), CGT/shipyard total area (Resource utilization), SC/total employees (Production capacity), total employees/total area (Resources utilization), annual CGT/Shop Area (Resource utilization), and CGT/building berth area (Resources utilization).

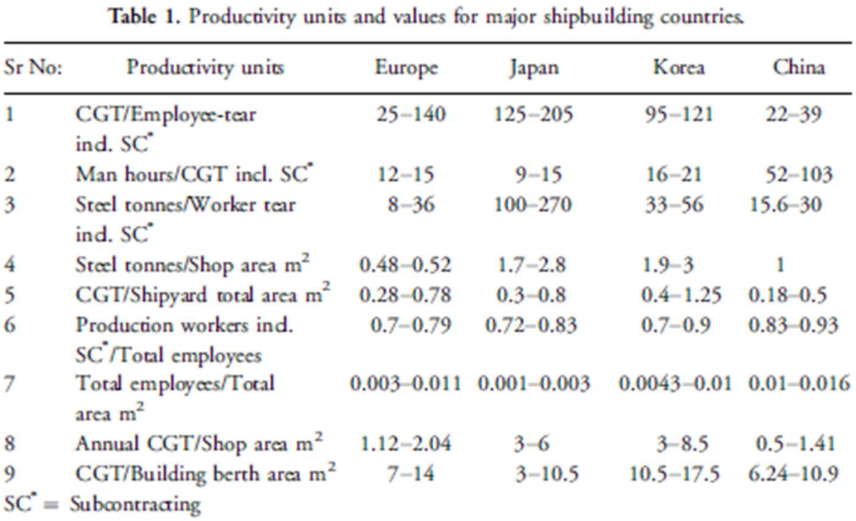


Table 1. Productivity units and values for major shipbuilding countries.

Sr No:	Productivity units	Europe	Japan	Korea	China
1	CGT/Employee-tear incl. SC^*	25–140	125–205	95–121	22–39
2	Man hours/CGT incl. SC^*	12–15	9–15	16–21	52–103
3	Steel tonnes/Worker tear incl. SC^*	8–36	100–270	33–56	15.6–30
4	Steel tonnes/Shop area m^2	0.48–0.52	1.7–2.8	1.9–3	1
5	CGT/Shipyard total area m^2	0.28–0.78	0.3–0.8	0.4–1.25	0.18–0.5
6	Production workers incl. SC^*/Total employees	0.7–0.79	0.72–0.83	0.7–0.9	0.83–0.93
7	Total employees/Total area m^2	0.003–0.011	0.001–0.003	0.0043–0.01	0.01–0.016
8	Annual CGT/Shop area m^2	1.12–2.04	3–6	3–8.5	0.5–1.41
9	CGT/Building berth area m^2	7–14	3–10.5	10.5–17.5	6.24–10.9

SC^* = Subcontracting

Tab. 1.3 - Productivity and values for major shipbuilding countries

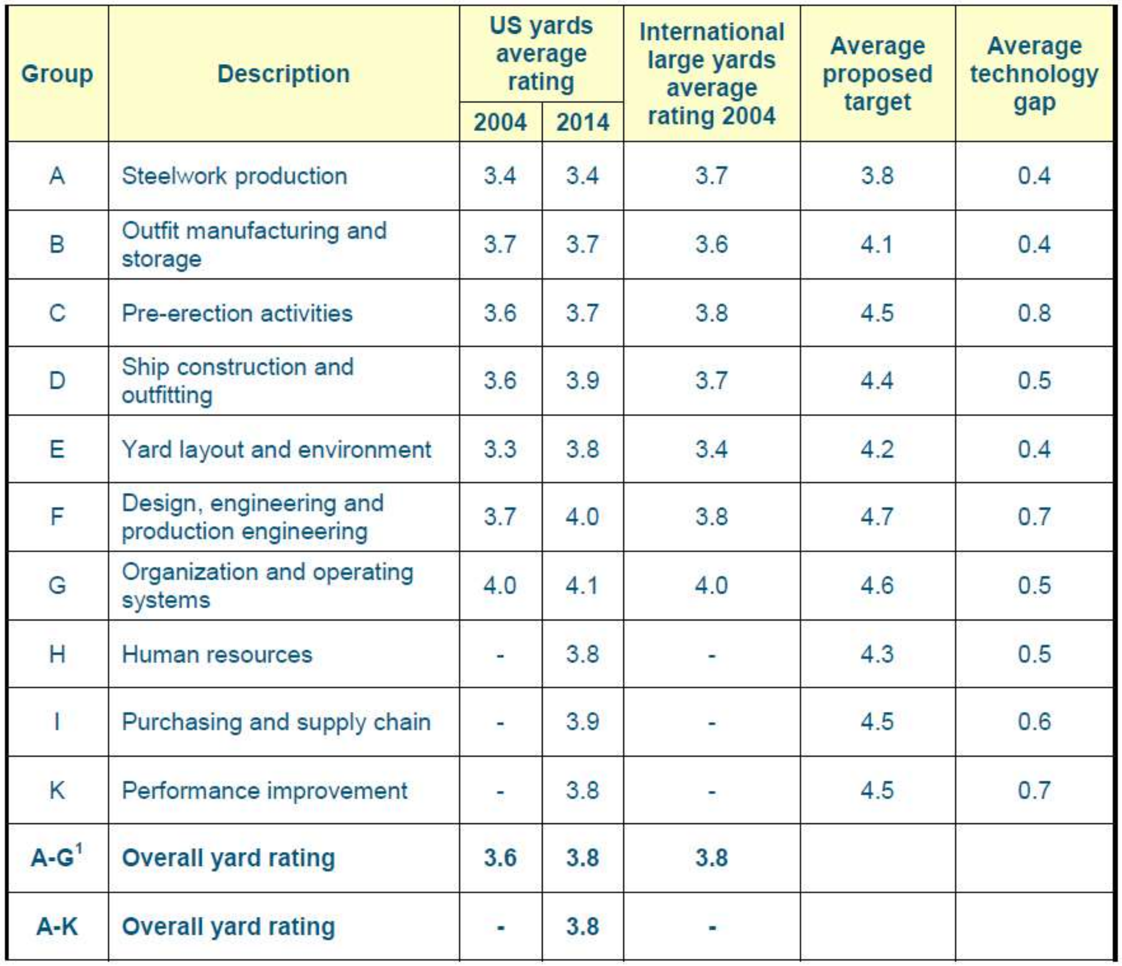
In: Lamb (2007)

3.2 Inputs for productivity measurement

Productivity measurement tries to quantify, for a certain finality in view, the productivity of shipyards or countries shipbuilding industries. Several methods have been proposed and used over time and different measurement methodologies require different inputs.

There is a large amount of possible inputs. If one thinks of a simple production task such as a worker using a gas torch to cut a plate, then the inputs may be the time spent by the worker to cut the plate (labour), the amount of gas used on the torch (consumables), and the price of the torch with its respective amortization (capital input). When we escalate from a simple soldering task to the complex activity of building a ship, the amount of possible inputs escalates in such a way that it turns out unviable to measure and keep track of them all. For this reason, depending on the finality of the productivity measurement, different authors have identified and categorized what they consider the most relevant inputs.

First Maritime International (2016), divided the shipyard into 10 main areas, which are then subdivide further into elements. Those elements, and areas where benchmarked, being assigned a value between 1 to 5 (where 5 would represent the state of the art), this value in then compared with the market average ratings and then an average target is proposed. This resulted in more than one hundred elements being evaluated and benchmarked. These studies are very thorough and provide a deep analysis of the yard, allowing for the technology gap to top ranking yards to be found. The disadvantage is the extensive, and thorough, amount of data required to build a database that would allow the comparison of yards. There is also some reluctance from yards to provide such specific data.



Group	Description	US yards average rating		International large yards average rating 2004	Average proposed target	Average technology gap
		2004	2014			
A	Steelwork production	3.4	3.4	3.7	3.8	0.4
B	Outfit manufacturing and storage	3.7	3.7	3.6	4.1	0.4
C	Pre-erection activities	3.6	3.7	3.8	4.5	0.8
D	Ship construction and outfitting	3.6	3.9	3.7	4.4	0.5
E	Yard layout and environment	3.3	3.8	3.4	4.2	0.4
F	Design, engineering and production engineering	3.7	4.0	3.8	4.7	0.7
G	Organization and operating systems	4.0	4.1	4.0	4.6	0.5
H	Human resources	-	3.8	-	4.3	0.5
I	Purchasing and supply chain	-	3.9	-	4.5	0.6
K	Performance improvement	-	3.8	-	4.5	0.7
A-G[1]	**Overall yard rating**	**3.6**	**3.8**	**3.8**		
A-K	**Overall yard rating**	**-**	**3.8**	**-**		

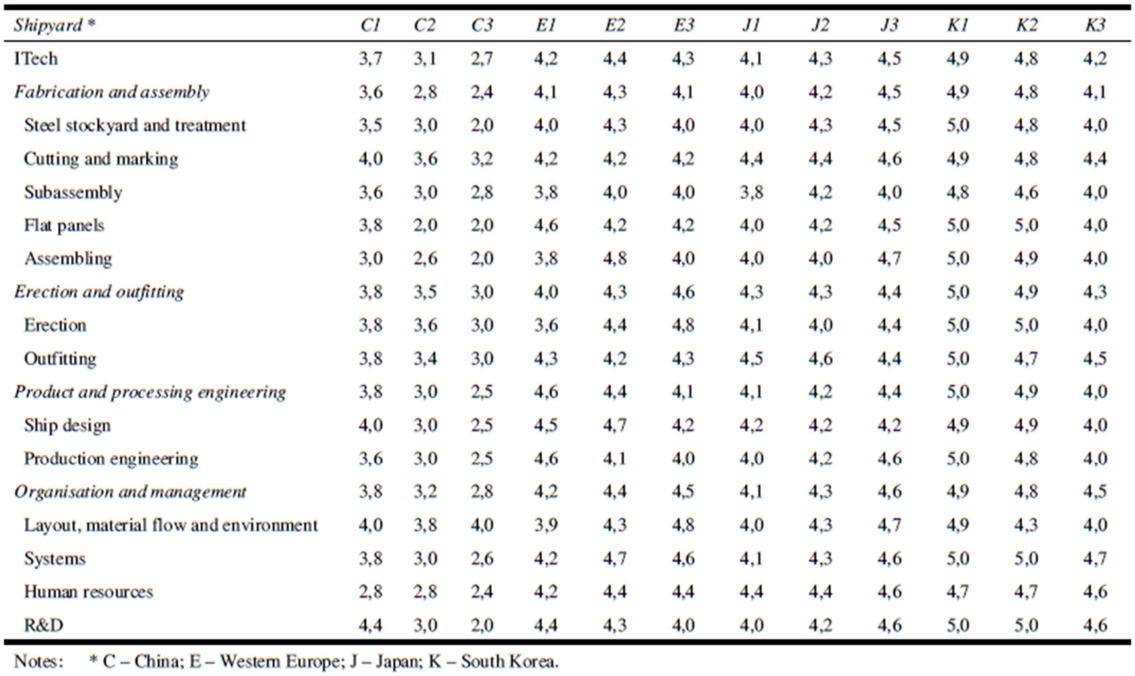
Tab. 1.4 - Average technology gaps

In: First Maritime International (2016)

Krishnan (2012) focuses on inputs such as labour (measured as man-hours/man-days man-month/man-year), ship launching area, shop floor area and total shipyard yard, among others.

Pires *et al.* (2009), presents production cost, building time and quality as the basic criteria to evaluate the performance of a shipyard from the competitiveness point of view. While capacity (in terms of total area, erection area and capacity for moving blocks), industrial environment (Production chain organization, workforce and shipbuilding policies) and technology are presented as shipbuilding indicators and influencing factors.

With a combination of several technological indicators, it is possible to calculate a technological development index that allows to compare different yards, like the comparison made by Pires *et al.* (2009) presented in Table 1.5.



*Shipyard **	*C1*	*C2*	*C3*	*E1*	*E2*	*E3*	*J1*	*J2*	*J3*	*K1*	*K2*	*K3*
ITech	3,7	3,1	2,7	4,2	4,4	4,3	4,1	4,3	4,5	4,9	4,8	4,2
Fabrication and assembly	3,6	2,8	2,4	4,1	4,3	4,1	4,0	4,2	4,5	4,9	4,8	4,1
Steel stockyard and treatment	3,5	3,0	2,0	4,0	4,3	4,0	4,0	4,3	4,5	5,0	4,8	4,0
Cutting and marking	4,0	3,6	3,2	4,2	4,2	4,2	4,4	4,4	4,6	4,9	4,8	4,4
Subassembly	3,6	3,0	2,8	3,8	4,0	4,0	3,8	4,2	4,0	4,8	4,6	4,0
Flat panels	3,8	2,0	2,0	4,6	4,2	4,2	4,0	4,2	4,5	5,0	5,0	4,0
Assembling	3,0	2,6	2,0	3,8	4,8	4,0	4,0	4,0	4,7	5,0	4,9	4,0
Erection and outfitting	3,8	3,5	3,0	4,0	4,3	4,6	4,3	4,3	4,4	5,0	4,9	4,3
Erection	3,8	3,6	3,0	3,6	4,4	4,8	4,1	4,0	4,4	5,0	5,0	4,0
Outfitting	3,8	3,4	3,0	4,3	4,2	4,3	4,5	4,6	4,4	5,0	4,7	4,5
Product and processing engineering	3,8	3,0	2,5	4,6	4,4	4,1	4,1	4,2	4,4	5,0	4,9	4,0
Ship design	4,0	3,0	2,5	4,5	4,7	4,2	4,2	4,2	4,2	4,9	4,9	4,0
Production engineering	3,6	3,0	2,5	4,6	4,1	4,0	4,0	4,2	4,6	5,0	4,8	4,0
Organisation and management	3,8	3,2	2,8	4,2	4,4	4,5	4,1	4,3	4,6	4,9	4,8	4,5
Layout, material flow and environment	4,0	3,8	4,0	3,9	4,3	4,8	4,0	4,3	4,7	4,9	4,3	4,0
Systems	3,8	3,0	2,6	4,2	4,7	4,6	4,1	4,3	4,6	5,0	5,0	4,7
Human resources	2,8	2,8	2,4	4,2	4,4	4,4	4,4	4,4	4,6	4,7	4,7	4,6
R&D	4,4	3,0	2,0	4,4	4,3	4,0	4,0	4,2	4,6	5,0	5,0	4,6

Notes: * C – China; E – Western Europe; J – Japan; K – South Korea.

Tab. 1.5 - Example of technological development index

In: Pires *et al.* (2009)

In 2005, Coelli *et al.* divides inputs into five major types, discussed below: Capital, Labour, Energy, Material and Purchased Services, aggregating the last three as a single input.

3.2.1. Labour inputs

One of the major input categories is labour inputs, which measures or quantifies the human work employed to produce the output and can be seen as the human time and/or effort employed.

Labour inputs may be classified into several different types, in which case it may become necessary to derive and aggregate. Both the composition, quality and level of skill of the labour (skilled or unskilled, usually based on the educational qualifications required to do the job) should be taken into account (OECD, 2001). A differentiation between types of labour can also be obtained by using an index number, like those proposed by Coeli *et al.* in his study.

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. For this, employers may need to be classified by their qualifications (such as welder, engineer and manager, among others). A more simplified way of classifying employees is using two major categories – production employees (known as blue collar workers, associated with production) and non-production employees (known as white collar workers, generally associated with engineering, management, planning, procurement, quality and security). With sufficient data, taken from several yards, this differentiation between labour types could lead to conclusions about ideal ratios of blue to white-collar workers.

OECD (2001) recommends hours worked as the preferable metric indicator of labour, as opposed to paid hours since the last will also include hours paid but not worked, due to vacations, personal leaves, holidays and illness. Therefore, the use of paid hours can lead to a biased growth of hours worked.

Another way to measure labour is the total wages and salaries bill. However, as Coelli *et al.* (2005) points out, for yards on different countries, sometimes even different regions, wages can have considerable variations which would need to be addressed. As OECD (2001) states, when using total wages and salaries bill it is necessary to adjust for differences in wage and salary levels faced by different enterprises (due to location) and take into account that wages are affected by the quantity and composition of labour.

However, it is possible to convert total wages input into paid hours of labour input, by knowing the average price per hour of a worker.

Sousa (2019) states that in 2007, a naval industry worker in Portugal would have an average salary of 25€/h (value including all costs with average worker, both belonging to the company and subcontracted workers). To change from paid hours to worked hours, for the same year, we need to find the ratio between worked hours / paid hours. In 2007, a worker in Portugal would be paid 40 h/week (Diário da República nº. 30/2009, article 203) and according to Figure 1.13 would work 35.5 h/week (shipyard workers correspond to the industry indicator). This results in a ratio of 0,887 worked hours / paid hours. If a hypothetical small fishing vessel built in Portugal in 2007 had a total wages cost of 100 000€, it means that it would have had approximately 100.000/(25€/0,887) = 3.548 worked hours. In the hours worked there will be productive and non-productive hours included, where the productive are the hours where the worker is engaging on his task, while non-productive hours are the portion of the worked hours when that the worker is not engaged on productive tasks, such as dislocation to work area, which on a yard can be a significant amount of time.

