Some relationships between build strategy and shipbuilding time in European shipbuilding

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Abstract: The build strategy of a ship specifies what is to be produced how, when, where and with what resources. Although it has been emphasised to play an important role in determining shipbuilding time and cost, scientific research on build strategy is limited. In this study, we focus on three interrelated build strategic factors of particular importance in European shipbuilding: hull production offshoring, pre-erection outfitting and the overlap between engineering and production. The study investigates how each of these three factors relates to physical ship production time and to total ship delivery time from contract signing to delivery. We use multiple linear regression on data about European shipyards and the ships they have built, which were obtained from a questionnaire and ship databases. The sample consists of 76 specialised ships, predominantly offshore support vessels, fishing vessels, ferries and other non-cargo carrying vessels, built at 24 European yards. The results provide evidence that yards practicing hull production offshoring have shorter ship production and delivery times than yards building the hulls at their own premises, even though the practice of offshoring itself is likely to have an adverse effect on shipbuilding time. The study also found a significant relationship between the level of pre-erection outfitting and physical production time. On the other hand, overlapping engineering and production only seems to have a limited impact on the production and the delivery time. Several of our results challenge established thinking and provide new insights into the factors affecting production and delivery time in European shipbuilding.

1. Introduction

Shipbuilding is a highly competitive global industry. Over the past decades, European shipyards have lost a considerable part of their market share to East-Asian shipyards, especially within the conventional and high-volume cargo-carrying segments, that is, tank ships, bulk carriers and container ships. In these segments, European shipyards now play a marginal role (SEA Europe 2020).[1] In the past decade, they have predominantly built specialised ships, in particular passenger, offshore support and other non-cargo carrying vessels (SEA Europe 2020).[1] At the end of 2019, in the aftermath of the oil price drop of 2014, almost 90% of Europe's order book, in terms of compensated gross tonnage (CGT), was made up of passenger vessels (SEA Europe 2020).[1] The European order book still stood for most of the global order book's value in the passenger and non-cargo carrying vessel segments other than offshore support (SEA

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[1] Based on data from IHS Markit Ltd., including EU, UK and Norway.

Europe 2020).[2] It constituted approximately 15% of the global order book in terms of compensated gross tonnage (CGT) (Addamo et al. 2020).[1] Due to the high value of ships in these segments, this corresponded to a share of around 34% in terms of value (Addamo et al. 2020).[1] During 2020, this share dropped quite drastically to around 6% in terms of CGT and 19% in terms of value (Addamo et al. 2021). [1] Likely causes for this reduction include the COVID-19 pandemic as well as China and South Korea's recently introduced strategies and policies supporting their local shipyards in stepping into the passenger and other noncargo carrying vessel segments (SEA Europe 2020). Irrespectively, the total number of ships ordered in these segments is relatively small. Orders are typically one-of-a-kind, rather than series of ships. With the current low demand for ships in general, margins are low and yards are struggling to a make profit from their projects, especially when unfamiliar types of ships are built. To remain competitive despite other parts of the world benefitting from lower wages, lower material costs and stronger governmental financial support, there is a critical need for European shipbuilders to understand what affects shipbuilding performance and how it can be improved.

The build strategy of a ship specifies what is to be produced how, when, where and with what resources. Clark and Lamb (1996) and Bruce and Garrard (2013) present and discuss this concept in detail. Each ship is built with a certain build strategy, although the degree to which this strategy is formalised and used as a strategic approach varies among shipyards. The build strategy is the application of the yard's shipbuilding policy (manufacturing strategy) to a particular contract. The shipbuilding policy is developed from the company's business plan and specifies the organisation and build methods required to meet the targets set in the business plan. Crucial elements in the shipbuilding policy include facilities development, productivity targets, make-or-buy and subcontracting and technical and production organisation. The build strategy defines how this policy is realised for a particular ship.4 It also incorporates the ship's master plan, also called the master programme, master schedule, main schedule or milestone plan, which contains key dates, such as (Bruce and Garrard 2013; Clark and Lamb 1996; Okayama et al. 1993):

- Contract signing: The date when the shipyard and the shipowner formally sign the contract for the building of the ship
- Start of steel cutting: Initiation of the physical construction of the ship. The date when the first steel plate is placed on the steel cutter and cut into one or several specific components intended for the ship to be built
- Keel laying: Traditionally, the date when the keel was laid in the ship erection area. Today, most ships are assembled from blocks, and keel laying is, for regulatory purposes, formally defined by the International Convention for the Safety of Life at Sea (SOLAS) as the stage of construction in which the assembly of the ship has commenced and used at least 50 t, or 1% of the ship's estimated mass of all structural material, whichever is less.
- Launch: The date when the ship is transferred from land to water, either by sliding it via its own weight down a slipway; floating it out of a dry dock; or utilising a ship lift, floating dock or pontoon (Eyres and Bruce 2012)
- Delivery: The date when the ship is formally handed over to the customer

The master plan is closely related to and affected by other parts of the build strategy. It is also affected by factors external to the build strategy, such as ship type, size, complexity and degree of novelty, as well as the current workload at the yard and its subcontractors and suppliers (Semini et al. 2022). It may have to be modified repeatedly during project execution, for example, due to customer- or supplier-caused changes and delays (Semini et al. 2022).

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[2] Based on data from Clarkson Research, including EU, UK, Norway, Turkey and Russia.

Clark and Lamb (1996) emphasise the importance of the build strategy, which is likely to have a significant effect on shipbuilding cost and time. Despite its importance, scientific research on build strategy is limited. Specifically, we are only aware of a small number of studies empirically quantifying the relationships between build strategy and performance. Lamb and Hellesoy (2002) developed a shipyard labour productivity predictor equation based on six factors, among which a technology best-practice rating had the strongest impact on performance. Pires et al. (2009) performed data envelopment analysis to assess shipyard performance, also using a technology best-practice rating as one of the controllable input factors. (Lamb 2004) and Schank et al. (2005) estimated the effect of pre-erection outfitting based on case studies and a survey. Recently, Semini et al. (2022) used multiple regression analysis to assess production time differences between the various degrees of production offshoring practiced at Norwegian yards. The findings in these studies confirm the relevance of the build strategy in determining shipbuilding performance.

In the present study, we use multiple linear regression to analyse how some build strategic factors of relevance to European shipbuilding relate to shipbuilding time. We use two indicators to measure time performance (Figure 1): production time, measured as the time from keel laying[3] to delivery; and delivery time, measured as the time from contract signing to delivery. Each of these two measures has its merits. The delivery time is considered a critical competitiveness factor in shipbuilding, and it can provide the customer with increased business opportunities and earlier cash flows (Semini et al. 2022; Pires et al. 2009). However, delivery time often depends on the balance between supply and demand as well as on other market- and business-related considerations. Production time is likely to better reflect the direct effects of build strategic choices. As a measure of operational performance, it is, therefore, considered more appropriate than delivery time.

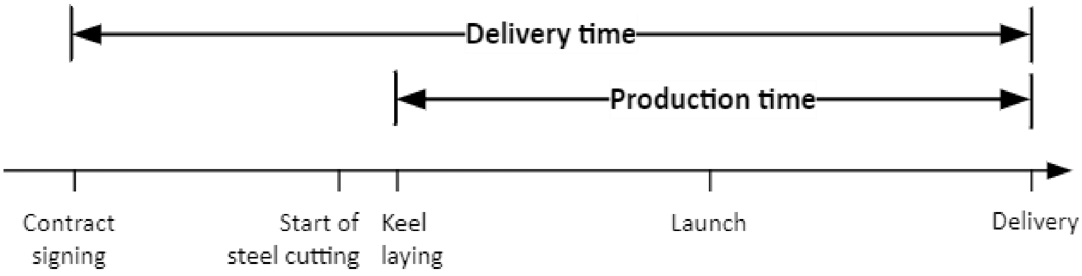

Figure 1: Production time and delivery time as measured in this study.