3.2.1. 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 shown in Pries *et al.* (2009) the area of the yard should also be considered as a productive asset.

Ideally capital assets would be measured used the PIM (Perpetual Inventory Method).

This method classifies the yard assets into heavy machinery, small machinery, buildings and equipment's.

In order to find their current value, Coelli *et al*. (2005) presents four steps for measure of capital:

1. Time series of investment expenditure on the asset over a sufficiently long period, depending on the productive life of the asset.
2. Secondly it is required to produce the price index numbers to deflate the invested expenditure. An appropriate deflation series should be used for each item category considered.
3. The retirement pattern for the assets must be obtained, which depend on the service life and utilization pattern of the asset. This information must be obtained through surveys, manufacturers or company records. The most commonly used patterns are: linear, delayed linear, bell-shaped, simultaneous exit and Winfrey mortality functions.
4. Lastly the age-efficiency pattern of the productive asset is required. These patterns reflect the wear of the assets and their consequent loss of the productive capacity.

Anos	Sectores de actividade económica					
	Total	Agricultura e Pesca	Indústria	Comércio	Bancos e seguros	Administração pública, Educação e Saúde
2001	36,0	37,0	36,4	38,1	34,7	32,7
2002	35,7	37,0	36,0	37,8	35,0	32,4
2003	35,3	37,4	35,9	37,3	34,8	32,1
2004	35,4	37,2	36,1	37,7	36,2	32,2
2005	35,7	36,8	36,6	37,8	35,1	32,7
2006	35,7	36,7	36,8	37,5	34,9	32,5
2007	35,2	35,3	35,9	37,2	35,2	32,3
2008	⊥35,1	⊥36,0	⊥36,2	⊥36,7	⊥34,9	⊥32,1
2009	35,0	34,4	35,9	36,9	35,7	32,5
2010	35,5	35,9	36,3	37,0	35,6	32,9
2011	⊥34,9	⊥36,1	⊥36,5	⊥36,0	⊥36,9	⊥32,2
2012	34,7	34,9	36,1	36,2	37,3	32,6
2013	34,9	35,9	36,2	36,4	37,1	33,1
2014	35,0	33,5	35,9	36,1	36,2	33,8
2015	34,9	35,0	35,9	35,8	35,9	33,9
2016	34,2	33,7	35,3	35,6	35,9	32,6
2017	34,2	34,7	35,4	35,8	35,9	32,0
2018	34,2	34,7	35,5	35,4	35,7	31,9

Fontes/Entidades: INE, PORDATA
Última actualização: 2019-02-12

Fig. 1.13 - Average weekly hours worked for Portuguese workers
In: Pordata, consulted on 10/2019

This method is quite comprehensive and accounts the aging and loss of efficiency of the asset. However, it requires the investment history of the asset as well as an appropriate price index number for each asset. The amount, and specify, of data required makes this method unsuitable for comparison among yards.

Therefore, an alternative measure of capital must be considered. Coelli *et al*. (2005) presents the following alternative measures of capital:

1. Replacement value: An undepreciated value of capital stock held by a firm should, in theory, be equal to the undepreciated value of capital stock in constant process. Estimating the replacements costs of all items of firms amounts to a large-scale survey of assets.
2. Sale price: This is market price obtained from the sale of an enterprise. Estimates of capital stocks from sale prices could be unreliable.
3. Physical measures: Use of some physical measures or proxies. Classify capital into broad categories and identify some simple measures. Ex: buildings, small machinery, heavy machinery, vehicles, total horsepower of a machinery etc. Variation in quality of the indicators is a major problem. Requires an inventory from the company.
4. Other measures: Other measures of capital stock include the undepreciated and depreciated capital stock. Such values are routinely reported in annual accounts of the enterprises.

From the alternative measures of capital two option stand out as the ones which have the information required 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.

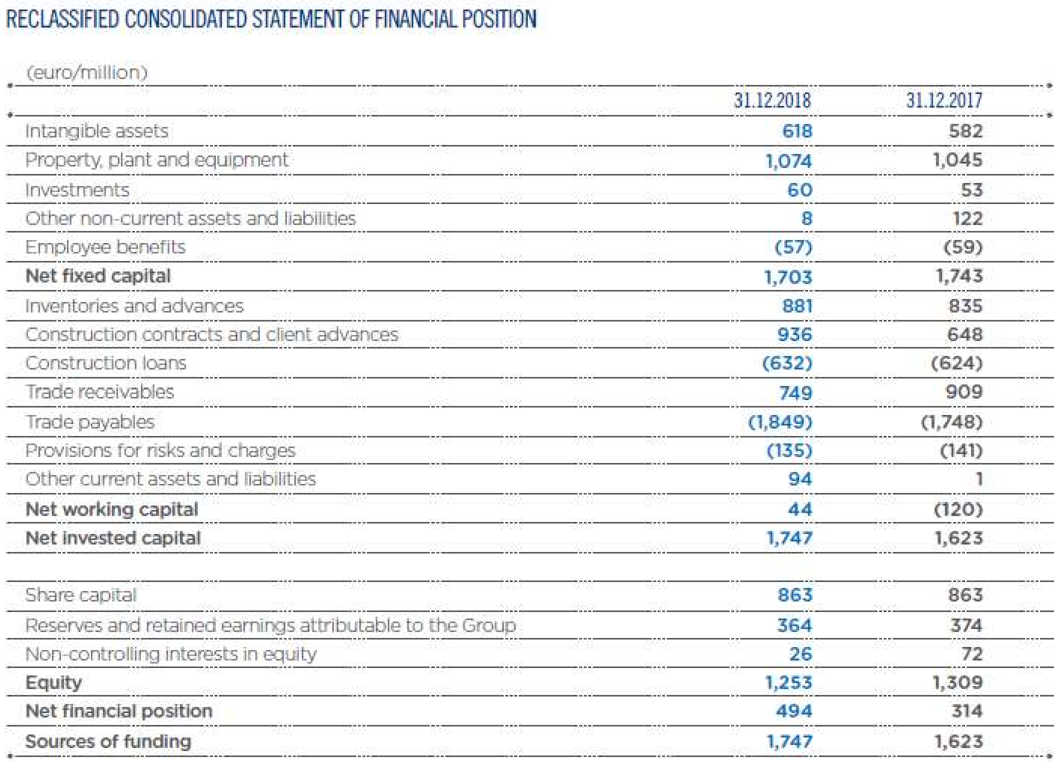
For these reasons the depreciated capital stock of the yard is a preferable method, since the majority of yards will either publish annual financial reports or keep track of their depreciated capital stock for finances purposes. In Figure 1.14 such an example can be seen for Fincantieri, which has the yard depreciated capital stock under "Property, plant and equipment".

3.2.1. Energy, materials and purchased services inputs

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 a good theme for an economy's master's thesis. 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.

As seen previously the services of painting, interiors, insulation, cleaning, HVAC and Scaffolding, and all 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.

Energy expenses should be obtained from the yard accounts.



RECLASSIFIED CONSOLIDATED STATEMENT OF FINANCIAL POSITION

(euro/million)	31.12.2018	31.12.2017
Intangible assets	618	582
Property, plant and equipment	1,074	1,045
Investments	60	53
Other non-current assets and liabilities	8	122
Employee benefits	(57)	(59)
Net fixed capital	**1,703**	**1,743**
Inventories and advances	881	835
Construction contracts and client advances	936	648
Construction loans	(632)	(624)
Trade receivables	749	909
Trade payables	(1,849)	(1,748)
Provisions for risks and charges	(135)	(141)
Other current assets and liabilities	94	1
Net working capital	**44**	**(120)**
Net invested capital	**1,747**	**1,623**
Share capital	863	863
Reserves and retained earnings attributable to the Group	364	374
Non-controlling interests in equity	26	72
Equity	**1,253**	**1,309**
Net financial position	**494**	**314**
Sources of funding	**1,747**	**1,623**

Fig. 1.14 - Fincantieri 2018 annual report, depreciated capital stock (property, plant and equipment) *In*: Fincantieri (2018)

3.3 Outputs of Productivity measurement

Traditionally the main product being built in shipyards is the ship. Nowadays there are some yards which have shifted production from ships to other marine structures such as offshore platforms while some yards will occasionally also produce other types of steel structures. We will focus on the shipbuilding industry, for other marine structures other metrics would need to be used.

While a ship is the ultimate output of a yard, it is not an adequate measure, due to the variation in complexity and size. Not all ships are equal - we have only to think on the difference in complexity and size between a 150m cruise ship and a 30m fishing vessel to understand that simply considering the ship as the yard output without taking into account the complexity and size of the ship would result in a meaningless comparison, unless the comparison comprised uniquely shipyards building exactly the same ships.

Therefore, there is a need for a metric that accounts for the actual work required to build ships with different complexity and size, allowing the comparison between yards that build different types of ships.

3.3.1. CGT

From the existing metrics available to measure productivity, the Compensated Gross Tonnage is the most recommended one since it takes into account and adjusts for the complexity and size of the ship and is the best approach to provide an equilibrate comparison between different ships. CGT is often the recommended metric to measure shipbuilding productivity, recommended and used, among others, in the works of Lamb *et al.* (2001), Pires *et al.* (2009) and Krishnan (2012), among others.

Neither DW nor GT accounts for ship complexity; weight of outfit and weight of steel by themselves also do not account for the ship complexity, even though the ration between outfit weight and steel weight is related to the ship complexity, Cragg *et al.* (2004), derived a base CGT coefficient for naval surface ships as a function of this ratio. The CGT (compensated gross tonnage) is the most adequate as it addresses both those issues. CGT is a measure of shipyard output which begun to be developed at late 1960s/early 1970s by the CESA and SAJ as a metric that would take into account both ship size and complexity and is described by the OECD as “CGT is a unit of measurement intended to provide a common yardstick to reflect the relative output of merchant shipbuilding activity in large aggregates such as “World”, “Regions” or “Groups of many yards”, that reflects workload and accounts for complexity (output, design., working methods, …)”. Since its inception has been revised. In 2007 the current, improved, CGT system was developed (OECD, 2007).

The CGT of a ship can be calculated with Equation 1.1 and requires only the GT of the ship and two coefficients, A and B which depend on the type of ship and can be found on Table 1.6.

$$cgt = A * gt^{B}$$

Eq. 1.1. - CGT calculation equation

In: OECD (2007)

Through recent works made in this area it became possible to calculate the CGT for naval vessels and mega yachts. However, those coefficients are far from being definitive and would still benefit from further development and more data points to increase their accuracy.

There is still variance between ships of the same type, due to some ships being more complex than others, but would still have the same coefficient. This is an issue which was also noticed on the data collected, one solution would be for a more complete assessment of ship types and creation of more coefficients. This by itself would require data to be constantly gathered and constantly updating the existing coefficients. This makes CGT more appropriate for use in big aggregates, where this simplification would be “diluted”. For comparison of individual yards, this shortcoming should be acknowledged, and introduces some uncertainty in the results obtained.

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

Tab. 1.6 - CGT coefficients including Mega Yachts

In: OECD (2007)

Despite its advantages this system also has some limitations, as seen on OECD (2015):

- Current practices to calculate CGT for offshore vessels and mega-yachts do not reflect the real workload and value of building these ships.
- Some yards do not use the CGT coefficients for big offshore projects because they consider that it is absolutely not fitting the reality
- Differences in production depths (i.e. amount of parts and blocks produced in a shipyard, relative to the amount which is subcontracted to outside suppliers) by shipyards, purchasing raw materials or even entire steel blocks.
- Different degree of rationalization and range of shipbuilding equipment (cranes, machine tools) and productivity.
- Despite ships of same size and type, there are still various differences within ship types on hull-form, maximum speed and means of propulsions, equipment and quality level.
- Controlling for series effects (i.e. learning curves) when evaluation shipyard capacity.
- Doesn’t account for naval vessels.

Concerning the first point, recently effort has been made to calculate the CGT of super yachts, Hopman *et al.* (2010) analysed a database of 41 super yachts; for whom the CGT was calculated by expressing the work involved in building the vessels in equivalent man-hours, the method was validated with 18 ships for whom the CGT was known. A factor A=278 and B=0.58 was proposed for super yachts. However, Hopman shows that the bigger the vessels the bigger would be the uncertainty, as can be seen in Figure 1.15, and recommends that this work is continued in order to provide more reliable results for bigger vessels.

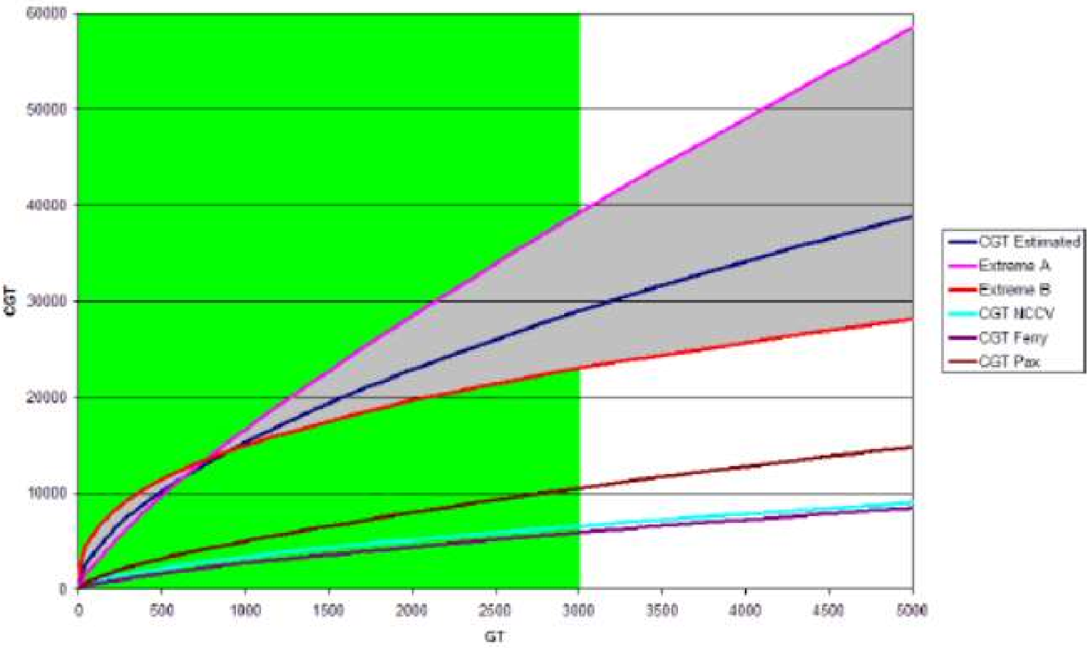


Fig. 1.15 - CGT for yacht vessels

In: Hopman *et al.* (2010)

Concerning the differences in production depths and different degree of rationalization and range of shipbuilding equipment, the production depth is accounted. The production depth is accounted for by considering subcontracted labour under inputs, while the rationalization and range of shipbuilding equipment is accounted for by including the yard capital stock. Therefore, a yard with higher automation will have fewer man hours per CGT but a higher capital stock associated.

3.3.1. CGT for other naval vessels

Concerning naval vessels, following the work made by Craggs *et al.* (2003 and 2004), the CGT can be obtained by multiplying the ship GT by a base CGT coefficient and by a customer factor (Equation 1.2), where BC is the base coefficient given by Equation 1.3 and CF is the customer factor, which represents the additional effort required when building naval vessels, taken from Table 1.7.

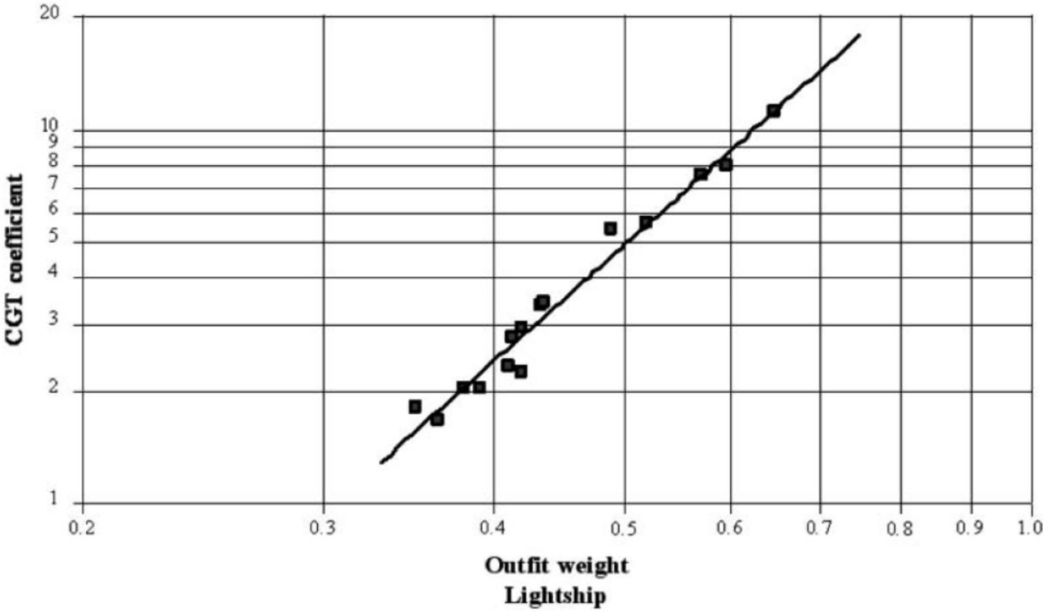


Fig. 1.16 - Proportionality between outfit weight and CGT coefficient
In: Craggs *et al.* (2004)

$$cgt = gt * BC * CF$$

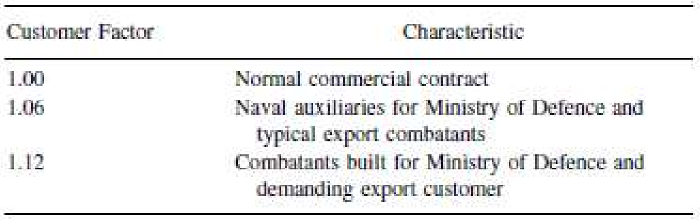
Where:

GT	Is the ship gross tonnage
BC	Is the base CGT coefficient for naval vessels
CF	Is the customer factor

Eq. 1.2. - CGT coefficient for naval vessels
In: Craggs *et al.* (2004)

$$Base\ CGT\ coefficient = 44.65 \times \left(\frac{Outfit\ weight}{Lightship}\right)^{3.19}$$

Eq. 1.3. - Base CGT coefficient for naval vessels
In: Craggs *et al.* (2004)



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

Tab. 1.7 - Customer factor

In: Craggs *et all* (2004)

3.3.2. SCGT

Pires *et al.* (2009) explored the use of a metric that accounts for the learning effect when building several ships for the same series, SCGT. They also consider building time and quality as outputs.

$$scgt = cgt \times f_s$$

where $f_s = -0.1483 \times \ln(n) + 0.9995 \qquad , 1 \leq n \leq 10$

and $f_s = -0.1483 \times \ln(10) + 0.9995 \qquad , n > 10$

and $n = ship\ ordinal\ position\ in\ the\ series$

Eq. 1.4. - Calculation of SCGT

In: Pires *et al.* (2009)

3.3.3. Productivity

Hellesoy *et al.* (2001) proposed that shipbuilding productivity is a function of the total number of employees, best practice rating, ratio of total/production employees, number of ships delivered over 3 years divided by the number of ship types delivered over the same 3 year period, vertical integration and dual purpose (commercial versus naval). In this approach, productivity is calculated using Eq. 1.4, which gives the productivity in MH/CGT as a function of these parameters. The productivity was calculated using its average labour hours for producing a CGT based on a period of 3 to 5 years, and the coefficient a, and exponentials b, c, d, e, f and g where calculated by Hellesoy *et al.* (2001).

Hellesoy *et al.* (2001) also shown the concept of competitive constant cost curve, based on plotting the productivity metric, MH/CGT against fully burdened labour. This allows to compare country averages or individual shipbuilders with the price setter, which will be the constant curve that passes through the lowest entry.

The average throughput (TP) in CGT is derived as the average annual total employees (TE) for each shipyard over the period of 4 years. Productivity (PD) is calculated as TExN(Number of hours in years)/TP and is given in MH/CGT.

The total number of employees (TE) and the number of production employees (PE) is obtained via questionnaires. PR is obtained as the ratio of total number of workers divided by the number of production workers.

$$PD = a \times TE^{b} \times BP^{C} \times PR^{d} \times ST^{e} \times VI^{f} \times DP^{g}$$

Where:

PD	Productivity (MH/CGT)
TE	Total Number of Employees
BP	Best Practice Rating
PR	Total/Production Employees
ST	Number of ships delivered over 3 years divided by the number of ship types delivered over the same 3 year period
VI	Vertical Integration
DP	Dual purpose (commercial versus naval)

Eq. 1.5. - Productivity equation as presented by Lamb and Hellesoy
In: Hellesoy *et al.* (2001)

Vertical integration (VI), is the ratio of value added by the shipyards versus total ship value, it is defined as percentage of labour cost to total costs.

Dual purpose (DP), is 1 if a shipyard builds commercial or naval ships only, and 2 if the yard builds both.

Ships delivered/ship type (ST), is a parameter that accounts for the total number of ships built compared to number of the ship series built over a given time.

A sensitivity analysis showed that the ratio of number of ships delivered to the range of ships delivered has minimum impact on productivity, having an impact of only 1%, while the best practice rating is the parameter with higher impact, of 41%, followed by the dual purpose with an impact of 30%.

The cost to produce a CGT can be used to compare shipyards global competitivity, both for individual yards and for aggregates such as countries. The cost/CGT does not include the costs of material, which is not under direct control of the yards.

The equation coefficients were obtained by a regression, using the total employment data for a period of 3 years, which was obtained either directly from yards or estimated, while the best practice rating was based on the technology level taken from Lamb (1998).

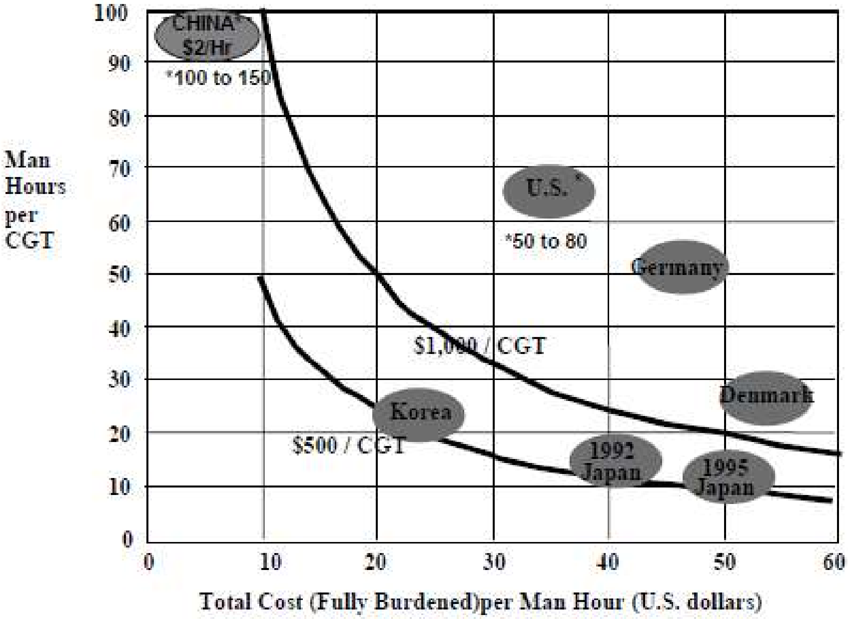


Fig. 1.17 - Iso-cost curves

In: Hellesoy *et al.* (2001)

3.3.4. Other Output Metrics

Many metrics are available to measure the output, and there is not a worldwide standard indicating which should be used. As a result, different yards will often use different metrics. Ton of steel (TS) and ton of outfit weight is often used in tendering and accounts for some differentiation in complexity between ships, since more complex ships will often have a higher ration of outfit weight to steel weight. Gross Tonnage (GT) and Deadweight (DWT) are also often used to measure a country yearly throughput.

European, Korean, Japanese, and generally, yards subject to OECD studies use CGT, which accounts for both ship size and complexity, while China and India use mostly DWT (Krishnan, 2012).

Some yards, and countries, have also create their own specialty metrics specifically suited for the yard needs, such as the equivalent frigate unit (EFU) and standard ship unit (SSU) used by the yards under the Indian ministry of defence. These custom metrics can be particularly interesting for internal use of yards, especially yards which specialized on building a specific type of ship and could be used to gauge the effect of improvements within the yard. Or for consortiums where there are several yards building the same ship, and this allows a direct comparison between yards. But if we wish to compare the efficiency between yards building different ships then there needs to be a common base for measuring output that accounts for the difference between ships.

There are also other metrics which can be used, such as added value, sale price and others which are more indicated when comparing yards from a purely economic point of view, since there are external factors which can benefit some yards from an economical point of view, such as national policies and credit at lower rates. By comparing the technical aspect of shipbuilding those external factors which yards are not able to control are eliminated, so that the yards can be compared in equal ground.

3.4 Effects of production series

The effect of the improving productivity when building a series of ships was also studied. Due to organizational learning and ship learning the productivity of a yard will increase with the number of equal ships build, until, ideally it would eventually reach the shipyard core productivity.

Fig.1.18 represents the effect of series on the productivity of a yard. X represents how close to the core productivity is the first-of-class (FOC) ship and Y indicates the number of vessels for the core productivity to be achieved. The better the best practice the smaller will X and Y will be.

The performance drop when building FOC is around 2% to 3% for a new class of vessels identical similar in type to a previous class and can be about 10% for a complete change in a vessel type. For military vessels the performance drop will be even higher and can be as high as 40%.

When establishing the CGT coefficients OEC also studied the series effect and reached a logarithmic function which shows the reduction in the workload necessary for the xth ship in a series.

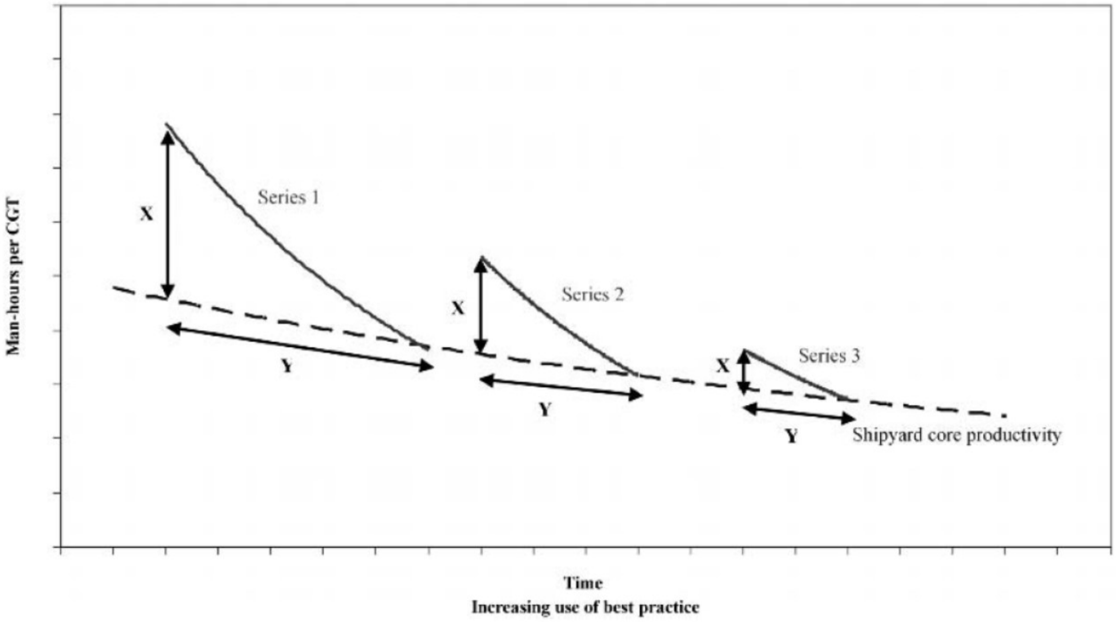


Fig. 1.18 - Organizational and ship learning

In: Craggs *et al.* (2004)

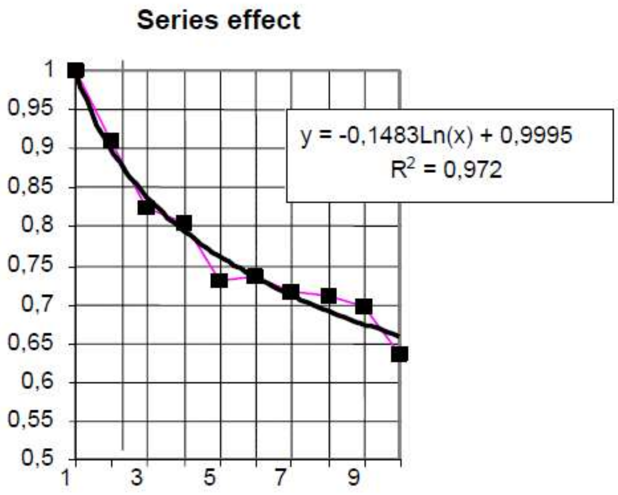


Fig. 1.19 - Reduction of Workload due to the Series Effect

In: OECD (2007)

3.5 Sources of information

There are several sources from where data is available, each source will have its advantages and disadvantages. In this chapter an overview of the available sources is made, and its cons and pros discussed.

3.5.1. Sources for labour inputs

Labour inputs can be obtained through several sources, each with advantages and disadvantages. Some will be easy to obtain but not very accurate, or require additional processing, while more precise sources will require exhaustive and thorough information to be taken from each individual yard.

This subchapter presents the tree most common sources for labour inputs, presenting some of its pros and cons – annual reports by shipbuilding associations, yards financial reports and data collected directly from yards through queries.

The best source for labour input is direct queries to yards, where man hours per ship, divided by cost center are given. This gives a more detailed information that will allow for a deeper analysis to be made.

Shipbuilding association reports are more adequate for macroscopic analysis since they provide aggregate data of the industry and will be more adequate if a comparison between countries is wished. This data needs to be processed to obtain usable results, and this can induce further errors by simplification and generalization of results.

Yearly results reports can also be used if queries are not a viable option, however the information obtained this way is less detailed and needs to be processed in order to obtain man hours worked.

The labour should be divided into five main cost structures: Structures, Outfitting, Painting, Support and Project. Labour, which was subcontracted should be included into labour, this can be achieved by using the equivalent man hours. The equivalent man hours are the budgeted man hours assigned by the yard to a certain job, these hours can be spent by the yard workforce or by subcontracts. If the equivalent man hours are not available, then the services must be accounted for on the subcontracted services. By having data from each ship, it also becomes possible to study the learning effect, when building ships in series, and to study the weight of different cost centers depending on ships types.

- **Annual reports by shipbuilding associations:**

Annual reports by shipbuilding associations will typically show the number of workers or agglomerate number of workers of the country yards. The level of detail of this information varies from study to study.

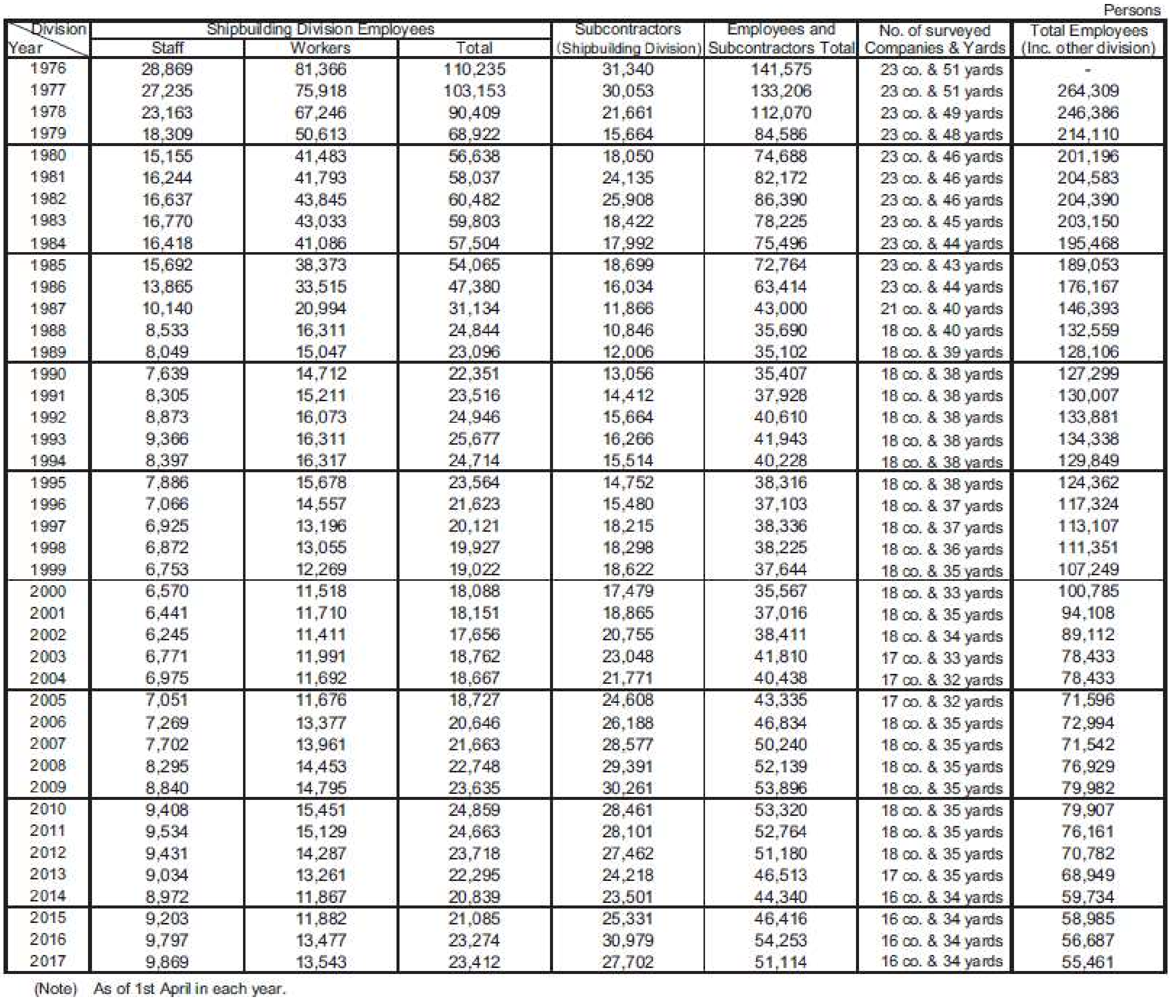
The Portuguese report from AIM (*Associação das indústrias marítimas)* shown on Table 1.8 does not account for subcontracted labour, does not indicate the amount of hours worked on each of its ships nor does it present data for different years, but it shoes the number of blue-collar and total workers per yard, allowing to make national yards comparisons.