The importance of time in engineer-to-order production, such as shipbuilding, has been emphasised repeatedly in the literature (Parc and Normand 2016; Birkie and Trucco 2016; Gosling et al. 2015; Stavrulaki and Davis 2010; Pires et al. 2009; Olhager 2003; Alfnes and Strandhagen 2000) Especially in good market times, short delivery times can play a decisive role in winning contracts (Haugland et al. 2021). Generally, in manufacturing, short response times are associated with lower costs and higher effectiveness. Several

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[3] We follow Pires et al.'s (2009) reasoning and use keel laying, rather than the start of steel cutting, in our measure of production time. Although the yard and the customer have some degree of freedom in setting the keel laying date, it is usually triggered, according to SOLAS's definition, by the first section reaching the required weight. Production activities before keel laying typically do not occupy critical resources, nor do they bind up a great deal of capital. Their timing will often be determined by prevailing workstation time windows. It is mainly after keel laying that fast production begins to become a concern, both for the customer and the yard. Therefore, we consider the time from keel laying to delivery a more appropriate measure of production performance. Keel laying dates are, for most ships, available in maritime databases, such as Sea-web, which is an additional advantage of using keel laying rather than the start of steel cutting.

management paradigms focus on time and highlight its importance, such as Stalk and Hout’s (1990) time-based competition and Suri’s (2010) quick response manufacturing. Nevertheless, it should also be mentioned that short times are not always required by the customer. This may, for example, be the case when ships are ordered for fleet renewal. Nor are short times necessarily advantageous for shipbuilders: some slack can provide the flexibility needed to carry out tasks in the most appropriate sequence, and whenever appropriate, and it allows a more balanced use of key resources and lower peak manning levels per project. It can also provide economies of scale by allowing for the building several ships in parallel. Finally, it can reduce the risk of delivery delays, which can be more detrimental to the reputation of the yard than somewhat longer delivery times.

We identified the factors likely to influence production or delivery time in European shipbuilding based on a review of the relevant literature as well as our experience from research in shipbuilding and discussions with relevant academics and practitioners. Previous studies specifically investigating the factors affecting shipbuilding performance include (Semini et al. 2022; Pires et al. 2009; Moyst and Das 2005; Lamb and Hellesoy 2002). We paid particular attention to factors considered to belong to the build strategy, but also included factors that are external to the build strategy. The set of identified factors, shown in Table 1, constituted our initial research model.

Table 1: Factors likely to affect ship production and delivery time in European shipbuilding, including literature sources.

Factors		Sources
Build strategy		
F1	**hull production offshoring**	(Semini et al. 2022; Semini et al. 2018; Arlbjørn and Mikkelsen 2014; Kinkel 2014)
F2	offshoring of outfitting work	(Semini et al. 2022; Arlbjørn and Mikkelsen 2014; Kinkel 2014)
F3	level of integration with the hull yard (if applicable)	(Mello and Strandhagen 2011; Held 2010; Singh 2009; Beckman and Rosenfield 2008; Vickery et al. 2003)
F4	offshoring of engineering work	(Arlbjørn and Mikkelsen 2014; Kinkel 2014; Nadja Lee Hansen et al. 2013; Beckman and Rosenfield 2008)
F5	**pre-erection outfitting**	(Eyres and Bruce 2012; Schank et al. 2005; Lamb 2004; Hagen et al. 1996)
F6	**overlap between engineering and production**	(Mello et al. 2015; Moyst and Das 2005; Hicks et al. 2000a)
F7	number and size of blocks to erection (lifting/transportation capacity)	(Pires et al. 2009; Colin and Pinto 2009)
F8	ship production stages performed under cover	
F9	type of erection facility	(Pires et al. 2009)
F10	use of information technologies	(Pires et al. 2009)
F11	use of manufacturing technologies	(Pires et al. 2009)
F12	use of principles and practices from manufacturing theory	(Pires et al. 2009)
F13	vertical integration	(Slack et al. 2010; Lamb and Hellesoy 2002)
Factors external to build strategy		
F14	market situation	(Semini et al. 2022; Durdyev and Hosseini 2020; Mellbye et al. 2015; Bruce and Garrard 2013; ECORYS 2009; Pires et al. 2009; Moyst and Das 2005)
F15	industrial environment	(Bruce and Garrard 2013; Pires et al. 2009; ECORYS 2009; Moyst and Das 2005)
F16	product variety at the yard, degree of ship novelty and customization, and repeat production	(Semini et al. 2022; Semini et al. 2014; Pires et al. 2009; OECD 2007; Moyst and Das 2005; Hicks et al. 2000b; Erichsen 1994)
F17	**ship size**	(Semini et al. 2022; Pires et al. 2009; OECD 2007; Lamb and Hellesoy 2002)
F18	ship complexity	(Semini et al. 2022; Pires et al. 2009; OECD 2007; Lamb and Hellesoy 2002)
F19	yard size/capacity	(Pires et al. 2009; Colin and Pinto 2009; Lamb and Hellesoy 2002)

The factors included in this study's statistical analysis are highlighted in bold.

Based on this initial research model, we developed a questionnaire and used it to collect data from European shipyards. In examining the responses, we realised that, given the nature of the data collected, only some of the factors in Table 1 were appropriate for an analysis in terms of their influence on shipbuilding time. We focus on the following three factors (highlighted in bold in Table 1):

- hull production offshoring (F1), that is, having the hull produced at a yard located in a country with lower factor costs
- pre-erection outfitting (F5), that is, installing ship equipment components in sections and blocks before they are assembled into a closed ship structure
- overlapping of engineering and production (F6), that is, partly performing these two processes in parallel by initiating physical production before engineering is completed

Our focus on these three factors can be justified based on their importance and relevance within the context of build strategy in European shipbuilding. They are interrelated and frequently discussed topics both in theory and practice, when addressing shipbuilding performance. Among the factors external to build strategy, we include ship size (F17) in the analysis to control for its likely strong effect on production and delivery time. We exclude the remaining factors from the analysis, even though this entails a deviation from the initial research model. The reasons for these omissions will be explained in detail in the methodology chapter, and they must be kept in mind when interpreting the results.

Figure 2 shows the two research models finally used, with arrows indicating the main presumed relationships investigated. The difference between the two models is their differing dependent variables: production time in Model A and delivery time in Model B. The figure also indicates the hypotheses corresponding to the presumed relationships (H1–H3). These hypotheses are developed in the next section based on a review of the relevant literature. We then provide details about the research methodology. Next, we present the analyses we carried out and the results obtained. We discuss these results, comment on the research limitations, and make suggestions for future research.