			Employees	
Name	District	Area [m2]	Total	Industrial Activities
Réplica Fiel - Construção Naval Unipessoal, Lda	Setúbal	50	2	2
Cecílio Carlos Sanfins, Lda	Setúbal	80000	5	5
VIANAPESCA - Construções e Reparações Navais, Lda	Viana do Castelo	1200	20	16
Estaleiros Navais do Mondego, SA	Coimbra	49000	52	38
NAVALRIA-Docas, Construção e Reparações Navais, SA	Aveiro	124000	84	71
Navalrocha - Sociedade de Construção e Reparações Navais, SA	Lisboa	45000	28	18
Samuel & Filhos, Lda	Porto	22828	24	21
ENP - Estaleiros Navais de Peniche, SA	Leiria	44900	105	82
Nautiber-Estaleiros Navais do Guadiana,Lda	Faro	5600	38	25
Portinave	Faro	1300	8	8

Tab. 1.8 - Portuguese Shipyards Labour report

In: “Diagnóstico Tecnológico dos estaleiros Navais Portugueses” (2008)

The Japanese report from SAJ (Shipbuilders’ Association of Japan) shown on Table 1.9 agglomerates all yards within the country and doesn’t indicate the amount of hours worked on each of its ships, but divides the number of workers in different categories (distinguishing between blue and white-collar workers and subcontractors) and presents the data for what was at the time the last 41 years, allowing more elaborated analysis and a national time evolution comparison. It is noted that from 1976 Japan has increased its shipbuilding output while the employees’ number has been constantly reducing, this shows a continuous productivity improvement over the years.



Persons

Division / Year	Shipbuilding Division Employees			Subcontractors (Shipbuilding Division)	Employees and Subcontractors Total	No. of surveyed Companies & Yards	Total Employees (Inc. other division)
	Staff	Workers	Total				
1976	28,869	81,366	110,235	31,340	141,575	23 co. & 51 yards	-
1977	27,235	75,918	103,153	30,053	133,206	23 co. & 51 yards	264,309
1978	23,163	67,246	90,409	21,661	112,070	23 co. & 49 yards	246,386
1979	18,309	50,613	68,922	15,664	84,586	23 co. & 48 yards	214,110
1980	15,155	41,483	56,638	18,050	74,688	23 co. & 46 yards	201,196
1981	16,244	41,793	58,037	24,135	82,172	23 co. & 46 yards	204,583
1982	16,637	43,845	60,482	25,908	86,390	23 co. & 46 yards	204,390
1983	16,770	43,033	59,803	18,422	78,225	23 co. & 45 yards	203,150
1984	16,418	41,086	57,504	17,992	75,496	23 co. & 44 yards	195,468
1985	15,692	38,373	54,065	18,699	72,764	23 co. & 43 yards	189,053
1986	13,865	33,515	47,380	16,034	63,414	23 co. & 44 yards	176,167
1987	10,140	20,994	31,134	11,866	43,000	21 co. & 40 yards	146,393
1988	8,533	16,311	24,844	10,846	35,690	18 co. & 40 yards	132,559
1989	8,049	15,047	23,096	12,006	35,102	18 co. & 39 yards	128,106
1990	7,639	14,712	22,351	13,056	35,407	18 co. & 38 yards	127,299
1991	8,305	15,211	23,516	14,412	37,928	18 co. & 38 yards	130,007
1992	8,873	16,073	24,946	15,664	40,610	18 co. & 38 yards	133,881
1993	9,366	16,311	25,677	16,266	41,943	18 co. & 38 yards	134,338
1994	8,397	16,317	24,714	15,514	40,228	18 co. & 38 yards	129,849
1995	7,886	15,678	23,564	14,752	38,316	18 co. & 38 yards	124,362
1996	7,066	14,557	21,623	15,480	37,103	18 co. & 37 yards	117,324
1997	6,925	13,196	20,121	18,215	38,336	18 co. & 37 yards	113,107
1998	6,872	13,055	19,927	18,298	38,225	18 co. & 36 yards	111,351
1999	6,753	12,269	19,022	18,622	37,644	18 co. & 35 yards	107,249
2000	6,570	11,518	18,088	17,479	35,567	18 co. & 33 yards	100,785
2001	6,441	11,710	18,151	18,865	37,016	18 co. & 35 yards	94,108
2002	6,245	11,411	17,656	20,755	38,411	18 co. & 34 yards	89,112
2003	6,771	11,991	18,762	23,048	41,810	17 co. & 33 yards	78,433
2004	6,975	11,692	18,667	21,771	40,438	17 co. & 32 yards	78,433
2005	7,051	11,676	18,727	24,608	43,335	17 co. & 32 yards	71,596
2006	7,269	13,377	20,646	26,188	46,834	18 co. & 35 yards	72,994
2007	7,702	13,961	21,663	28,577	50,240	18 co. & 35 yards	71,542
2008	8,295	14,453	22,748	29,391	52,139	18 co. & 35 yards	76,929
2009	8,840	14,795	23,635	30,261	53,896	18 co. & 35 yards	79,982
2010	9,408	15,451	24,859	28,461	53,320	18 co. & 35 yards	79,907
2011	9,534	15,129	24,663	28,101	52,764	18 co. & 35 yards	76,161
2012	9,431	14,287	23,718	27,462	51,180	18 co. & 35 yards	70,782
2013	9,034	13,261	22,295	24,218	46,513	17 co. & 35 yards	68,949
2014	8,972	11,867	20,839	23,501	44,340	16 co. & 34 yards	59,734
2015	9,203	11,882	21,085	25,331	46,416	16 co. & 34 yards	58,985
2016	9,797	13,477	23,274	30,979	54,253	16 co. & 34 yards	56,687
2017	9,869	13,543	23,412	27,702	51,114	16 co. & 34 yards	55,461

(Note) As of 1st April in each year.

Tab. 1.9 - Japanese Shipyards Labour report

In: SAJ (2018)

For both sources the data provided needs to be processed if we intend to use it for a microeconomic analysis. In order to calculate the average of hours worked per CGT, the yards outputs must be known. Since the SAJ data agglomerates all the country’s yards outputs only an agglomerate average productivity can be found.

Both sources present number of employees but not the number of worked hours so, as already seen, further processing is required.

Yearly reports also create problems concerning the outputs: the labour presented is for the whole year, but some of the ships delivered will have started construction on the previous year and by the end of the year workers might be working on ships which will only be delivered next year thus making it difficult to account measure the output generated by those workers during that year. The use of data across a larger amount of time, 3 to 5 years can minimize this effect.

- **Yards financial reports:**

Most of the yards have publicly available yearly financial reports. Those reports will show the average workforce of the yard and capital cash flow among others. The total number of workers can be obtained from such reports, but again those reports do not show the amount of hours worked, so they need to be further processed to obtain hours worked and thy have the same yearly analysis problem already presented for shipbuilding associations reports. Some financial reports may also show only expenditure instead of number of employees; in that case it becomes necessary to know the average pay for a marine industry worker, in order to obtain the hours worked. Table 1.10 shows an example of a financial report that includes the number of employees.

(number)

	2018	2017
Average number of employees:		
- Senior managers	357	361
- Middle managers	1,013	1,028
- White collars	6,758	6,327
- Blue collars	11,203	11,598
Total average number of employees	**19,331**	**19,314**

Tab. 1.10 - Fincantieri 2018 annual report, number of employees

In: Fincantieri (2018)

- **Data collected directly from yards cost centers:**

Hours worked taken directly from the yard cost centers is the most accurate source of information.

Yards keep a record of hours worked per workstation; these hours are submitted to the cost control center which will fill those under the correct ship and cost center. Generally, there will be five main cost structures in a shipyard: Structures, Outfitting, Painting, Support and Engineering/Project. Support includes all support activities such as transport, quality control, scaffolding among others. In Figure 1.20 we can see cost centers associated with the shipyard layout. The structures cost center is represented in red while Outfitting is represented in blue. Painting and Support are also present during the entire process. Having this data allows the yards to keep track of the expenditure in current projects, to monitor if they are on budget. By having different cost centers, the yards can also build databases for each ship built, which are later used to tender new projects.

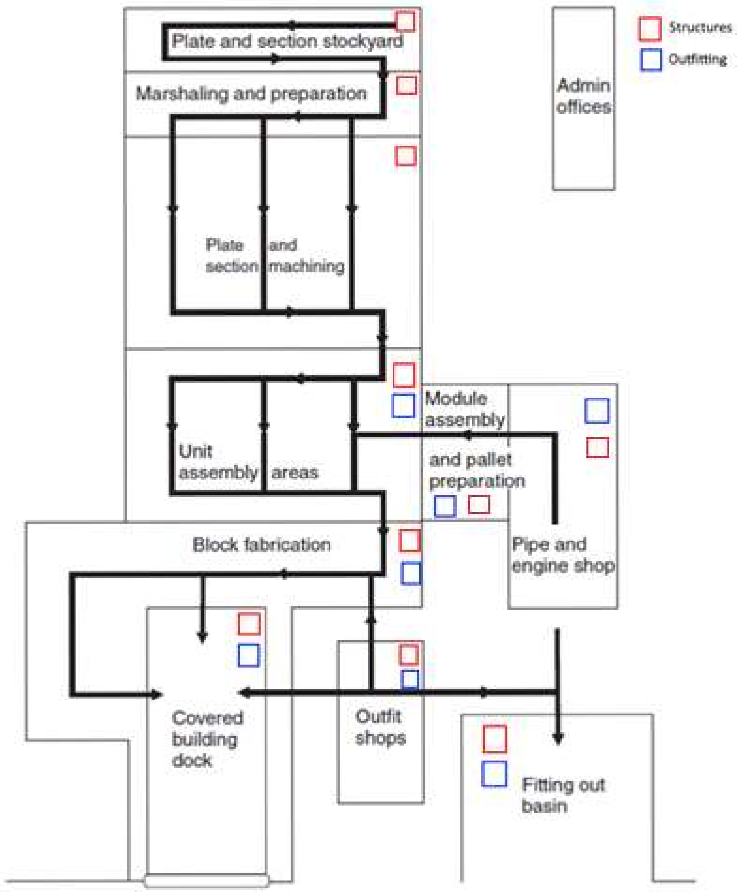


Fig. 1.20 - Shipyard layout

Adapted From: Bruce *et al.* (2012)

- **Inaccurate sources**

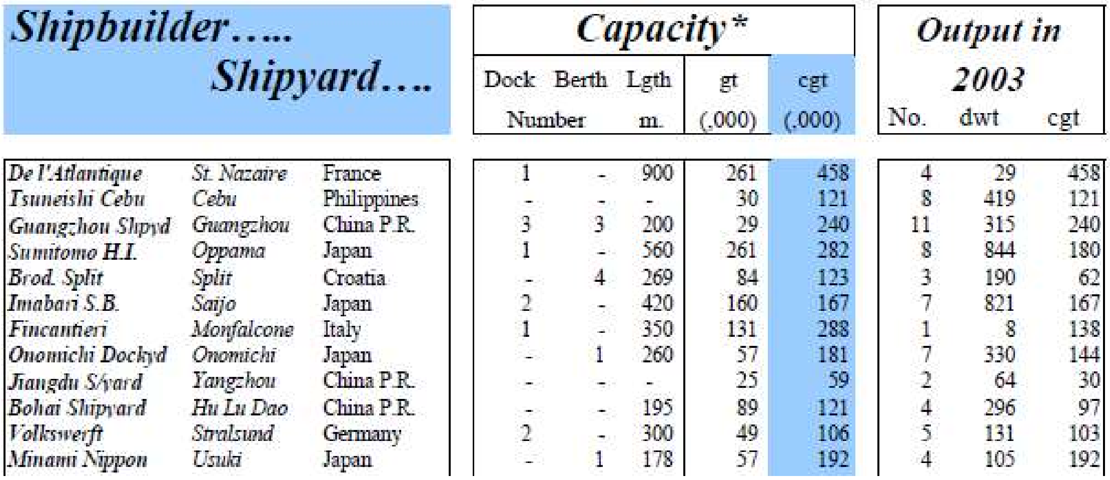
No matter the source of information, there are two sensible issues that if not attended may lead to distorted results, due to the use of subcontracted labour and the use of increased automation on shipyards.

Subcontracted labour would normally be registered under purchased services, but this could originate some misinterpretations from the results. For example, a shipyard with higher level of subcontracted labour may seem more efficient than a shipyard which relies more on full time workers, since the first shipyard would appear to require less man hours per CGT, which in this case would not represent the real number of hours worked. Ideally the subcontracted work would be filled under labour, however this would also not be correct, since some subcontractors contract will include both labour and materials. Interiors, Painting, Insulation, Cleaning, HVAC and Scaffolding are examples of services that often include materials on their cost. If the equivalent man hours are known for those services they can be registered under labour, otherwise they will have to be registered under subcontracted services.

3.5.2. Sources for outputs

The most accurate source to get the ships delivered by a yard would be a simple query to the yard since every shipyard will keep track of the ships delivered. The query would ask the yard to enumerate the ships it delivered in a given time period and their CGT. If the yard did not calculate the CGT for those ships then it should be asked the GT and ship type, in order to compute the corresponding CGT. If the ship was built in a series then a brief description of ship peculiarities should also be registered, so that any peculiarity that might make the ship more complex than an average ship of the same time is registered. In Annex C a sample query is presented. This would present the most detailed information, which can be beneficial when studying the results obtained.

When it isn’t possible to use queries, other sources for shipyard outputs are available. Reports, such as the World Monitor report can be used. Reports from shipbuilding associations will have agglomerate outputs, often in CGT, that allows agglomerate comparisons. One of such is the yard annual report, which will often enumerate the ships delivered for that year. Reports such as the one shown in Table 1.11, which shows the annual output of major shipyards across the world, and the yard capacity (docks and berths number, length as well as the maximum output, in GT and CGT, previously produced on the yard). These kind of reports have the disadvantage of being paid, which limits its availability and use in academic studies.



Shipbuilder…..	Shipyard….		Capacity*					Output in 2003		
			Dock Number	Berth	Lgth m.	gt (,000)	cgt (,000)	No.	dwt	cgt
De l'Atlantique	*St. Nazaire*	France	1	-	900	261	458	4	29	458
Tsuneishi Cebu	*Cebu*	Philippines	-	-	-	30	121	8	419	121
Guangzhou Shpyd	*Guangzhou*	China P.R.	3	3	200	29	240	11	315	240
Sumitomo H.I.	*Oppama*	Japan	1	-	560	261	282	8	844	180
Brod. Split	*Split*	Croatia	-	4	269	84	123	3	190	62
Imabari S.B.	*Saijo*	Japan	2	-	420	160	167	7	821	167
Fincantieri	*Monfalcone*	Italy	1	-	350	131	288	1	8	138
Onomichi Dockyd	*Onomichi*	Japan	-	1	260	57	181	7	330	144
Jiangdu S/yard	*Yangzhou*	China P.R.	-	-	-	25	59	2	64	30
Bohai Shipyard	*Hu Lu Dao*	China P.R.	-	-	195	89	121	4	296	97
Volkswerft	*Stralsund*	Germany	2	-	300	49	106	5	131	103
Minami Nippon	*Usuki*	Japan	-	1	178	57	192	4	105	192

Tab. 1.11 - Shipyards Yearly Outputs Report, in CGT

In: World Shipyard Monitor (2004)

Annual reports containing aggregate data are more accessible but will have the output of all the shipyards in the country aggregated. Examples of such reports are the Shipbuilding Market Monitoring, by SEA (Ships & Maritime Equipment Association) Europe and the SAJ shipbuilding statistics.

4. Case Study

This chapter presents the developed case study, where a European Shipyard's productivity was measured, in function of the provided information. The shipyard organization optimized the use of resources among the several ships being simultaneously built and used a block build strategy. The shipyard made available information about the last 30 ships built, which included thirteen chemical tankers and seventeen containerships. The chemical tanks were divided by the yard in eight chemical tankers with inox tanks (series A), three chemical tankers with painted tanks (series B) and two chemical tankers icebreakers (series C). The ships were built in during a 14-year period.

4.1 Collected data

Using systematic coding and classification systems (as ESWBS and SFI), yards are able to assign costs and labour MH to cost centers, according to the implemented system and the build strategy. Even though each yard will have its own cost centers, it is expected that they follow a similar base, which allows a common ground to compare shipyards. However, the coding system used by the yard (Figure 1.21) was a system developed by the yard for its internal and don't match neither the ESWBS nor the SFI groups (Table 1.2). This makes difficult the comparison between yards, since there is no correspondence between the yard's groups. The use of common groups, such as SFI, would allow for direct comparison of yards.

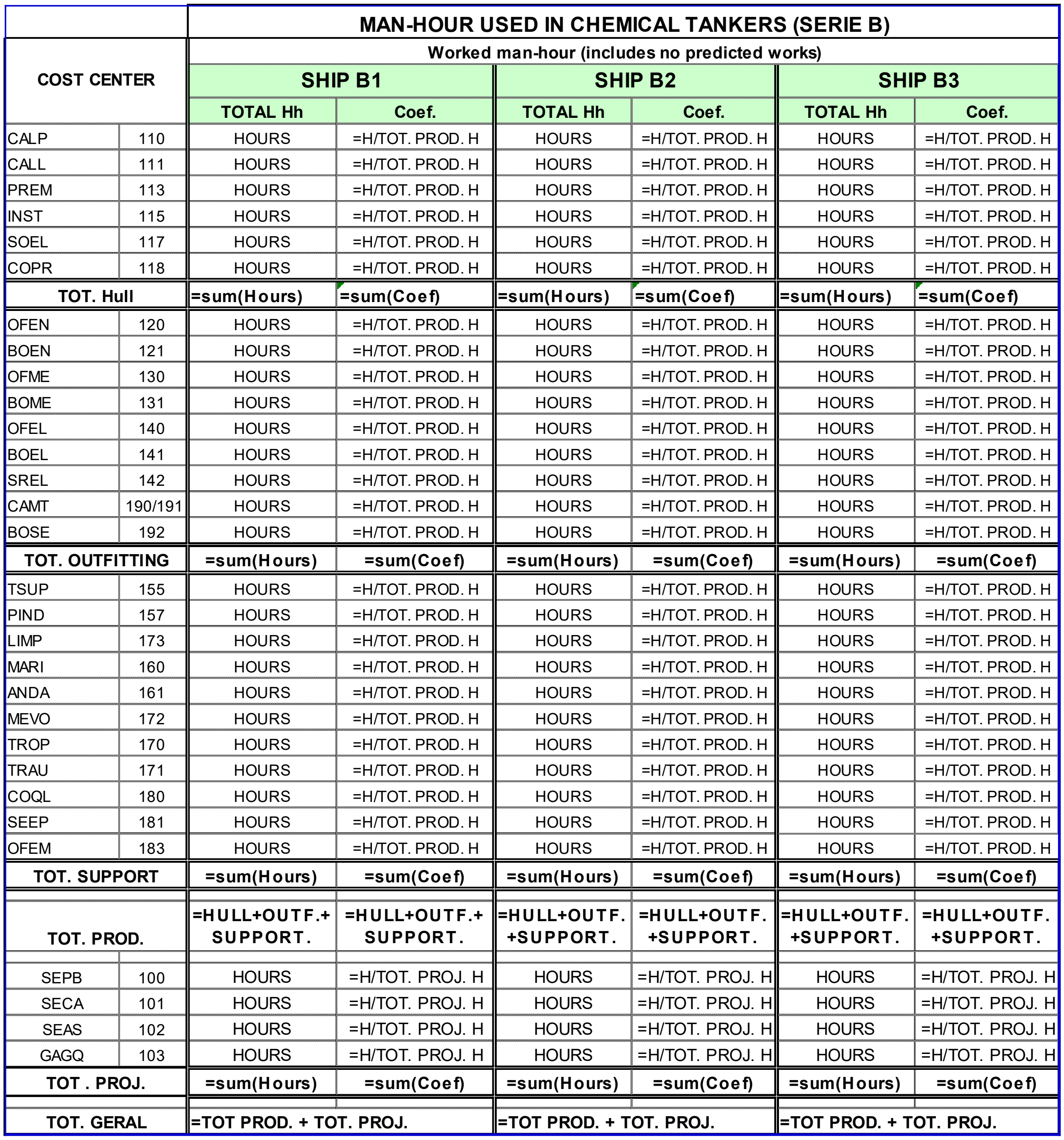
Hull
- 110 (CALP) - Heavy steel works
- 111 (CALL) - Steel outfitting
- 113 (PREM) - Block fabricat.
- 115 (INST) - Installation
- 117 (SOEL) - Welding
- 118 (COPR) - Cut of steel

Outfitting
- 120 (OFEN) - Pipping
- 121 (BOEN) - Pipping
- 130 (OFME) - Mechanics
- 131 (BOME) - Mechanics
- 140 (OFEL) - Electricity
- 141 (BOEL) - Electricity
- 142 (SREL) - Electricity
- 190/191 (CAMT) - Finishes
- 192 (BOSE) - Onboard steel outfitting
- 193 (ISOL) - Insulation

Support
- 155 (TSUP) - Painting
- 157 (PIND) - Painting
- 173 (LIMP) - Cleaning
- 160 (MARI) - Cables and mooring
- 161 (ANDA) - Scaffolding
- 172 (MEVO) - Others
- 170 (TROP) - Transport
- 171 (TRAU) - Transport
- 180 (COQL) - Quality
- 183 (OFEM) - Others

Fig. 1.21 - Case study's cost centers

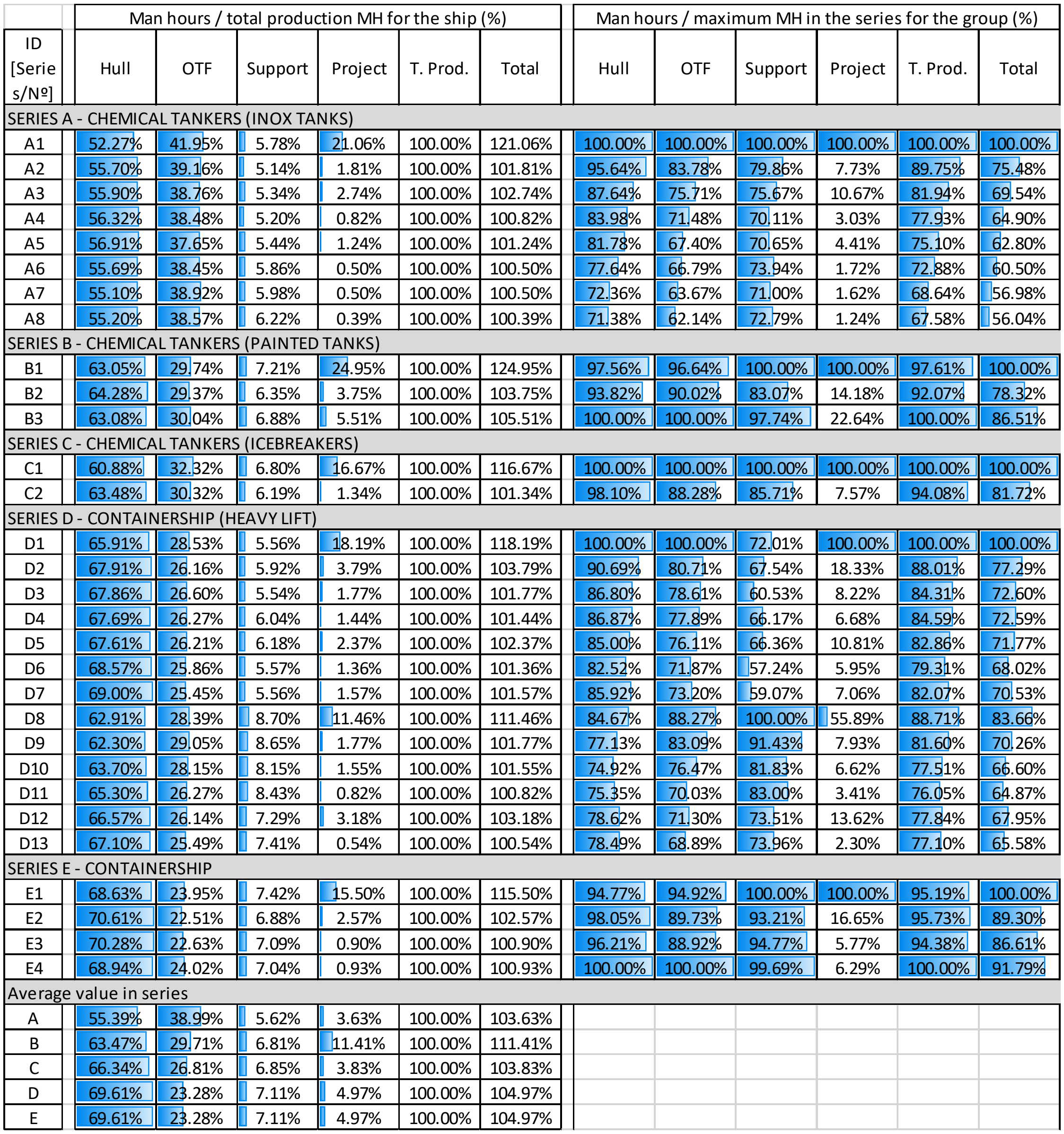
The yard kept a weekly registry of man hours spent on each ship categorized by cost centers, and organized those into three main groups: Hull, Outfitting and Support. In Fig. 1.22 the cost centers associated with each of those groups are presented. This kind of breakdown structure allows the yard to keep a registry at each step of the shipbuilding process and with that, keep track of the performance of each process. This data can be used to discover bottlenecks to production and monitor gains from new improvements (new machinery, new process, new organization, layout among others).



COST CENTER		MAN-HOUR USED IN CHEMICAL TANKERS (SERIE B)					
		Worked man-hour (includes no predicted works)					
		SHIP B1		SHIP B2		SHIP B3	
		TOTAL Hh	Coef.	TOTAL Hh	Coef.	TOTAL Hh	Coef.
CALP	110	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
CALL	111	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
PREM	113	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
INST	115	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
SOEL	117	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
COPR	118	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
TOT. Hull		=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)
OFEN	120	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
BOEN	121	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
OFME	130	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
BOME	131	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
OFEL	140	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
BOEL	141	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
SREL	142	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
CAMT	190/191	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
BOSE	192	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
TOT. OUTFITTING		=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)
TSUP	155	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
PIND	157	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
LIMP	173	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
MARI	160	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
ANDA	161	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
MEVO	172	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
TROP	170	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
TRAU	171	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
COQL	180	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
SEEP	181	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
OFEM	183	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H	HOURS	=H/TOT. PROD. H
TOT. SUPPORT		=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)
TOT. PROD.		=HULL+OUTF.+ SUPPORT.	=HULL+OUTF.+ SUPPORT.	=HULL+OUTF. +SUPPORT.	=HULL+OUTF. +SUPPORT.	=HULL+OUTF. +SUPPORT.	=HULL+OUTF. +SUPPORT.
SEPB	100	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H
SECA	101	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H
SEAS	102	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H
GAGQ	103	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H	HOURS	=H/TOT. PROJ. H
TOT . PROJ.		=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)	=sum(Hours)	=sum(Coef)
TOT. GERAL		=TOT PROD. + TOT. PROJ.		=TOT PROD. + TOT. PROJ.		=TOT PROD. + TOT. PROJ.	

Tab. 1.12 - Case Study inputs: man-hours per ship and per cost center (hours and %)

The data provided by the yard (example in Table 1.12) contained total worked hours per cost center and percentage of hours (total hour of the cost center divided by the total production hours). In order to keep the confidentiality, the hours were used for calculations but only percentages are presented in this study. The advantage of registering worked hours over paid hours is that these hours include only hours that were actually spent working on the construction, while paid hours would also include absent workers, such as those on annual leave or sick. Table 1.12 shows how the received data was organized. Table 1.13 shows all the MH information. It shows the % of MH for each ship, calculated as the MH of a specific cost center group divided by the total MH of the production. It also presents the % of MH for each ship, calculated as the division between the MH of a specific cost center group for that particular ship and the MH for the same cost center group for the worst ship in the series. The first percentage allows to understand the weight of different cost centers in the total MH and the second percentage allows to understand the gains in MH obtained through the effects of production series.



	Man hours / total production MH for the ship (%)						Man hours / maximum MH in the series for the group (%)					
ID [Series/Nº]	Hull	OTF	Support	Project	T. Prod.	Total	Hull	OTF	Support	Project	T. Prod.	Total
SERIES A - CHEMICAL TANKERS (INOX TANKS)												
A1	52.27%	41.95%	5.78%	21.06%	100.00%	121.06%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
A2	55.70%	39.16%	5.14%	1.81%	100.00%	101.81%	95.64%	83.78%	79.86%	7.73%	89.75%	75.48%
A3	55.90%	38.76%	5.34%	2.74%	100.00%	102.74%	87.64%	75.71%	75.67%	10.67%	81.94%	69.54%
A4	56.32%	38.48%	5.20%	0.82%	100.00%	100.82%	83.98%	71.48%	70.11%	3.03%	77.93%	64.90%
A5	56.91%	37.65%	5.44%	1.24%	100.00%	101.24%	81.78%	67.40%	70.65%	4.41%	75.10%	62.80%
A6	55.69%	38.45%	5.86%	0.50%	100.00%	100.50%	77.64%	66.79%	73.94%	1.72%	72.88%	60.50%
A7	55.10%	38.92%	5.98%	0.50%	100.00%	100.50%	72.36%	63.67%	71.00%	1.62%	68.64%	56.98%
A8	55.20%	38.57%	6.22%	0.39%	100.00%	100.39%	71.38%	62.14%	72.79%	1.24%	67.58%	56.04%
SERIES B - CHEMICAL TANKERS (PAINTED TANKS)												
B1	63.05%	29.74%	7.21%	24.95%	100.00%	124.95%	97.56%	96.64%	100.00%	100.00%	97.61%	100.00%
B2	64.28%	29.37%	6.35%	3.75%	100.00%	103.75%	93.82%	90.02%	83.07%	14.18%	92.07%	78.32%
B3	63.08%	30.04%	6.88%	5.51%	100.00%	105.51%	100.00%	100.00%	97.74%	22.64%	100.00%	86.51%
SERIES C - CHEMICAL TANKERS (ICEBREAKERS)												
C1	60.88%	32.32%	6.80%	16.67%	100.00%	116.67%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
C2	63.48%	30.32%	6.19%	1.34%	100.00%	101.34%	98.10%	88.28%	85.71%	7.57%	94.08%	81.72%
SERIES D - CONTAINERSHIP (HEAVY LIFT)												
D1	65.91%	28.53%	5.56%	18.19%	100.00%	118.19%	100.00%	100.00%	72.01%	100.00%	100.00%	100.00%
D2	67.91%	26.16%	5.92%	3.79%	100.00%	103.79%	90.69%	80.71%	67.54%	18.33%	88.01%	77.29%
D3	67.86%	26.60%	5.54%	1.77%	100.00%	101.77%	86.80%	78.61%	60.53%	8.22%	84.31%	72.60%
D4	67.69%	26.27%	6.04%	1.44%	100.00%	101.44%	86.87%	77.89%	66.17%	6.68%	84.59%	72.59%
D5	67.61%	26.21%	6.18%	2.37%	100.00%	102.37%	85.00%	76.11%	66.36%	10.81%	82.86%	71.77%
D6	68.57%	25.86%	5.57%	1.36%	100.00%	101.36%	82.52%	71.87%	57.24%	5.95%	79.31%	68.02%
D7	69.00%	25.45%	5.56%	1.57%	100.00%	101.57%	85.92%	73.20%	59.07%	7.06%	82.07%	70.53%
D8	62.91%	28.39%	8.70%	11.46%	100.00%	111.46%	84.67%	88.27%	100.00%	55.89%	88.71%	83.66%
D9	62.30%	29.05%	8.65%	1.77%	100.00%	101.77%	77.13%	83.09%	91.43%	7.93%	81.60%	70.26%
D10	63.70%	28.15%	8.15%	1.55%	100.00%	101.55%	74.92%	76.47%	81.83%	6.62%	77.51%	66.60%
D11	65.30%	26.27%	8.43%	0.82%	100.00%	100.82%	75.35%	70.03%	83.00%	3.41%	76.05%	64.87%
D12	66.57%	26.14%	7.29%	3.18%	100.00%	103.18%	78.62%	71.30%	73.51%	13.62%	77.84%	67.95%
D13	67.10%	25.49%	7.41%	0.54%	100.00%	100.54%	78.49%	68.89%	73.96%	2.30%	77.10%	65.58%
SERIES E - CONTAINERSHIP												
E1	68.63%	23.95%	7.42%	15.50%	100.00%	115.50%	94.77%	94.92%	100.00%	100.00%	95.19%	100.00%
E2	70.61%	22.51%	6.88%	2.57%	100.00%	102.57%	98.05%	89.73%	93.21%	16.65%	95.73%	89.30%
E3	70.28%	22.63%	7.09%	0.90%	100.00%	100.90%	96.21%	88.92%	94.77%	5.77%	94.38%	86.61%
E4	68.94%	24.02%	7.04%	0.93%	100.00%	100.93%	100.00%	100.00%	99.69%	6.29%	100.00%	91.79%
Average value in series												
A	55.39%	38.99%	5.62%	3.63%	100.00%	103.63%						
B	63.47%	29.71%	6.81%	11.41%	100.00%	111.41%						
C	66.34%	26.81%	6.85%	3.83%	100.00%	103.83%						
D	69.61%	23.28%	7.11%	4.97%	100.00%	104.97%						
E	69.61%	23.28%	7.11%	4.97%	100.00%	104.97%						