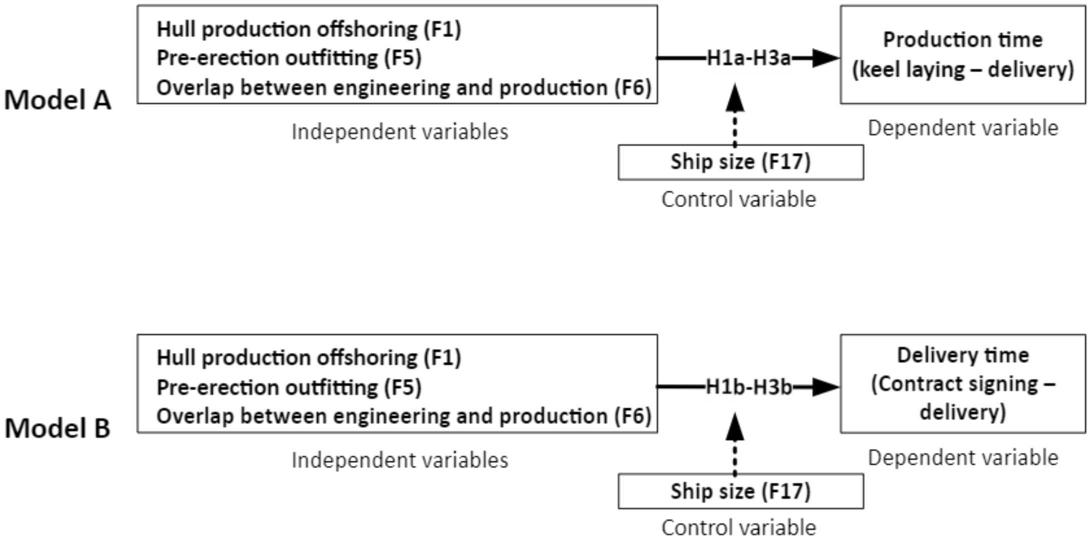

Figure 2: This study's research models

2. Development of hypotheses

2.1. Hull production offshoring

Generally, in shipbuilding, hull production and outfitting are performed in proximity, at an integrated yard. In some high-cost European countries, however, such as Norway and Denmark, yards often offshore the production of the hull to a country with lower labour costs, such as Poland, Romania or Turkey. The yards in the high-cost countries focus on outfitting, that is, installing pipes and machinery; cabling and electrical systems; heating, ventilation and air conditioning (HVAC) and accommodation and hotel functions (Semini et al. 2018). In such cases, the ship is built at two yards in different countries. The hull yard produces the blocks, erects the hull and even outfits the ship to some degree. The ship is then towed to the outfitting yard, which performs the remaining outfitting work and commissions and delivers the ship to the customer. This is illustrated in Figures 3 and 4.

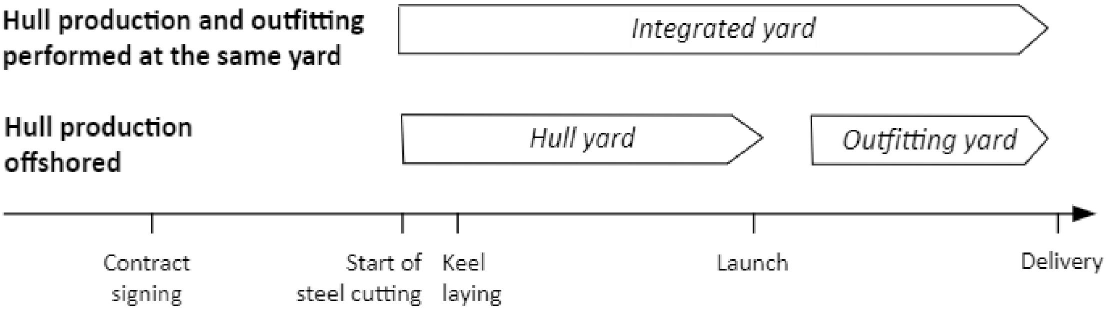

Figure 3: Hull production offshoring leads to a geographical split and interruption in the ship production process.

Figure 4: The main stages in the ship production process when hull production is offshored: (I) and (II): Block production, ship erection, and some outfitting at hull yard; (III): towing to outfitting yard; (VI) and (V): outfitting and commissioning at outfitting yard (with the permission of Ulstein).

Based on two previous studies by Semini et al. (Semini et al. 2022; Semini et al. 2018), hull production offshoring is likely to prolong both the production and the delivery time of the ship for several reasons:

- Hull transportation time, which is usually part of the critical path in physical ship production because production on the ship itself has to be paused
- Reduced direct control of progress and quality of hull production, which implies an increased risk of late hull completion and rework after arrival at the outfitting yard
- Increased number of parties involved in engineering and production, as well as a geographical and working-cultural distance between them, which complicates the interfaces between the various disciplines
- Potentially hampered information exchange due to intellectual property concerns, for example, exchange of drawings

Hull production offshoring may also sometimes imply a delay in the initiation of physical production because of large order books at the hull yards, potentially further increasing delivery time.

On the other hand, yards in high-cost European countries may also benefit from their location. Taking Norway as an example, locational advantages include proximity to customers and suppliers (for certain ship types), competitors and research and development institutions; a skilled workforce, with knowledge and experience built up through generations of seafaring and workshop workmanship development; flat and informal organisational structures with autonomous employees; tripartite co-operation between unions, management and the government; proud and loyal employees in local communities; a long-term planning horizon, with a focus on customer satisfaction and quality; and well-developed infrastructure, including financial and jurisdictional institutions (Semini et al. 2018). Norwegian shipyards also often emphasize their multi-disciplinary workforce and the various outfitting disciplines' ability to carry out work in parallel rather than sequentially. Such factors are likely to have a beneficial effect on performance, including production and delivery time. We therefore propose the following hypotheses:

H1a: Hull production offshoring is related to ship production time.

H1b: Hull production offshoring is related to ship delivery time.

Hull production offshoring may also be related to preerection outfitting and the overlap between engineering and production. In this study, we treat these latter factors as individual variables, so as to separate their effects on shipbuilding time from that of hull production offshoring.

2.2. Pre-erection outfitting

Today, most ships are erected by assembling a relatively small number of large prefabricated blocks (Eyres and Bruce 2012). This gives the opportunity to perform pre-erection outfitting, that is, installing ship system components prior to assembly of the ship. Pipes, cables, HVAC ducts, machinery and other outfit may be installed on the prefabricated units and blocks. Surface treatment (sandblasting and painting) may also to a degree be performed at the block stage. Figure 5 shows an example of a prefabricated, painted block with installed pipe systems.

Figure 5: Prefabricated, painted block with installed pipe systems.

In general, the earlier outfit parts and components are installed, the better work access and working positions are, the shorter walking distances for workers and transportation distances for materials and equipment are, the more controlled the production environment is, the easier quality control is and the more work can be performed in parallel. An outfitting task performed along the quayside is likely to be several times more costly and time consuming than if it had been carried out at the block stage (Lamb 2004). Pre-erection outfitting also allows for better balancing of the outfitting workload. This is particularly beneficial at small yards with few ships being built in parallel because it reduces the need to mobilise and demobilise operational capacities and capabilities in the various ship production phases. The benefits in terms of time and cost derived from preerection outfitting have been reported and emphasised repeatedly (Eyres and Bruce 2012; Schank et al. 2005; Lamb 2004; Hagen et al. 1996; Chirillo and Chirillo 1985), and production time reduction has been highlighted as one of the main goals of preerection outfitting (Lamb 2004). Pre-erection outfitting means overlapping steel structural work and outfitting, executing more physical work in parallel and, thereby, reducing production time.

Nevertheless, pre-erection outfitting also has drawbacks, including increased work-in-progress, with its associated costs and risks of damage; reduced opportunities for the simultaneous execution of engineering and production; more difficult accommodation of late change orders; heavier blocks and potential obstacles to later access. Pre-erection outfitting has been practiced by shipyards all over the world, to varying degrees and with varying benefits. These benefits seem to depend on factors such as discipline (more benefits for steel outfits, pipes, HVAC and paint but fewer for electrical components and accommodation), ship type (more for cargo but fewer for passenger and naval) and shipyard practices and capabilities (Schank et al. 2005; Lamb 2004). In this study, we therefore advance the following hypotheses:

H2a: Pre-erection outfitting is related to ship production time.

H2b: Pre-erection outfitting is related to ship delivery time.