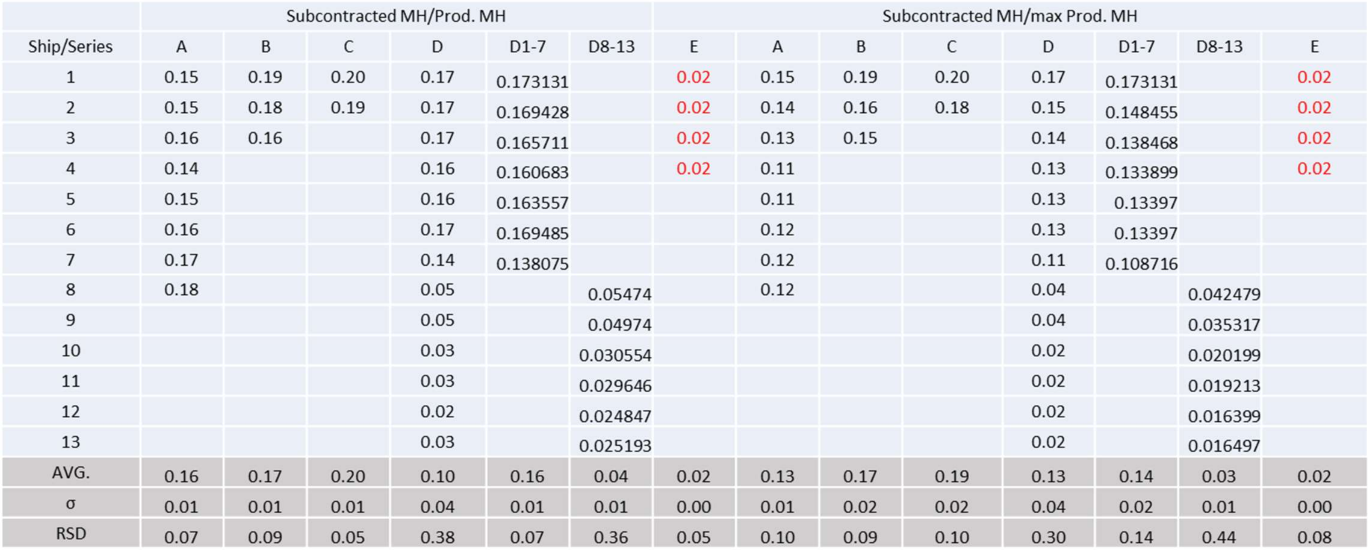
Tab. 1.13 - Man hour in % of Production MH and of worst in series

4.2 MH of subcontracted services

On the data received from the yard, there were mixed MH from the shipyard workforce and estimated MH for the subcontracted labours acquired as purchased service. This purchased services (Finishing and Interiors, Insulation, Painting, Cleaning, Scaffolding and HVAC) included in its cost both the MH and the materials necessary for the service. In those cases, the yard estimated a percentage of the costs to attribute to MH and a percentage to attribute to materials costs. After that, it converted the MH cost in worked MH, using a method similar to the one explained in chapter 3.

However, given the uncertainty regarding the accuracy of the estimated MH of subcontracted services, we chose to not include those MH values (and therefore its cost centers) in the comparison. This has the advantage of having more accurate values to compare. On the other hand, when calculating the shipyard's productivity (MH/CGT) those estimated MH had to be included. If they weren't, by ignoring the subcontracted services, the yard would seem more efficient or productive than in reality. Ultimately, a hypothetical ship that had only subcontracted services would appear as if no MH labour were needed for its production.

The subcontracted services where measured as the price of the subcontracted, in euros. Series D where excluded because it wasn't possible to gather accurate data. For each of the remaining series, the average of all ship's subcontracted services cost was calculated. In order to keep the confidentiality of the yard expenditure on those services, the values are presented in percentage, calculated as the average cost of the series divided by the maximum ship cost, always for the subcontracted services. The relative standard deviation was also found for each series.



	Subcontracted MH/Prod. MH							Subcontracted MH/max Prod. MH						
Ship/Series	A	B	C	D	D1-7	D8-13	E	A	B	C	D	D1-7	D8-13	E
1	0.15	0.19	0.20	0.17	0.173131		0.02	0.15	0.19	0.20	0.17	0.173131		0.02
2	0.15	0.18	0.19	0.17	0.169428		0.02	0.14	0.16	0.18	0.15	0.148455		0.02
3	0.16	0.16		0.17	0.165711		0.02	0.13	0.15		0.14	0.138468		0.02
4	0.14			0.16	0.160683		0.02	0.11			0.13	0.133899		0.02
5	0.15			0.16	0.163557			0.11			0.13	0.13397		
6	0.16			0.17	0.169485			0.12			0.13	0.13397		
7	0.17			0.14	0.138075			0.12			0.11	0.108716		
8	0.18			0.05		0.05474		0.12			0.04		0.042479	
9				0.05		0.04974					0.04		0.035317	
10				0.03		0.030554					0.02		0.020199	
11				0.03		0.029646					0.02		0.019213	
12				0.02		0.024847					0.02		0.016399	
13				0.03		0.025193					0.02		0.016497	
AVG.	0.16	0.17	0.20	0.10	0.16	0.04	0.02	0.13	0.17	0.19	0.13	0.14	0.03	0.02
σ	0.01	0.01	0.01	0.04	0.01	0.01	0.00	0.01	0.02	0.02	0.04	0.02	0.01	0.00
RSD	0.07	0.09	0.05	0.38	0.07	0.36	0.05	0.10	0.09	0.10	0.30	0.14	0.44	0.08

Tab. 1.14 - Subcontracted Services, average per series and relative standard deviation

Contrarily to the production and project for production MH (and consequentially cost), the value of the services shows a relative standard variation of less than 10% for all series (except series D), and maintain its share relatively constant along the series showing small gains when compared to the first ship in the series. This might be related to the use of group technology, that optimizes the yard resources when building several ships at the same time while purchased services which will often be purchased individually for each ship, and as such it is expected to have greater gains on production activities than on subcontracted labour.

4.3 Total production man hours

With the provided inputs of man hours, the first analysis to do is to compare the total production man hours for different ships in the same series. The subcontracted services were excluded for better accuracy, due to inaccuracies on their estimation. Figure 1.22 and 1.23 presents, for each ship, the percentage of total production man hours, calculated as the total production MH for that ship divided by the total production MH of the worst ship in the series.

By building several similar ships the efficiency is steadily increasing until a limit efficiency is achieved. In Series A this peak efficiency starts to be reached by the 8th ship. Series D was interrupted by ships that belong to other series and series B, C and E don’t have enough data to achieve the limit efficiency.

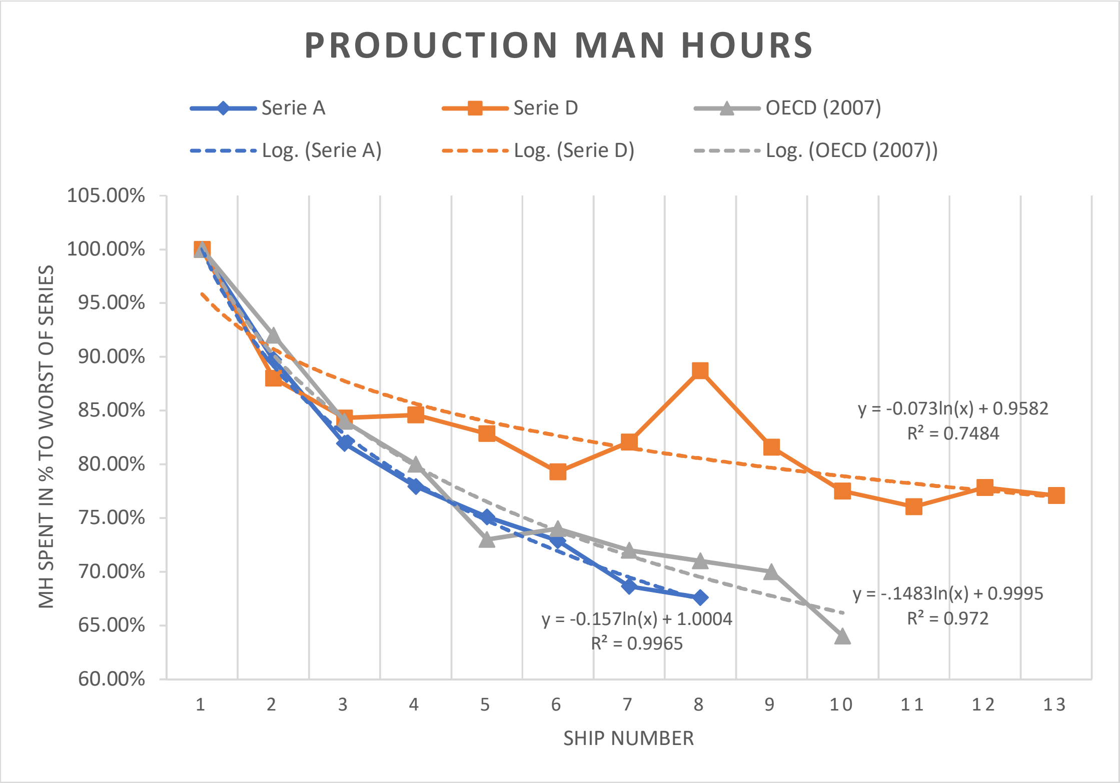


Fig. 1.22 - Evolution of man hours required per ship in series A, series D and OECD (2007)

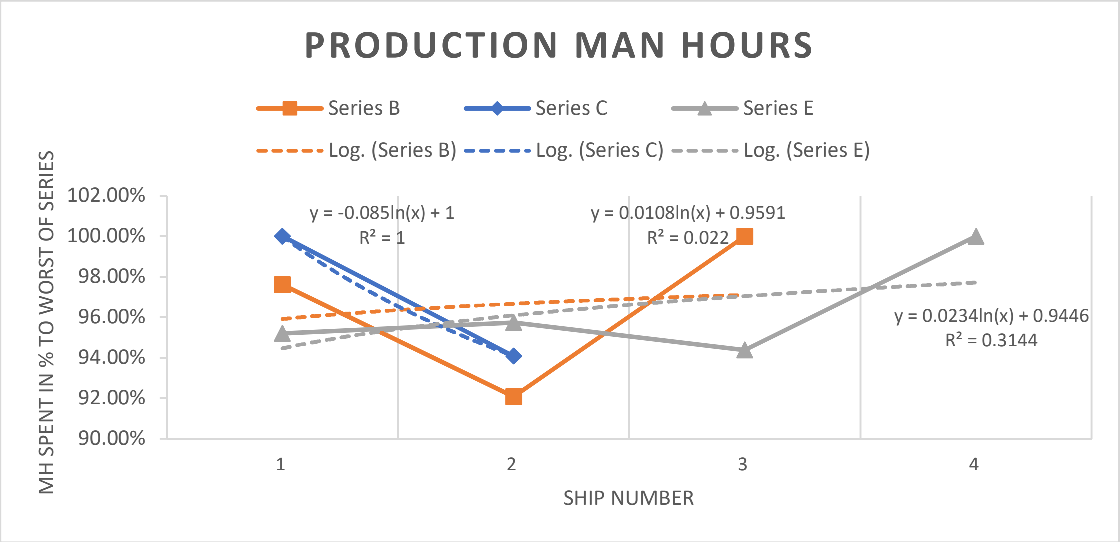


Fig. 1.23 - Evolution of man hours required per ship in series B, C and E

To better understand the effects of this behaviour, a logarithmic regression was made for each series. Series A and D were compared with the results of OECD (2007). As shown in Figure 1.22 and in Table 1.15, both Series A and Series D show gains with production series. Series A show a behaviour very close to the theory. Its function is close to the function from OECD (2007) and its R^2 shows a very good approximation of the logarithmic regression. In series A each subsequent ship in the series haves a MH gain and this gain decreases logarithmically trough the series. Series D also show gains from production series, but it shows a more erratic behaviour and in fact the logarithmic regression does not constitute a good approximation to the reality, with a R^2 of only 0.748. In its first ships series D decreasing the MH as supposed. Not as consistently as series A, but still an acceptable behaviour, until D7-D8 are reached. Those two ships seem to restart the series as if the series started from the beginning again. In fact, if we make two separate logarithmic regression of D1-D6 and of D8-D13, the R^2 increases to 0.92 and 0.84, respectively, indicating that somewhere between D7 and D8 there was an important change in the yard or that the ships D8-D13 should not have been classified as D series. Ship D7 was delivered only one year after Ship D6, so the production series effects should have been present in Ship D7. Ship D8, on the other hand, was delivered five years after Ship D6, so the benefits of production series could have been lost because of the break in the production of the D series.

Series	f(x)	R^2
A	$f(x) = -0.157\mathrm{l} * \ln x + 1.000$	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

Tab. 1.15 - Logarithmic regression showing increase of efficiency when building ships in series

From the collected data a few conclusions can be drawn. Firstly, it appears that the support and design cost structures have an identical share of the total hours across projects. For the support it is around 5% to 7% while for project it would be around 3 to 4% for ships build in large series (four or more ships), and 8 to 10% for ships built in smaller series. To fully validate this more data should be collected.

Regarding Hull and OTF, which together compose between 85% to 90% of the labour, the data shows that their share is related with the ship type/complexity, as can be seen in Table 1.16. For chemical tankers the hull area has a share of 56% while OTF has a share of 31%. For containerships hull will have a 65% share with OTF having 24%. This gives an OTF to Hull ratio of 0.55 and 0.37 for chemical tankers and containerships, respectfully. In Figure 1.24 the share of each cost structure can be consulted for each series.

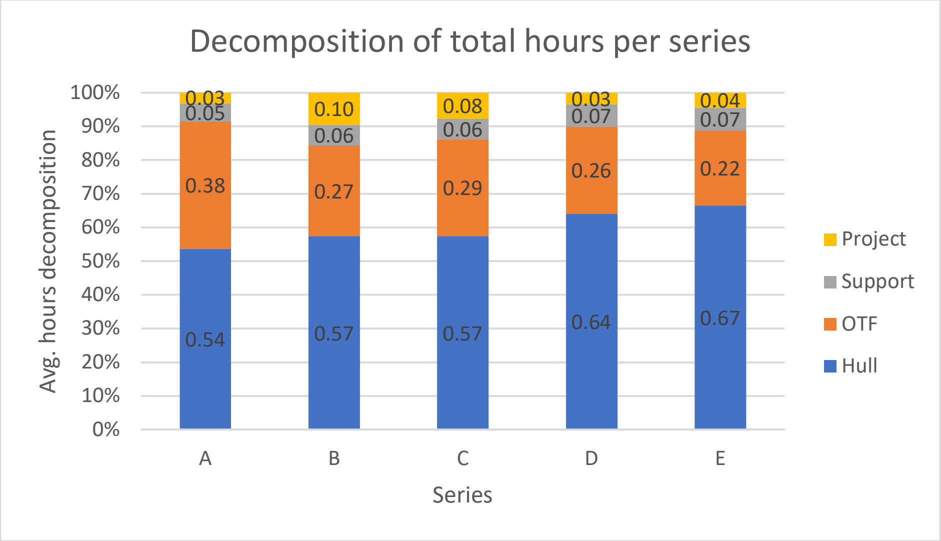


Fig. 1.24 - Average share of the 4 main areas in the total hours spent, by ship series

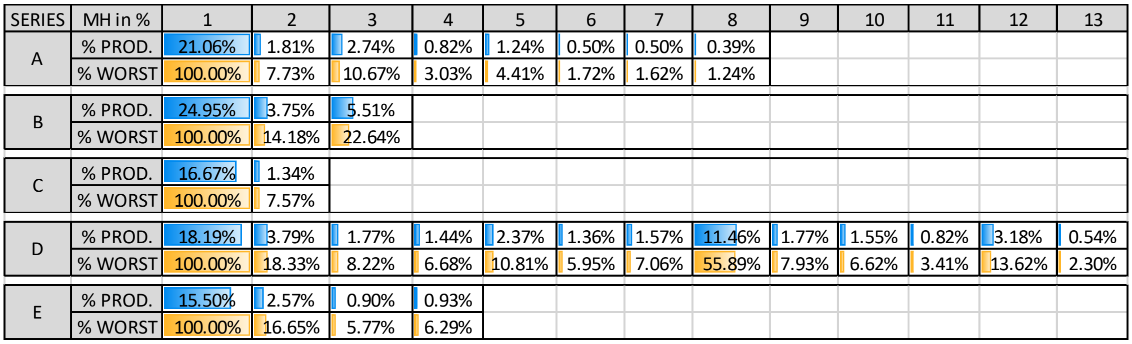
It is expected that this OTF/Hull ratio is proportional to the complexity of the ship, therefore more complex ships have a higher outfitting share, since the complexity of the ship is mainly dependent on the ship systems, and as such it is reflected mainly on the hours spent on outfitting. Data collected shows that chemical tankers are more complex than container ship, since they have a higher OTF share, this is in accordance with OECD factors for these ships, which also classify chemical tankers as more complex than containerships, OECD (2007).