2.3. Overlap between engineering and production

As illustrated in Figure 6, the physical production of a ship is usually initiated before all engineering work is finalised (Semini et al. 2014; Moyst and Das 2005; Cushing 2003). Such simultaneous execution of engineering and production activities is claimed to be a common practice to allow for delivery time compression in shipbuilding and other engineer-to-order industries (Emblemsvåg 2020; Thomsen et al. 2012; Chen 2006; Hicks et al. 2000a; Tu 1997). In construction, the concept is known as fast-tracking (Thomsen et al. 2012). It allows engineering more time to finalise certain drawings without affecting total project time. This is particularly advantageous for systems and solutions that are engineering intensive or subject to high uncertainty and frequent changes, but not too complex from a production perspective.

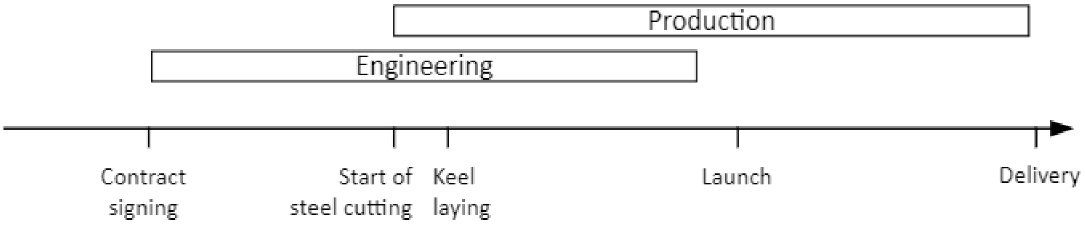

Figure 6: Illustration of the overlap between engineering and production in shipbuilding.

However, overlapping engineering and production may not necessarily lead to shorter delivery time. Such overlap is based on sharing incomplete design information (Mello et al. 2015); it makes cost calculations, planning and coordination more challenging (Emblemsvåg 2014; Hicks et al. 2000a); and it can lead to rework in production caused by design errors and changes (Moyst and Das 2005; Lamb 2004). According to Mello et al. (2015) and Moyst and Das (2005) it may be particularly challenging when there are a large number of design changes, which is common for the specialised ships European yards focus on. Based on these considerations, we formulate the following hypotheses:

H3a: Overlapping engineering and production is related to ship production time.

H3b: Overlapping engineering and production is related to ship delivery time.

3. Methodology

For hypothesis testing, we performed a multiple linear regression analysis of a sample consisting of ships delivered by European yards between 2014 and 2016. Multiple linear regression is a statistical technique used to examine the strength of the relationship between one dependent and several independent variables as well as the importance of each of the independent variables to this relationship. It is appropriate when the object of investigation is a statistical, not a functional, relationship. In general, the regression equation (regression variate) is the linear combination of independent variables that best predicts the dependent variable (Hair Jr. et al. 2014):

$$Y = b_0 + b_1X_1 + . . . + b_nX_n + e$$

where

- Y = dependent variable
- X_i = independent variables
- b_i = regression coefficients
- e = prediction error (residual)

Multiple linear regression seeks values for the regression coefficients that will ensure the maximal prediction of the dependent variable based on the set of independent variables. To measure the explanatory strength (predictive capability) of the regression equation, the coefficient of determination (R^2) is used. This coefficient measures the proportion of the variability of the dependent variable that is explained by the independent variables. For readers not familiar with multiple regression, we recommend the textbook written by Hair Jr. et al. (2014).

3.1. The data

The data material analysed in this paper was initially collected as a part of the second author's unpublished master's thesis, which was supervised by the remaining authors. We used the European Shipyards' and Maritime Equipment Association's (SEA Europe) website, the Sea-web ship database and the shipyards' own websites to identify European (EU-28 plus Norway) shipyards delivering sea-going, propelled newbuild ships with gross tonnage (GT) over 1000. Because little information on naval ship details was publicly available, shipyards producing only naval ships were not further considered. This left us with 117 shipyards. We performed total population sampling by sending an online questionnaire to all these shipyards via e-mail.

The purpose of the questionnaire was to collect data on the factors in the initial research model (Table 1), with a focus on data that would not normally be publicly available. Essentially, the questionnaire consisted of two parts. The first part collected general information about the shipyard, such as name, location and number of employees. We also asked the shipyards to specify the type of ship over 1000 GT most frequently delivered in the 2014–2016 period, if any, and to complete the remainder of the questionnaire for this specific ship type. The second part of the questionnaire consisted of questions concerning the build strategic factors F1–F12. We decided early on to exclude F13, vertical integration, from the questionnaire because correct measurement of this multidimensional concept would have brought the size of the questionnaire beyond what was considered reasonable (see Schank et al. (2005) for a survey focusing on vertical integration in shipbuilding).

Not unexpectedly, the response rate was low, so we used various direct contact means to increase the sample (convenience sampling). A random choice of nonresponding yards was contacted via telephone and, if the yard consented, the questionnaire was completed by means of a telephone interview. The second author also participated at the 2017 NOR-Shipping conference in Oslo, 30.5.-2.6.2017, and completed the questionnaire with some of the yards present. We also collected the necessary data from some Norwegian yards as a part of an ongoing research collaboration.

When possible, we used open data to validate responses, for example, the yards' websites. We, then, used maritime databases, such as Sea-web, to collect information about the ships each of the responding yards delivered between 2014 and 2016, particularly size, contract signing date, keel laying date and delivery date. Sea-web also provided information about which yard produced the hull of a given ship, if it was not the yard that delivered the ship to the customer. When a yard delivered fewer than three ships of the type it answered the questionnaire for, we also included ships of that type delivered some time before or after the 2014-2016 period in an attempt to have at least three ships per yard (although this was not always possible). This helped reduce the impact of ship-specific factors on the results. We found this approach justifiable because the main data used to test the hypotheses are unlikely to be very different some time before or after the analysis period. The yard and ship data obtained in this way allowed us to measure all the factors in the initial research model (other than F13) for the responding yards.

To obtain a more homogeneous sample, we excluded the one responding yard (now closed) that offshored block production but carried out ship erection itself (a hybrid between an integrated yard and an outfitting yard). Furthermore, only two of the responding yards focused on general cargo ships during the analysis period and answered the questionnaire for this type of ship. All the remaining yards positioned themselves within more specialised segments. Therefore, we decided to narrow the scope of the study to specialised ships, and we excluded the two former yards.

In some cases, external factors can lead to delays and have a large impact on production and delivery time, for example, a change in the customer or the bankruptcy of the hull supplier. In other cases, customer and yard agree on delayed delivery for external reasons, for example, reasons related to the market. While it would have been most appropriate to identify and exclude such cases when studying the effects of build strategy, we did not consider the additional data collection effort justifiable. It is unlikely that the occurrence of such cases is strongly correlated with any of the independent variables. Therefore, we did not expect that leaving such cases in the sample would strongly affect the independent variables' regression coefficients (i.e. the strengths of the independent variables' individual relationships with the dependent variables), although it may have somewhat increased the unexplained variability and reduced the significance of the results. Note that we did exclude two extreme outliers in the sample of ships, two well-known cases with production times over 2000 days, which were a consequence of factors external to production. All other ships had production times below 1000 days.

The sample we obtained consisted of 76 specialised ships delivered from 24 yards. This corresponds to approximately 20% of the 117 European shipyards in the general population. Because we restricted the target population to yards that delivered specialised ships, and not all the 117 shipyards necessarily did so between 2014 and 2016, the sample versus target population ratio is likely to be higher than 20%. The measures used for the factors given in Table 1, as well as descriptive statistics for the data obtained, are included in Tables A1 and A2 in the Appendix.

To protect the identity of the participating yards, we do not provide detailed information about their locations. However, to ensure appropriate result interpretation, it is important to know that most of them were Spanish or Norwegian. This is due to the data collection approach: the predominance of Spanish yards is a consequence of their presence at the Nor-Shipping conference; the high number of responses from Norwegian yards is likely to be due to the study being carried out at the Norwegian University of Science and Technology, which is well-known in Norway and has the main national responsibility for education and research in engineering and technology. All the Spanish yards were integrated yards, and they constitute 9 of the 12 integrated yards included in the sample. All the Norwegian yards were outfitting yards, constituting 9 of the 12 outfitting yards in the sample. Table 2 shows the yards' sizes in terms of the average number of production workers during the period of analysis (2014– 2016), separately per yard type and location. Almost all yards were small, except for the three integrated yards outside Spain. For the outfitting yards, we also asked about the sizes of the hull yards they used. Most of these were also relatively small (see Table A1 in the Appendix).

Table 2: Sizes of the yards included in the sample (average number of production workers between 2014 and 2016).

	Integrated yards		Outfitting yards		Total
	Spain	other	Norway	other	
Under 500	7		6	2	15
500-1000	2		3	1	6
1001-2000					
2001-3000		2			2
Over 3000		1			1
Total	*9*	*3*	*9*	*3*	*24*

Table 3 shows the number of ships included in the sample, per ship type and type of yard delivering them. As can be seen, most ships included in the study are offshore support and fishing vessels. The table also shows that, in the sample, the types of ships delivered from integrated yards and those delivered from outfitting yards were similar, although outfitting yards had an even stronger specialisation in these two ship types.

Table 3: Number of ships included in the sample, per ship type and yard type.

	Integrated yards	Outfitting yards	Total
Dredgers	8	1	9
Ferries	2	3	5
Fishing vessels	10	15	25
Heavy load carriers	2		2
Offshore support vessels	14	17	31
Research vessels	4		4
Total	*40*	*36*	*76*

3.2. The variables and measures used in the regression analysis

Although, ideally, we would have included all the factors identified in Table 1 in the regression analysis, we realised that only for some of them, the obtained data would provide meaningful results and relevant new insights into how they relate to shipbuilding time.

Table 4 provides an overview of the variables and measures included in the regression analysis. Hull production offshoring was, in the questionnaire, measured as the percentage of steelwork offshored. Due to the dichotomous nature of the responses (see Table A1 in the Appendix), we model it using a binary variable. We use the natural logarithmic transformation of gross tonnage (GrossT) because this results in a stronger explanatory strength (R^2) in the regression analysis than the untransformed value of GrossT. This makes sense because the effect of size is likely to decrease with increasing size (due to relatively less structural material, as well as effects of economies of scale).

Table 4: Variables and measures used in the multiple regression analysis to test the study's hypotheses.

Variable	Variable type	Measure
Dependent		
Production time (ProdTime)	Metric	Number of days between keel laying and delivery
Delivery time (DelTime)	Metric	Number of days between contract signing and delivery
Independent		
Hull production offshoring (Offsh)	Binary	1 if hull production is offshored, 0 otherwise
Pre-erection outfitting (PreOutf)	Metric	Percentage of outfitting work performed before ship erection, measured by means of five discrete choices (1 = 0–20%, 2 = 21–40%, 3 = 41–60%, 4 = 61–80%, 5 = 81–100%)
Overlap between engineering and production (Overl)	Metric	Percentage of engineering performed after the keel is laid, measured by means of five discrete choices (1 = 0–20%, 2 = 21–40%, 3 = 41–60%, 4 = 61–80%, 5 = 81–100%)
Control variable		
Size (GrossT and lnGrossT)	Metric	GT and its natural logarithmic transformation

Several of the remaining factors are left out because the variance in the data is too low to allow for a meaningful statistical assessment of their relationships with shipbuilding time. Specifically, F2 (offshoring of outfitting work) is left out because very few yards practiced this to a higher degree than was necessary for practical reasons. F3 (level of integration with the hull yard) is left out because in most cases, it was low or low to medium. F4 (offshoring of engineering work) is excluded because it was, at most yards, only practiced to a relatively low degree. Responses are also similar across the sample regarding F8 (stages of the ship production process carried out under cover): block construction and block outfitting were usually performed under cover, the remaining stages were usually carried out outdoor. The responding yards were also similar in size (F19): most of them had below 1000 production workers. F9 (type of erection facility) also shows limited spread in the data. Furthermore, this factor is correlated with F1 (hull production offshoring): most integrated yards used slipways. This can be seen in Table 5, which shows how the type of erection facility relates to hull production offshoring, and to yard size (the reader is reminded that, for outfitting yards, ships are erected at their hull yards' facilities). The industrial environment (F15) is also so strongly correlated with hull production offshoring (F1) that its inclusion would not provide reliable regression coefficients.

Table 5: Type of erection facility used.

	Large, integrated yards	Small, integrated yards	Hull yards
Slipway	1	8	6
Building dock		1	5
Ground-level system	2		1

F7 (lifting capacity) and F10–F12 (technological maturity) have been previously shown to have strong effects on performance (Pires et al. 2009; Lamb and Hellesoy 2002), and they are likely to be correlated with some of the factors included in the regression analysis, especially pre-erection outfitting. Including also any of F7, F10, F11 or F12 in the regression does not notably increase its explanatory strength (R^2), however. From discussions with some of the respondents, we became aware of likely weaknesses in the measures used, which were caused by unclear question wording and low content validity. Although it is unfortunate, we therefore omit these factors as well. It is important to keep these and all other excluded factors in mind when interpreting the results, especially the ones likely to be related to the factors included in the regression (confounding factors). In such cases, the estimated effects of the latter represent not only their actual effects but also the effects that they share with the former (Hair Jr. et al. 2014). The present study provides insights into how time consumption varies with the selected factors, but it does not allow drawing conclusions regarding causality.

We also temporarily included the remaining factors (F14, F16 and F18) in the regression, one by one, but they could not explain much of the variability in production or delivery time. Low explanatory strength of these factors may be due to the measures used. In the case of the market situation (F14), it may also be due to the relatively short period of time investigated, which did not properly cover both good and bad market times. Ship complexity (F18) was entered by replacing the control variable (lnGrossT) with CGT and lnCGT, but this did not increase the explanatory strength of the regression models. To restrict the number of variables (principle of parsimony), we did not include these factors in the regression models we ultimately used.

In summary, with the given data, the inclusion of additional factors in the multiple regression analysis would not have had a substantial impact on the results. It should be noted that the number of factors we could reasonably include was also limited by the size of the sample we managed to obtain, so as to maintain an acceptable level of statistical power (Hair Jr. et al. 2014).

3.3. The analyses

To test the hypotheses, we carried out two multiple linear regression calculations with the sample of 76 ships, one for each of the models shown in Figure 2. The difference between the models is in their differing dependent variables. Model A was used to assess the independent variables' relationships with production time (H1a–H3a) and Model B was used to assess their relationships with delivery time (H1b–H3b). We tested the normality, homoscedasticity and linearity assumptions underlying regression analysis and did not come across any prohibitive statistical violations, so we considered them to be satisfactorily met. We also assessed the independence of error terms. By plotting the residuals obtained from the regression calculation with Model B against the contract signing date, we noted a slight negative trend, probably caused by some market-related factors we are not able to represent with our measures of the market situation. Inclusion of the contract signing date as an additional independent variable in Model B somewhat increased its explanatory strength (R^2), but it did not remarkably change the remaining independent variables' results, so we chose to take this additional variable out of the model again.

We also assessed correlations and multicollinearity. We calculated Pearson's correlation coefficients (a sample size of 76 justifies the use of Pearson's correlation coefficients, despite some non-normality in some of the individual variables; see Table 6). Even though PreOutf is significantly correlated with both Offsh and Overl, all the independent variables' variance inflation factors obtained in the regression calculations turned out to be below 1.7, and, thus, well below Hair et al.'s (2014) recommended cutoff. Therefore, the regression coefficients can be considered rather reliable. Based on studentised residual plots, there are no extreme outliers in the sample.