	Average			
Ship Type	Hull	OTF	Support	Project
CT	0.56	0.31	0.06	0.07
C	0.65	0.24	0.07	0.04

Tab. 1.16 - Average share of the 4 main areas, by ship types

4.4 Design man hours

After analysing the production man hours, this subchapter analyses the design man hours and its gains with production series. In Table 1.17 it's possible to verify that on the first ship in a series, the project MH assumes a significant cost, representing 16 to 21% of the ship's production MH summed to the fact that project's average MH cost is greater than the production's average MH cost. However, project MH rapidly benefits from production series, dropping its value between 82% and 92%, from the fist to the second ship in the series, resulting in a second ship's project MH of only 1.3 to 3.79% of the production total. After this initial gain (first to second ship), the subsequent ships have little gains and sometimes may even have more MH than the precedent projects. This reflects the particularities of each ship, even when sharing its typology with previous projects.



SERIES	MH in %	1	2	3	4	5	6	7	8	9	10	11	12	13
A	% PROD.	21.06%	1.81%	2.74%	0.82%	1.24%	0.50%	0.50%	0.39%					
	% WORST	100.00%	7.73%	10.67%	3.03%	4.41%	1.72%	1.62%	1.24%					
B	% PROD.	24.95%	3.75%	5.51%										
	% WORST	100.00%	14.18%	22.64%										
C	% PROD.	16.67%	1.34%											
	% WORST	100.00%	7.57%											
D	% PROD.	18.19%	3.79%	1.77%	1.44%	2.37%	1.36%	1.57%	11.46%	1.77%	1.55%	0.82%	3.18%	0.54%
	% WORST	100.00%	18.33%	8.22%	6.68%	10.81%	5.95%	7.06%	55.89%	7.93%	6.62%	3.41%	13.62%	2.30%
E	% PROD.	15.50%	2.57%	0.90%	0.93%									
	% WORST	100.00%	16.65%	5.77%	6.29%									

Tab. 1.17 - Project hours in % of total production hours and % to worst in series

Ship D8 is an exception and shows a big increase in project MH (increase of 48.89%). Even if the production had lost the advantages of production series because of the 5 years gap between the delivery of Ship D6 and D8, this wouldn't explain such an increase in the project MH, strengthening the theory that Ship D8 and the subsequent ships don't fit in the D1-D6 series and should have been considered in a different series. If Ship 8 was to be assumed as the first of its own series, then the gain from D8 to D9 would be of 86%, fitting in the standard behaviour of first to second ship gains in a series.

To compare the project MH between chemical tankers and containerships, the data was condensed in Tables 1.18 and 1.19. For the first ship in the series, chemical tankers have a slightly higher ratio of hours spent in project. This can be indicative of the complexity of the ship, but more data was needed to support this theory. For the second ship in the series containerships registered a higher amount of project MH. This can be explained if the containerships required more changes from first to second ship than the chemical tankers ships. However, on the average of the rest of the ships in series, chemical tankers require again more MH than containerships. Series C don't have a third ship to analyse and Series B have only one ship with much higher MH than the rest of the sips which might indicate it was an exception. If only series A is considered from the Chemical Tankers (third ship forward), then the theory that containerships contain more changes between ships seems probable, however, more data would be necessary to be able to obtain properly substantiated conclusions.

	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%

Tab. 1.18 - Project hours (per ship series and per ship type), in % to total production hours

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

Tab. 1.19 - Drop in project hours, from 1st to 2nd ship, by ship series

From the data collected it can be concluded that there is a steep decline in hours needed for project from the first ship to the second on average of 86% less hours required, it is also noted that after the second ship the hours of project tend to be constant, at 2% of the production hours. This can easily be explained if we take into account that all the production design and documentation is produced during the first ship. Also, the largest amount of changes, retrofits will occur during the first and second ship while owner, designer and classification society might have changes, comments that will require change to the ship. After the first one is built the design for production will remain the same, for the majority, and other than some improvements over the previous ship only a residual amount of engineering work, around 2% of that required for the first ship, is required.

4.5 Man-hours per cost center group

After analysing production MH and project MH, this subchapter focuses on the analysis of the production MH per cost center group (excluding the cost centers where some ships had subcontracted services, as already explained), in order to determine if they're equally affected by the effects of the production series.

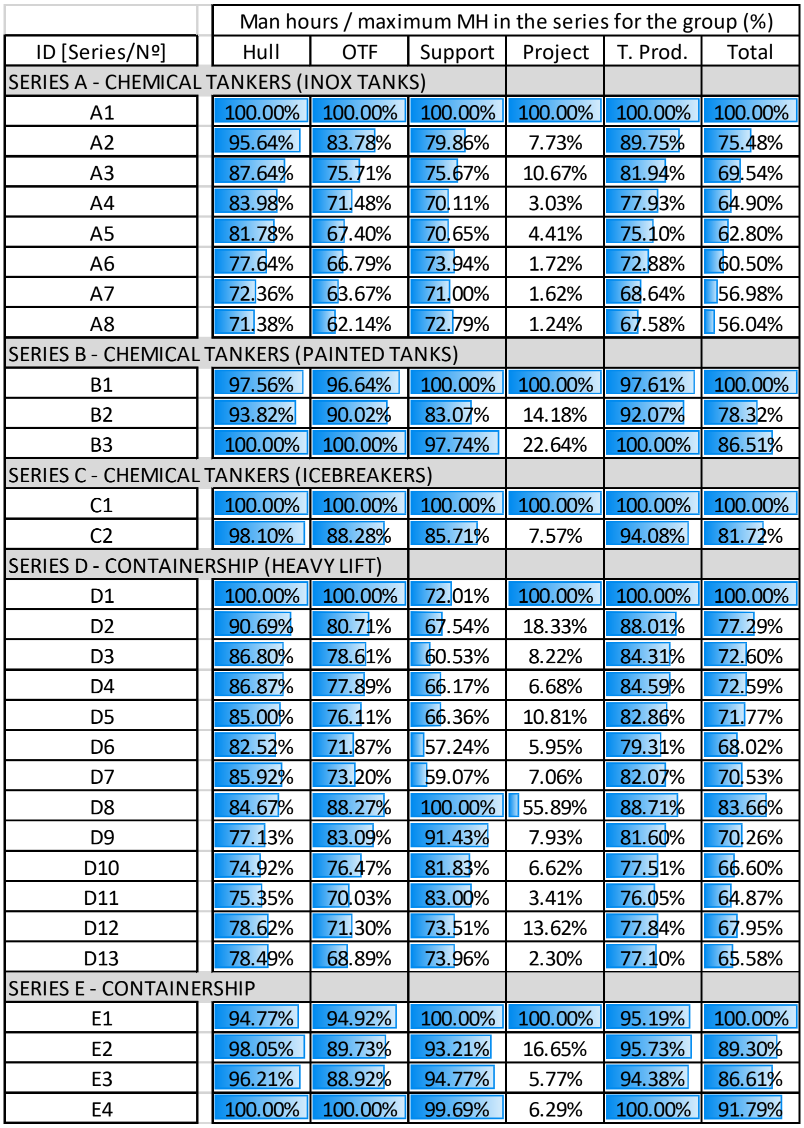
In Fig. 1.26 we present, for each ship, the percentage of man hours per group of cost centers, calculated as the man hours for that cost center divided by the total production MH for that ship. On a general rule, the distribution of man-hours between the cost center groups keeps uniform trough the subsequent ships, meaning that Hull and OTF all benefit in the same proportion with the effects of production series, when they exist. Support activities show a uniform percentage between the subsequent ships not because they behave like Hull and OTF, but because it represents a small percentage of the total project MH, its oscillations are not as perceptible when compared to the total production MH.

Fig. 1.25 - Evolution of MH/PMH required per ship

Looking to the weight of the average MH for each cost center group in the total production MH (Figure 1.25), it is visible that different types of ship require different proportions of hull MH and outfitting MH, as would be expected, but the weight of those keeps relatively constant trough the series, indicating that both benefit in the same proportion from the production series effects. The weight of the support is relatively constant trough the different series and trough different ships of the series (5-9% of the total production MH), meaning that it also benefits from the production series effects proportionally.

When analysing the project average MH, the first ship has to be ignored. Otherwise it will greatly increase the average of series with few ships compromising the comparison between series. If we ignore the ship with the most MH in each series, and ignore Series B (with only one value), the average % of MH spent in project would be 1,14% for series A, 1,34% for series C (with only two values to calculate the average), 1,83% for series D (ignoring ship D8) and 1,47% for series E. The average MH of the project for each series varies from 1,14 to 1,83% of the total production MH.

In Table 1.20 and Figure 1.26 we present, for each ship, the percentage of man hours per group of cost centers, calculated as the man hours for that cost center divided by the maximum MH for the same cost center group for the same ship series.



	Man hours / maximum MH in the series for the group (%)					
ID [Series/Nº]	Hull	OTF	Support	Project	T. Prod.	Total
SERIES A - CHEMICAL TANKERS (INOX TANKS)						
A1	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
A2	95.64%	83.78%	79.86%	7.73%	89.75%	75.48%
A3	87.64%	75.71%	75.67%	10.67%	81.94%	69.54%
A4	83.98%	71.48%	70.11%	3.03%	77.93%	64.90%
A5	81.78%	67.40%	70.65%	4.41%	75.10%	62.80%
A6	77.64%	66.79%	73.94%	1.72%	72.88%	60.50%
A7	72.36%	63.67%	71.00%	1.62%	68.64%	56.98%
A8	71.38%	62.14%	72.79%	1.24%	67.58%	56.04%
SERIES B - CHEMICAL TANKERS (PAINTED TANKS)						
B1	97.56%	96.64%	100.00%	100.00%	97.61%	100.00%
B2	93.82%	90.02%	83.07%	14.18%	92.07%	78.32%
B3	100.00%	100.00%	97.74%	22.64%	100.00%	86.51%
SERIES C - CHEMICAL TANKERS (ICEBREAKERS)						
C1	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
C2	98.10%	88.28%	85.71%	7.57%	94.08%	81.72%
SERIES D - CONTAINERSHIP (HEAVY LIFT)						
D1	100.00%	100.00%	72.01%	100.00%	100.00%	100.00%
D2	90.69%	80.71%	67.54%	18.33%	88.01%	77.29%
D3	86.80%	78.61%	60.53%	8.22%	84.31%	72.60%
D4	86.87%	77.89%	66.17%	6.68%	84.59%	72.59%
D5	85.00%	76.11%	66.36%	10.81%	82.86%	71.77%
D6	82.52%	71.87%	57.24%	5.95%	79.31%	68.02%
D7	85.92%	73.20%	59.07%	7.06%	82.07%	70.53%
D8	84.67%	88.27%	100.00%	55.89%	88.71%	83.66%
D9	77.13%	83.09%	91.43%	7.93%	81.60%	70.26%
D10	74.92%	76.47%	81.83%	6.62%	77.51%	66.60%
D11	75.35%	70.03%	83.00%	3.41%	76.05%	64.87%
D12	78.62%	71.30%	73.51%	13.62%	77.84%	67.95%
D13	78.49%	68.89%	73.96%	2.30%	77.10%	65.58%
SERIES E - CONTAINERSHIP						
E1	94.77%	94.92%	100.00%	100.00%	95.19%	100.00%
E2	98.05%	89.73%	93.21%	16.65%	95.73%	89.30%
E3	96.21%	88.92%	94.77%	5.77%	94.38%	86.61%
E4	100.00%	100.00%	99.69%	6.29%	100.00%	91.79%

Tab. 1.20 - Labour manhours in percentage to series' maximum MH

For series A and D it is visible that the Hull and OTF MH decreases trough the subsequent ships, meaning they both benefit with the effects of production series. In Serie A the Support activities MH decrease from the first to the fourth ship and then stabilizes with slight oscillations. Serie D shows a pike in OTF and Support MH in ship D8 and then starts decreasing the MH as if D8 had restarted the series. This problem was already approach and those ships should most probably have been considered in an independent series.

Serie B's sample size is too little to draw conclusions, but in Hull and OTF we can't see the decrease in MH seen in the first 3 ships of series A. The only cost center that shows benefit from the effect of production series is the project, despite the slight increase in B3. Serie C's sample is too little to draw conclusions, except for the project that fallows the tendency of the great MH decrease from the first to the second ship in the series. In series E the benefits from production in series in Hull and OTF are very small (around 1-5%) and in E4 all the gains are lost demanding the same or even more MH that the first ship in the series. Only the project MH follow the general behaviour showing great gains from the first to the second project and sub sequential small gains.

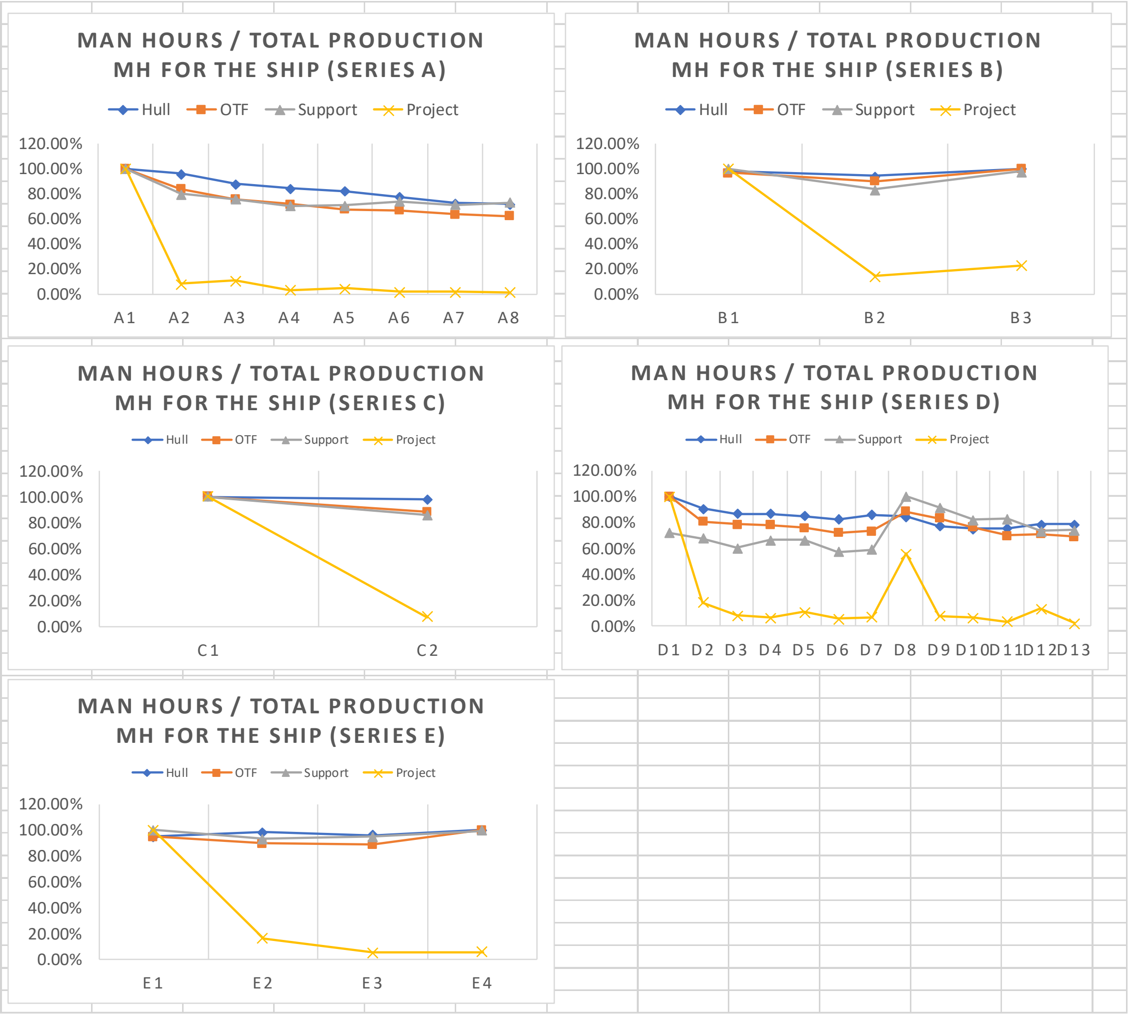


Fig. 1.26 - Evolution of MH / maximum MH required per ship

The Support group cost center of the series B and E seem to not benefit from the effects of production in series. But it might be that the fact that by analysing percentages the results can be misleading. If a cost center group were to decrease its MH on 5% and the total MH of the production would decrease 10%, then the percentage analysis would suggest that this cost center was spending more MH (worst performance) while other cost centers would show benefits greater than the reality. To make sure we weren't following in those errors, Figure 1.27 shows the values of MH without dividing them for the total production hours or the maximum MH of the series. In order to keep confidentiality, it wasn't possible to quantify the values (the YY scale is shown without numbers on its scale). However, the graph is enough to confirm the conclusions already taken – that series B and E are not benefiting from the production in series, and ships D8-D13 keep behaving as if they were an independent ship series.