Table 6: Pearson's correlations for the data and variables included in the regression analysis (N = 76 ships).

	ProdTime	DelTime	Offsh	PreOutf	Overl	lnGrossT
ProdTime						
DelTime	0.669**					
Offsh	-0.065	-0.270*				
PreOutf	-0.072	0.225	-0.543**			
Overl	-0.038	-0.057	-0.068	-0.271*		
lnGrossT	0.564**	0.520**	0.030	0.112	-0.009	

* $p < 0.05$, ** $p < 0.01$; p = p-value

To better understand the relationships between hull production offshoring and the other factors in the regression models, we calculated descriptive statistics separately for Offsh = 0 and Offsh = 1 (Table 7). One relevant observation is that, on average, ships delivered from integrated yards (Offsh = 0) had, before erection, installed over 20% more of the outfit than ships delivered from outfitting yards.

Table 7: Descriptive statistics for the data and variables included in the regression analysis (N = 76 ships).

	PreOutf				Overl				GT			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Offsh = 0 (N = 40)	1	4	2.80	1.14	2	4	3.10	0.55	1,336	46,373	7,676	11,280
Offsh = 1 (N = 36)	1	3	1.53	0.81	1	5	2.97	1.25	1,135	31,240	5,931	6,241
Total (N = 76)	1	4	2.20	1.18	1	5	3.04	0.94	1,135	46,373	6,849	9,226

In all the tests we carried out in this study, we used 0.05 as the conditional significance level. We used two-tailed tests because our hypotheses are non-directional (Cho and Abe 2013). The analyses were performed with the IBM SPSS Statistics software version 28.1.0.1 (142).

4. Results

Table 8 provides a summary of the two regression calculations performed to test H1–H3. We show both unstandardised (*b*) and standardised (*β*) regression coefficients. Unstandardised coefficients directly provide estimates of the expected change in production and delivery time (in days) for each unit of change in the independent variable. Standardised coefficients allow us to compare directly the relative importance of each independent variable in its relationship with the dependent variable (Hair Jr. et al. 2014).

Table 8: Summary of the results of the two regression calculations used to test the hypotheses (N = 76 ships in both models).

	Dependent variable	Coefficient of determination		Independent variables			Control variable
		R^2	R^2 adjusted	Offsh	Preoutf	Overl	lnGrossT
Model A (see Figure 2)	ProdTime	.389	.354	b = -90.65* β = -.268* p = .023	b = -46.76** β = -.323** p = .009	b = -25.03 β = -.139 p = .170	b = 114.21*** β = .607*** p = .000
Model B (see Figure 2)	DelTime	.357	.321	b = -126.14* β = -.301* p = .013	b = -3.42 β = -.019 p = .877	b = -17.46 β = -.078 p = .448	b = 123.26*** β = .530*** p = .000

R^2 = coefficient of determination; b = unstandardized regression coefficient; β = standardized regression coefficient; p = p-value.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

H1a/H1b suggest that there is a relationship between hull production offshoring and production/delivery time. The results support these hypotheses: ships delivered from outfitting yards had significantly shorter production and delivery times than ships delivered from integrated yards. The expected difference in production time was in the order of 3 months, and the expected difference in delivery time was in the order of 4 months.

H2a/H2b predict a relationship between pre-erection outfitting and production/delivery time. The results support H2a but not H2b. For the ships in the sample, ship production time significantly decreased with an increasing level of pre-erection outfitting. The expected production time reduction was approximately 47 days for each one-unit increase (20% of the total outfitting work) in pre-erection outfitting.

H3a/H3b are not supported: production and delivery time were not significantly related to the extent to which engineering and production overlapped. This may be due to the relatively low sample size and the resulting weak statistical power. Nevertheless, the regression coefficients are small in both models and unlikely to change dramatically if more ships were included in the sample. Thus, based on our data, overlapping did not seem to influence shipbuilding time.

Regarding ship size, the regression coefficients show strong significance. The relative importance of lnGrossT's relationship with production and delivery time (standardised regression coefficients) is higher than those of any of the other variables included in the models. This confirms the importance of using ship size as a control variable when studying shipbuilding performance. Collectively, the variables included in the models can explain somewhat more than one-third of the total variability in production and delivery time (R^2). Table 9 summarises the main results from this study's quantitative analyses.

Table 9: Summary of this study's hypothesis test results

Hypothesis		Result
H1a	Hull production offshoring is related to ship production time	Supported (Model A), *p* = .023, *N* = 76 ships
H1b	Hull production offshoring is related to ship delivery time	Supported (Model B), *p* = .013, *N* = 76 ships
H2a	Pre-erection outfitting is related to ship production time	Supported (Model A), *p* = .009, *N* = 76 ships
H2b	Pre-erection outfitting is related to ship delivery time	Rejected (Model B), *p* = .877, *N* = 76 ships
H3a	The overlap of engineering and production is related to ship production time	Rejected (Model A), *p* = .170, *N* = 76 ships
H3b	The overlap of engineering and production is related to ship delivery time	Rejected (Model B), *p* = .448, *N* = 76 ships

5. Discussion

5.1. Ships delivered from outfitting yards have shorter production and delivery times than ships delivered from integrated yards

The results provide support for H1a and H1b: the practice of hull production offshoring indeed seems to be related to ship production and delivery time. The sample's results show that, when other variables in the models are kept constant, ships delivered from outfitting yards were, on average, produced approximately 90 days more quickly than ships delivered from integrated yards. Also, delivery time was 126 days shorter. This is an interesting and perhaps somewhat surprising finding because hull production offshoring is generally considered to have an adverse effect on shipbuilding time (Semini et al. 2022; Semini et al. 2018). It suggests that certain characteristics of the shipbuilding process for ships delivered from outfitting yards have a stronger effect on shipbuilding time than hull production offshoring. Based on the initial research model (Table 1), such characteristics likely include the locational advantages of the outfitting yards (F15), as well as yard facilities, practices and levels of technological maturity (F7–F12).

When benchmarking production time performance between integrated yards and yards that offshored hull production, differences in pre-erection outfitting levels must be taken into consideration. From the average pre-erection outfitting levels shown in Table 7 and PreOutf's regression coefficient in Model A (Table 8), we calculate that the higher levels of pre-erection outfitting at integrated yards corresponded to almost 60 days of production time savings. The production time disadvantage of integrated yards was thereby reduced from 3 to 1 month. In contrast, it can be seen from PreOutf's regression coefficient in Model B, that the delivery time disadvantage was not notably reduced.

The results indicate that European outfitting yards are competitive in the fast delivery of specialised ships. In situations in which time is critical, which is often the case in good market conditions, 4 months of reduced delivery time can play a decisive role in obtaining contracts because they can imply 4 months more business opportunity for the customer. The findings are in accordance with and provide additional empirical support for studies on the global competitiveness of high-cost nations, such as Porter and Stern (2002) and Reve and Sasson (2012). These studies emphasise that competitive advantage must come from the commercialisation of new and knowledge-intensive products and processes, in our case specialised ships. Our study suggests that, when time is important, yards located in high-cost European countries may have a competitive advantage in the building of specialised ships.

5.2. Pre-erection outfitting is associated with shorter production time

The analysis provides support for the hypothesis suggesting a relationship between pre-erection outfitting and production time (H2a): in the study's sample, the production time was approximately 47 days shorter for each 20% increase in pre-erection outfitting, as a percentage of the total amount of outfitting work. Although our research design does not allow us to establish causality, the study does provide some empirical evidence and quantification of the benefits that might be derived from pre-erection outfitting in segments where they have, according to Lamb (2004) not been so clear cut. It sheds some light on the consequences for outfitting yards when they postpone large parts of the outfitting work until after the arrival of the hull at their premises.

Generally, the data collected from the yards indicate a relatively low level of pre-erection outfitting in European shipbuilding (see Table 7). Even though this may be justified based on the focus on specialised ships, yards may investigate whether a better distribution of outfitting over the production period, with a higher level of pre-erection outfitting, may be a way to increase productivity. Outfitting yards, in particular, may benefit from planning with somewhat more pre-erection outfitting (at the hull yard). Our data shows that some outfitting yards had 41–60% of the total outfitting work performed by the hull yard, before erection. It may be possible for others to follow, although this may require earlier completion of certain drawings, as well as a change in the practices at the hull yard. Hagen and Erikstad (2014) and Schank et al. (2005) provided a discussion of how to determine a suitable level of pre-erection outfitting.

Lamb (2004) emphasised that, in situations in which the benefits derived from pre-erection outfitting are relatively small, the focus should not be on pre-erection outfitting but, instead, on organising the work in the best possible way to suit the chosen approach. One opportunity to counteract the drawbacks of low levels of pre-erection outfitting is on-unit outfitting. On-unit outfitting is the construction of packages of equipment or bundles of pipes and other systems on a common foundation, in the workshop (Lamb 2004). Such packages can be installed during dock or quay outfitting, after ship erection. On-unit outfitting provides many of the benefits associated with pre-erection outfitting.

5.3. Overlapping engineering and production has little effect on the production or delivery time

H3a and H3b are rejected: neither production nor delivery time was significantly affected by the degree to which engineering and production overlapped. The lack of an association with delivery time may be somewhat surprising given the established literature's emphasis on the need for overlapping engineering and production to achieve acceptable delivery times in engineer-to-order production (Emblemsvåg 2014; Chen 2006; Hicks et al. 2000a; Tu 1997). Similarly, the lack of an association with production time somewhat contradicts the literature highlighting the negative effects on production due to overlap with engineering (Mello et al. 2015; Emblemsvåg 2014; Lamb 2004; Hicks et al. 2000a).

This could be a consequence of weaknesses in the collected data, such as a small sample size and low content validity. On the other hand, if production and delivery time indeed are largely independent of the degree of overlap between engineering and production, varying degrees of overlap reflect varying engineering period lengths (Figure 7). The length of the engineering period likely depends on the ship's novelty and corresponding design uncertainty. The more innovative the ship is, the more engineering must be stretched into production if delivery times are to be kept reasonably low. For less innovative ships, including the repeated production of similar ships, overlapping would typically be less critical and practiced to a lower extent. To validate this proposition, there is a need for an appropriate measure of design novelty, as well as ship-specific data about the degree of overlap between engineering and production. Such data were not available in this study, which suggests an opportunity for further research.

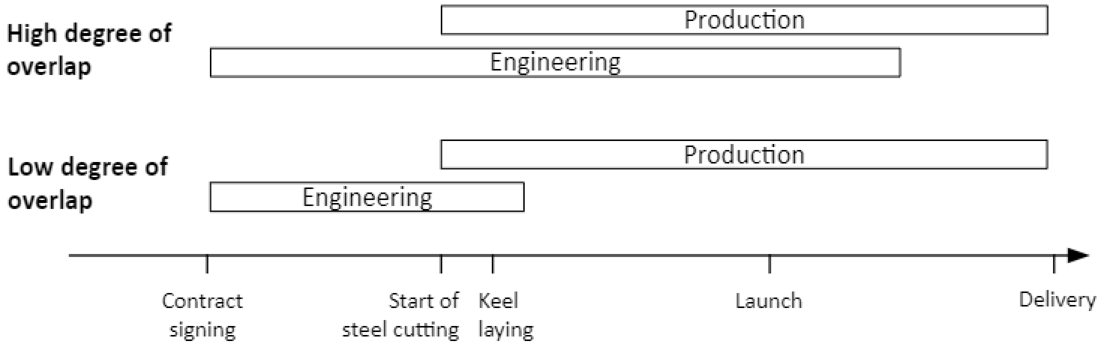

Figure 7: This study's findings suggest that varying degrees of overlap between engineering and production first and foremost reflect varying engineering period lengths.

An alternative interpretation of our findings may be that stretching engineering into the production phase is not, first and foremost, used to reduce delivery time, as has been stated in the literature, but, rather, to increase design flexibility by postponing engineering decisions until the last possible moment. Such a postponement simplifies incorporating the latest technologies; accounting for the latest changes in rules and regulations; as well as accommodating late customer requests, decisions and changes. Based on our discussions with yard managers, it is usually not engineering, but the yard's order book and the suppliers' delivery times of critical components and systems, that determine the critical path in the project. Long engineering periods seem to reflect a yard practice of delaying the completion of drawings and instructions until they are strictly needed by production. Such a practice also provides engineering with an increased opportunity to balance its workload and solve design challenges better. If necessary, engineering could, however, complete its work earlier. Late engineering also has its drawbacks, especially for production, such as reduced opportunities for pre-erection outfitting, an increased need for coordination and the risk of rework when work is initiated based on incomplete or approximate drawings. Completing drawings and instructions earlier may, under certain circumstances, provide an opportunity to reduce costs. This was further discussed by Semini et al. (2014), comparing two strategies for building customised ships, with different degrees of customer involvement and overlap between engineering and production.

6. Implications, limitations, and further research

6.1. Implications

To summarise the implications, we first note that the practice of hull production offshoring does not seem to impede time-based competitiveness. The results provide strong indications that yards in high-cost regions have capabilities enabling short shipbuilding times despite the presumed adverse effects of hull production offshoring. This finding strengthens the conception of such a practice as a viable build strategy if it helps reduce cost disadvantages.

Secondly, it seems reasonable to conclude that European shipyards should review their pre-erection practices because there may be unexploited performance improvement potential in this area. The study indicates that pre-erection outfitting may provide notable benefits, even for the types of specialised ships typically built at European yards.

Thirdly, in a similar vein, the findings suggest that yards should critically assess their practice of overlapping engineering and production. In some cases, it may be possible to obtain cost benefits from reducing this overlap without adversely affecting delivery time.

6.2. Limitations and suggestions for further research

This study contributes to shipbuilding theory with new knowledge about some relationships between build strategy and shipbuilding time. To the best of our knowledge, it is the first study to statistically assess differences in shipbuilding time between integrated yards and yards offshoring hull production. Similarly, we have not found previous statistical analyses of how pre-erection outfitting and the overlap between engineering and production relate to shipbuilding time. For ship owners, this study provides an improved understanding of how the choice of shipyard may impact delivery time. For shipyards, it provides a basis for performance benchmarking, as well as some indications of how build strategy can be expected to affect shipbuilding times.

This study identified two build strategic factors that were significantly related to shipbuilding time. Future research should include more factors from the initial research model (Table 1). This will allow researchers to investigate correlations among the factors and to isolate each factor's individual relationship with time, and it will help explain even more of the total variability in time. How strongly are the build strategic factors included in our regression models correlated with the omitted build strategic factors, such as technological maturity (F10–F12)? How much of the remaining variability in time can be attributed to them, and how much is related to factors external to build strategy, such as product and market characteristics? Furthermore, if data can be accessed, similar studies should be carried out using other performance criteria, such as productivity, cost and profitability.

Our initial research model covered a wide range of build strategic factors likely to affect ship production and delivery time in European shipbuilding. The questionnaire was built on this initial research model. To keep the questionnaire at a manageable length, several of the factors were operationalised by means of single items, including the factors ultimately used in the regression analysis. In future studies, content validity may be increased by narrowing down the scope of the data collection and using indices consisting of several items. More work is also needed to identify appropriate measures of the factors external to build strategy, such as the market situation and ship complexity and innovativeness, so that they can be appropriately controlled when assessing shipbuilding performance.