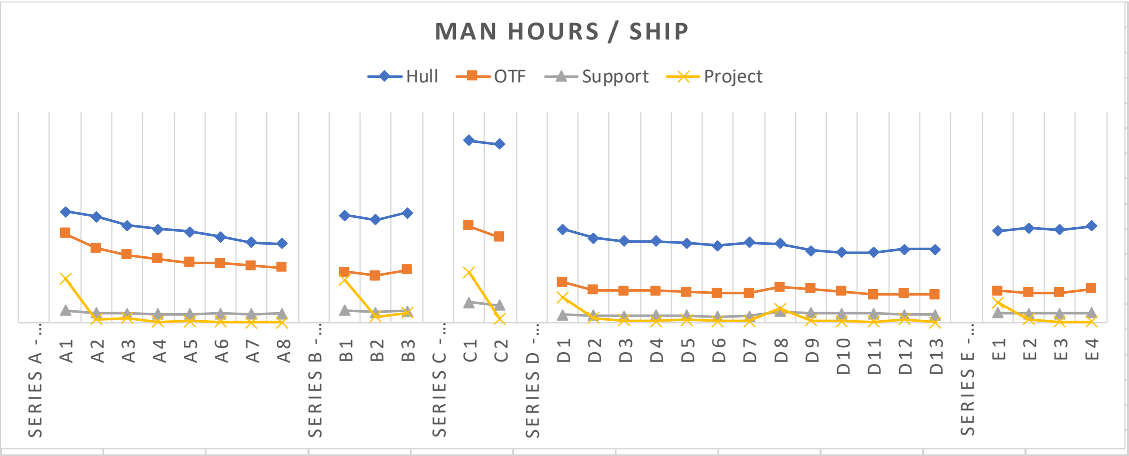


Fig. 1.27 - Man hour per ship, divided by ship series

4.6 Shipyard's productivity (CGT)

Besides the worked man hour, the yard also provided information about the different ships, necessary to calculate the CGT. This information included, for each ship: Name and delivery date, type of ship, deadweight, Gross tonnage, cargo capacity (m3), ship owner, length (total and LPP), beam, ship height, draft, main engines, engines power, number of engines and velocity.

To calculate the shipyard productivity and with the data that was provided, we chose to use MH/CGT as the way to calculate the yard's productivity. As presented in Chapter 3.3 there are other possible methods to calculate productivity. CGT was chosen because all the data necessary for its calculation was provided by the yard and it takes into account specific aspects of the ship like dimensions and complexity, depending on the ship type.

CGT was calculated using Equation 1.1 presented in chapter 3.3.1. The GT value for each ship was provided by the shipyard (including MH estimative for the subcontracted services) and with the ship description and Table 1.6, the factors A and B were obtained.

If the necessary data had been provided, it would have also been possible to directly calculate € / CGT.

These two measures of productivity are related and if one is obtained the other can be estimated by using the price per maritime industry worker. This means that in a thesis more focused in economy, the price per CGT could have been obtained through the use of a rate, which is the average price per hour worked. If further studies collect data from sufficient yards, it will be possible to calculate an iso-cost curve.

In Figure 1.28 the productivity for each ship is shown as MH/CGT.

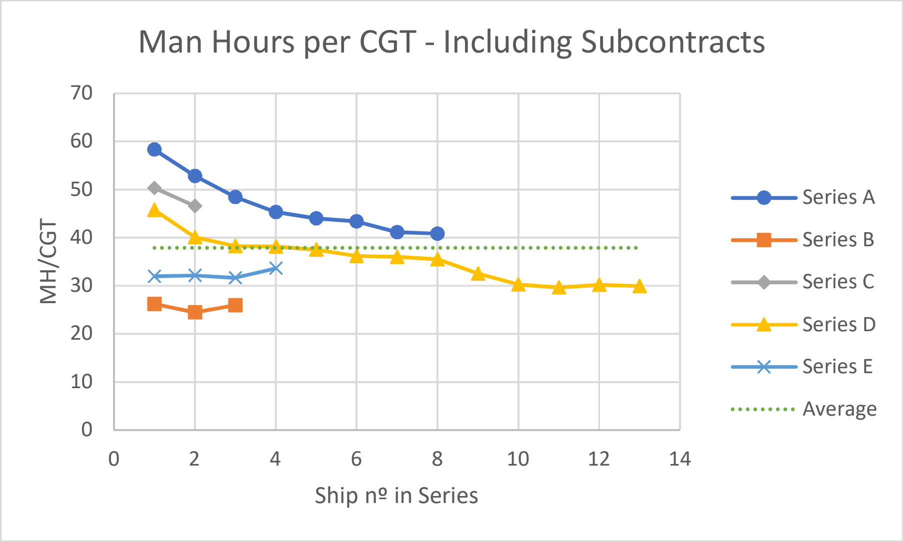


Fig. 1.28 - Case Study MH/CGT

The three lower points shown on the graph are the chemical tankers with painted tanks, which, had, in average, a 46% lower man hours/CGT ratio when compared to the tankers with stainless steel tanks. This shows a fragility of the CGT system, that it doesn't account for difference in complexity inside the same category. This effect can be minimized if sufficient data points are collected, as these efficiency differences will be averaged.

Comparing the man hour per CGT of the chemical tankers and the containerships we find that the average values obtained for each are different, 47.4 for the chemical tankers and 36.2 for the containerships which shows that the CGT, ideally the CGT factors would be such that the MH/CGT would be the same across all ships types, however this was not the case.

Ship Type	Average MH/CGT
Chemical Tanker	47.4
Container Ship	36.2
Shipyard Average	42.9

Tab. 1.21 - MH/CGT average by ship type

In order to be able to benchmark the yard's productivity with other yards, the same data would have to be gathered from several yards. In this comparison the CGT (output) of the yard should be a function of labour (MH), depreciated capital stock (€) and purchased services (€). By taking all three into account and not only the labour, the production depth and rationalization of the yard would be addressed. This enables balanced comparisons with yards with high automation, which require less MH/CGT but have a significantly bigger depreciated capital stock.

Having gathered sufficient data from yards it would be possible to use either data envelope analysis or stochastic analysis to establish the efficiency frontier, where the most efficient yards would lie.

5. Conclusions and further work:

5.1 Conclusions

To measure the yard productivity, it is essential to first make a work breakdown adequate to the building strategy adopted. Allied to a proper coding system, this enables the yard to assign the hours, resources and expenses used in each ship to organized cost centres. The study of the registered data allows the yard not only to keep track and manage an ongoing ship construction, but also to measure the yard's productivity and its evolution trough different cost centres and ships. This provides insightful information on the behaviour of each cost center and provides reference values the yard can use internally to benchmark future ships it will build.

Productivity is computed by dividing the output of the yard by its inputs. Both for outputs and inputs several metrics were available.

Some examples of possible outputs are outfitting and steel weight, DW and GT. For this case study, the chosen output metric was the compensated gross tonnage (CGT), calculated from the ships produced by the yard, which accounts for both the ship size and the ship complexity, through the application of different factors depending on the ship type. By using the latest works by Craggs et al. (2004) and Hopman et al. (2010) it became possible to also calculate the CGT for naval vessels and mega yachts. However, the CGT factors do not account for differences in complexity inside the same ship type that use the same coefficients, making a yard building simpler ships of the type A look more efficient than a yard building more complex ships of the same type. This was evident in this case study for the case of the chemical tankers, where the productivity for tankers with stainless steel hold and painted holds ranged from 47 MH/CGT to 26 MH/CGT respectfully.

Inputs are divided into three main categories, labour inputs, capital inputs and Energy, materials and purchased services. Capital inputs can be obtained by measuring the depreciated capital stock for the shipyard main equipment's and property. Some purchased services consist only of labour, but some services also include materials and other support activities, such is the case in scaffolding and painting. In this study only the subcontracts that did not include materials were considered, therefore Finishing and interiors, insulation, painting, cleaning, scaffolding and HVAC have not been considered, except for the final calculation of the yard productivity, were an estimate of the labour associated with those services (made by the yard) was used. Both of those groups would benefit by further developing in future works.

Labour inputs, despite representing a portion of up to 30% (Lamb, 2003) of a ship construction's cost, are of major interest for the yard, since it is the category which will benefit the most from improvements to the yard. To measure the labour of the yard, hours worked (Man-Hours) are gathered from the yard cost centers for each ship.

For this study data was obtained for 30 ships built in the same European shipyard: thirteen chemical tankers and seventeen containerships. The shipyard developed cost centers and a coding system specifically for its needs. The cost centers were organized into four main cost structures: Hull, Outfitting, Support and Project. The data obtained comprised of the spent man-hours organized by cost center, plus the project hours spent in each ship. Due to the use of custom cost centers and coding systems in shipyards, if a comparison between yards was sought then the data collected for different yards would have to be processed and assigned to common cost centers.

Subcontracted labour would ideally be accounted as labour, however it can be a source of data inaccuracy, as some of the services include both man hours and materials, and thus the equivalent labour can only be estimated by the yard with a variable degree of inaccuracy. For this reason, the subcontracts where not included on the cost center comparisons made in this study. However, even with an unknown level of inaccuracy, they were included in the calculation of the shipyard productivity. If they weren't, the productivity of the yard would appear mistakenly more efficient. It was found that the subcontracted services average share for the ships built remained moderately fixed along the series, with relative standard deviations ranging from 7.6% to 10.1%, depending on the series.

The ships in this study were categorized by the yard in five series, used here to study the series effect. Of those, two showed steady benefits from the series effect, while the remaining three, which were built in smaller quantities (up to four ships) showed an erratic behaviour. The two series which benefited from the series effect showed a logarithmic decrease in the total man hours required to build the ship, and one of them showed results very similar to those obtained in OECD (2007).

To analyse the weight of the work hours of each cost centre in a ship, the hours spent in each cost center, for each ship were studied. It was found that the average share of the four main cost centers were similar among different series. Structures and Outfitting represent the majority of the work, with structures ranging from 54% to 67% and outfitting from 22% to 38%. Support hours share remained virtually the same for each series ranging from 5% to 7%. Project hours ranged from 3% to 10%. It was also found a relation to the complexity of the ship and the outfit to structures ratio, chemical tankers had a ratio of 0.55, while containerships had a ratio of 0.37. This goes in accordance with the OECD coefficients for these ships that indicate that chemical tankers are more complex than containerships, and in accordance with Craggs *et al.* (2004) which used the ratio of outfit weight to lightship to calculate the base CGT coefficient for naval vessels.

Regarding the project hours, it was found that project hours suffered a great drop from the first ship in the series to the second, a drop of 82% to 92%, after which will improve slightly as the series progresses.

Lastly an average productivity of 37.7 MH/CGT was found for the yard, where in average, containerships showed a productivity of 33.9 MH/CGT and chemical tankers a slightly worse 40.3 MH/CGT.

5.2 Further work

The study of a shipyard productivity could be further developed by continuing the present studies. Both the capital and materials purchased services and energy categories of inputs are each worth of their own thesis, and as such there was no opportunity to further developed in this study, but they would benefit greatly from being further developed in further studies.

Another natural step would be to apply this study, and suggested methodology, to other yards. By studying enough yards, it would become possible to draw a production frontier, using either stochastic analysis or data envelope analysis, which would allow for the benchmarking of shipyards.

Lastly, as shown, there is still great variation in productivity for ships of the same type, due to the limitations of the CGT system, it would be interesting to further develop this system. Potentially the creation of further classes might be necessary to increase its accuracy.

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Annexes

Annex I – Fist two digits of the Coding and Classification system proposed, in Lamb (1986)

FIRST DIGIT BASED ON US NAVY SWBS	
0	
1	STRUCTURE
2	PROPULSION MACHINERY
3	ELECTRICAL
4	COMMAND & COMMUNICATION
5	AUXILIARY MACHINERY
6	OUTFIT
7	ARMAMENT
8	
9	SHIP ASSEMBLY & SUPPORT

	SECOND DIGIT							
FIRST DIGIT	**1 STRUCTURE**	**2 PROPULSION MACHINERY**	**3 ELECTRICAL**	**4 COMMAND & COMMUNICATION**	**5 AUXILIARY MACHINERY**	**6 OUTFIT**	**7 ARMAMENT**	**8 SHIP ASSEMBLY & SUPPORT**
0	PLATE	CCONTROLS	GENERATORS	SAFETY & SECURITY	HVAC	HULL MARKING		STAGING
1	SECTION	ENERGY GENERATOR	MOTORS	COMMAND & CONTROL	SAL WATER SYSTEMS	SHIP FITTING	GUNS & AMMUNITION	TEMPORARY SERVICES
2	SUB-ASSEMBLY	PROPULSION UNITS	TRANSFORMERS	NAVIGATION	FRESH WATER SYSTEMS	COMPARTIMENT-ATION	MISSILES & ROCKETS	MATERIAL HANDLING & REMOVAL
3	ASSEMBLY	TRANSMISSION	SWITCHBOARDS	INTERIOR COMMUNICATION	FUEL SYSTEMS	PRESERVATION & COVERINGS	MINES	CLEANING SERVICES
4	FOUNDATION	PROPULSOR	CONTROLLERS	EXTERIOR COMMUNICATION	LO SYSTEMS	LIVING SPACES	DEPTH CHARGES	MOLDS & TEMPLATES
5	CASTING	PROPULSION SUPPORT	PANELS	SURFACE SURVEILANCE	AIR, GAS & MISC. FLUID SYSTEMS	SERVICE SPACES	TORPEDOES	JIGS & FIXTURES
6	FLAT PANEL	FUEL & LO SUPPORT	CABLE	UNDERWATER SURVEILANCE	SHIP CONTROL	WORKING SPACES	SMALL ARMS & PYROTECHNICS	LAUNCHING
7	CURVED PANEL	AUXILIARY PROPULSION	LIGHTING	COUNTER-MEASURES	RAS/FAS	STOWAGE SPACES	CARGO MUNITIONS	DRYDOCKING
8	HULL MODULE	OPERATING FLUIDS		WEAPON CONTROL	MECHANICAL HANDLING		AIRCRAFT RELATED WEAPONS	TESTS
9	DECKHOUSE MODULE	SPARE PARTS	SPARE PARTS	SPARE PARTS	SPARE PARTS	SPARE PARTS	SPARE PARTS	TRIALS

Annex II – Ship intermediated products, in Lamb (2004)

Structural piece-parts

- Large parallel parts from plate
    - Flat
    - Simple Shaped
    - Complex Shaped
- Large non-parallel parts from plate
    - Flat
    - Simple shaped
    - Complex Shaped
- Small internal parts from plate
- Stiffeners from stock structural shapes/profiles
    - Straight
    - Simple Shaped
    - Complex Shaped
- Built-up stiffeners
    - Straight
    - Simple shaped
    - Complex Shaped

Structural subassemblies and sub-blocks made from structural piece-parts

- Large flat stiffened panels (typically shell, decks, bulkheads, tank tops, double bottoms)
- Medium-sized flat stiffened panels (typically large webs)
- Large curved stiffened panels (curved shell)
- Small flat stiffened panels (small webs, floors, internal structure)
- Structural outfitting components (simple foundations, supporting framework for outfit units, ladders, etc.)

Blocks, structural units, sections, or modules

- Flat
    - Open
    - Closed/sandwich
    - Special/irregular (hatch coamings, large foundations, casings, etc.)
- Curved
    - Open
    - Closed
    - Special/irregular
    - Superstructure

Outfitting parts and components

- Pipe spools classified by material type, size, number and type of bends and end preparations, and surface preparation or coating requirements
- HVAC ducting spools classified by size, and number and type of bends
- Joinery classified by material type, size, and number and type of bends
- Electrical cables classified by type and length
- Pipe hangers classified by type and size
- Wireway hangers classified by type and size
- Machined components and assemblies classified by required machining and assembly operations

Outfit units/assemblies/modules

- Machinery units
    - Large
    - Small
- Pipe units
    - Large
    - Small
- Electrical units
    - Large
    - Small
- Accommodation units

Hot or stage 1 outfitted blocks (blocks with all required welding work completed and any piping and machinery installed can withstand blasting and piping) classified by type of outfitting required

Blasted and painted blocks classified by type of coating system required, size, and whether open or closed

Grand blocks (sets of blocks joined together after blast and paint and prior to cold outfitting and erection)

- Flat
- Special flat
- Curved
- Special curved
- Superstructure

Cold or stage 2 outfitted blocks and grand blocks (with as much outfitting installed as possible prior to erection) classified by type of outfitting required

On-board outfit zones (spaces onboard the ship that enclose discrete and logical sets of required on-board outfitting work)

- Classified by type of space, which determines the predominate type of outfitting required
    - Exterior

  - Cargo
  - Accommodations
  - Machinery
  - Electrical
  - Tank

Ship systems (for the system testing stage of production; fuel oil, lube oil, auxiliary power, high pressure air, firefighting, radar, etc.) classified by type of testing work required

Integrated systems (for trials stage; propulsion, navigation, etc.) classified by type of integrated testing work required

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Annex III – Suggested query to gather shipyard outputs

Shipyard: Proxy Shipyard Time period: 2010 to 2018

(Fill GT if CGT is not known)

Ship Yard Nº	CGT	Ship Type	GT	Series	Notes
Build 001	4000	Cruise Ship		A	Dual fual LNG/MDO propulsion
Build 002	4000	Cruise Ship		A	Dual fual LNG/MDO propulsion
Build 003	4000	Cruise Ship		A	Dual fual LNG/MDO propulsion
Build 004	4000	Cruise Ship		A	Dual fual LNG/MDO propulsion
Build 005	5000	Containership		B	
Build 006	5000	Containership		B	
Build 007	5000	Containership		B	
Build 008	5000	Containership		B	
Build 009	5000	Containership		B	