The complexity and multi-dimensionality of build strategy (and the terminology related to it) also suggest that deeper, case study-based interaction between researcher and yard is likely to provide additional valuable insights. Case studies may also be used for explanatory studies. The present study provides quantitative, empirical evidence of how time consumption varies with certain selected build strategic factors, but it cannot identify the cause of these variations. For example, there is a need to better understand why yards that offshore hull production seem to have shorter production and delivery times than those building the hulls themselves. Benchmarking studies may be carried out involving both types of yards. Such studies may help identify operational characteristics that lead to differences in performance.

Due to the competitive nature of the industry, access to yard data is often limited. Arguably, this is one of the reasons statistical studies are scarce in shipbuilding research and samples are typically small and based on convenience. Within such a context, we consider our sample of 24 yards and 76 ships to provide valuable new empirical data. It is not, however, representative of the total population of European yards producing specialised ships. We cannot undertake statistical generalisation, and the results are, first and foremost, true for the yards and ships included in the sample. For other yards in the population, they are purely indicative. It should be noted that most shipyards included in the sample were small. When attempting to transfer the results to larger yards, it must be remembered that they may, for example, be better equipped to take advantage of pre-erection outfitting. What the statistically significant results in our study do imply is that the relationships were unlikely to be random, that is, caused by other, uncorrelated factors. Independent of statistical significance, the results also provide estimates of the extent of these relationships.

Generally, a small sample size also implies that, to maintain a satisfactory ratio of observations to independent variables (statistical power), only a limited number of all the potentially relevant performance-affecting factors can be included in the same research model. As Lamb and Hellesoy (2002) also emphasised, further attempts are required to collect data from a larger number of yards. One way to achieve this might be a collaborative, global effort among shipbuilding researchers and industrial organisations, such as SEA Europe. In addition, a potentially promising complementary approach might be to focus on best performing companies and look for common characteristics, thereby identifying best practices (McGrath 2013).

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Appendix

Table A1: Summary of the yard data used in this study, collected by means of a questionnaire (24 yards; for two of the yards, the questionnaire was only partly completed).

	Measure (question formulation)	Response alternatives with response frequencies
F1	Extent of steelwork performed in a country with lower labour costs (than in the responding yard's country).	0-20%: 12; 21-40%: 0; 41-60%: 0; 61-80%: 1; 81-100%: 11
F2	Extent of outfitting work performed in a country with lower labour costs (than in the responding yard's country)	0-20%: 21; 21-40%: 0; 41-60%: 1; 61-80%: 2; 81-100%: 0
F3	Level of integration with the hull yard	Part of the same shipbuilding group: 1; partial ownership: 0; long-term relationship: 1; repeated business: 6; no long-term relationship: 4; not applicable: 12
F4	Extent of engineering work performed in a country with lower labour costs (than in the responding yard's country)	0-20%: 15; 21-40%: 6; 41-60%: 2; 61-80%: 1; 81-100%: 0
F5	Extent of outfitting work usually completed before ship erection	0-20%: 10; 21-40%: 7; 41-60%: 3; 61-80%: 4; 81-100%: 0
F6	Drawing completeness at the keel laying date	0-20%: 1; 21-40%: 6; 41-60%: 11; 61-80%: 3; 81-100%: 3
F7	Typical number of blocks from which the ships were erected	Under 8: 2; 8-16: 0; 17-25: 5; 26-34: 4; over 34: 11
F8	Ship production stages performed under cover or outdoor. Index consisting of four items.	Block construction and outfitting: under cover 1; outdoor 21 Ship erection: under cover 3; outdoor 19 Dock outfitting: under cover 1; outdoor 21 Quay outfitting: under cover 0; outdoor 22
F9	Type of facilities used for ship erection	Slipway: 15; building dock: 6; ground-level system: 3
F10	Information technologies used to support ship production, either at own shipyard or at other contributing yards. Index consisting of six items. [a]	Computer-aided design: yes 21; no 1 Computer-aided manufacturing: yes 12; no 10 Computer-integrated manufacturing: yes 3; no 19 Computer-aided logistics system for tracking and tracing of materials: yes 7; no 15 Comprehensive and integrated supply chain management IT system: yes 5; no 17 3D simulation: yes 22; no 0
F11	Manufacturing technologies used to support ship production, either at own shipyard or at other contributing yards. Index consisting of six items. [a]	Automated plasma and laser cutting and marking: yes 19; no 3 Automatic statistical process control: yes 1; no 21 Laser welding: yes 0; no 22

		Fully automated production lines for cutting and welding of pipes: yes 4; no 18 Automated or robotic subassembly lines: yes 4; no 18 Employment of robots in painting: yes 0; no 22
F12	Practices used to support ship production, either at own shipyard or at other contributing yards. Index consisting of 12 items. [a]	Emphasis on design for production: yes 18; no 4 Minimum movement of workers and material handling between processes: yes 12; no 10 Production organised in product families (group technology): yes 11; no 11 Comprehensive coding system for all materials, products, work areas, operations, and personnel at all stages: yes 11; no 11 Zero-defect policy: yes 2; no 20 Structured performance evaluation programmes: yes 3; no 19 More than 5% of the working time of each employee dedicated to training; yes 2; no 20 Extensive employment of multifunctional labour: yes 6; no 16 24/7 production: yes 2; no 20 ISO9000-series: yes 13; no 9 ISO14000-series: yes 11; no 11 Extensive R&D activity in collaboration with external research institutes: yes 5; no 17
F15	Shipyard location	Spain: 9; Norway: 9; other: 6
F16	Number of different ship types delivered by the yard in the investigated period, divided by the total number of ships delivered by the yard in this period	0–0.2: 1; 0.2–0.4: 10; 0.4–0.6: 2; 0.6–0.8: 3; 0.8–1: 6
F19	Average number of production workers employed at the yard between 2014 and 2016, including subcontracted production personnel but excluding administration, design, and engineering personnel	At the yards delivering the ships included in the sample (outfitting yards and integrated yards): under 500: 15; 501–1,000: 6; 1,001–2,000: 0; 2,001–3,000: 2; over 3,000: 1 At the yards supplying hulls to the outfitting yards included in the sample (when an outfitting yard used several hull yards during the analysis period, the size indicated is an average): under 500: 4; 501–1,000: 5; 1,001–2,000: 2; 2,001–3,000: 0; over 3,000: 1

The factors F1-F19 refer to Table 1. For each factor, the table provides the measure used (question formulation), the response alternative, and the number of yards selecting each response alternative. Some of the factors included in the study (F14, F17, F18) are not shown in this table but the next (Table A2) because the data was collected from ship databases rather than the questionnaire. F13 was not part of the study.

[a] based on a selection of technologies and practices from Pires et al.'s (2009) more comprehensive technology assessment system

Table A2. Descriptive statistics of the ship data used in our study, collected from ship databases (N= 76).

	Measure	Min	Max	Mean	SD
F14 (both measures introduced by Semini et al. (2022))	Global *shipbuilding* intensity during the ship's production/delivery time. Measured in terms of the global demand for ships of the same type from 6 months before the ship's contract signing date until 6 months after. Calculated from normalised annual global contracting numbers and linear interpolation.	0.10	1.90	1.33	0.27
	Global *demand* intensity during the ship's production time. Measured in terms of the average annual global demand for ships of the same type, the average taken over the calendar years from keel laying to delivery of the ship. Calculated from normalised annual global contracting numbers.	0.07	1.55	1.05	0.40
F17	GT	1,135	46,373	6,849	9,226
F18	CGT	3,542	35,962	8,932	6,897
Delivery time	Number of days between contract signing and delivery	388	1449	773	210
Production time	Number of days between keel laying and delivery	157	929	492	170