Comparing Offshore Support Vessel Production Times between Different Offshoring Strategies Practiced at Norwegian Shipyards

Marco Semini,[1] Per Olaf Brett,[2,3] Jan Ola Strandhagen, [1] and Jørn Vatn[1]

[1] *Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Trondheim, Norway.*
[2] *Department of Marine Technology, Norwegian University of Science and Technology, Trondheim, Norway.*
[3] *Ulstein International AS, Ulsteinvik, Norway.*

Abstract: *To save costs and build competitiveness, Norwegian shipyards usually offshore some of the processes required to produce a ship, especially steel-related tasks, i.e., they have them carried out in a country with lower factor costs. This study aims to provide some quantitative evidence of the relationship between the degree of offshoring and the production time of offshore support vessels (OSVs) delivered from Norwegian shipyards. It builds upon a recent article that introduced a typology of offshoring in ship production (Semini et al. 2018, Journal of Ship Production and Design, 34(1), 59–71). We take into account contextual factors that are also expected to affect the production time of OSVs, in particular ship size and complexity, repeat production, and the global market situation. We apply multiple regression analysis on a sample of 156 OSVs delivered from nine Norwegian shipyards between 2010 and 2018. Each of these ships was, by plan and strategy, partly produced at a foreign yard, before one of the Norwegian yards took over, completed production, commissioned, tested, and finally delivered the ship. The results suggest that the higher the degree of offshoring is, the longer is the total ship production time. Only ship size explains even more of the production time variability in the sample than offshoring strategy. In addition to these two factors, evidence suggests that also repeat production and the global market situation have a significant impact on the production time. Our study contributes to the literature on the relationship between strategy and performance in shipbuilding. It provides new insights into how offshoring strategy and contextual, product- and market-related factors relate to ship production time based on quantitative, empirical evidence. From a methodological perspective, it illustrates how multiple regression analysis can be applied to ship-specific data as a benchmarking tool to measure and compare shipbuilding performance. Findings are first and foremost valid for the ships included in the study, which opens numerous opportunities for further research.*

1. Introduction

To save costs and improve international competitiveness, shipyards in high-cost countries, such as Norway, usually offshore a considerable part of the ship's production, especially steel-related work. That is, they have such work carried out in a region where factor costs are lower, such as Eastern Europe or Turkey. Semini et al. (2018) introduced a typology of ship production strategies based on the number of ship production stages offshored before a Norwegian yard takes over. It consists of four generic strategies that can be placed along a continuum according to the degree of ship completion at a foreign low-cost builder (lower part of Fig. 1). Strategy I (complete Norwegian production) is at the extreme point of the continuum where all work is performed at the Norwegian yard. In strategy II (Norwegian block outfitting), some or all steel blocks are constructed and partly outfitted by one or several foreign builders before they are transferred to the Norwegian yard. The Norwegian yard completes block construction and outfitting and carries out all the remaining ship production stages, including final ship erection, dock outfitting, quay outfitting, and commissioning and testing. Complex blocks may be entirely produced in Norway, which allows performing outfitting in parallel with steel construction. In strategy III (Norwegian dock outfitting), all blocks are constructed, to some limited degree outfitted, and erected into a steel ship structure at a foreign yard. The complete structure is then preliminarily launched for towing transport to Norway, where it is docked again for dock outfitting. Finally, it is officially launched, and production is completed at the quayside before commissioning and testing. In strategy IV (Norwegian quay outfitting), finally, also more complex outfitting tasks are offshored. The Norwegian yard typically focuses on installation of complex equipment, accommodation, and hotel functions, commissioning, and testing. In this strategy, the ship only returns to a dock in Norway in exceptional cases, such as to accommodate late change orders or for repairs. Usually, all the work in Norway can be done from the quayside. A key difference between the strategies is, thus, the number of outfitting stages performed in Norway. This is reflected in the strategies' names. Choice of offshoring strategy is likely to have an important effect on performance, and understanding this link is, therefore, vital.

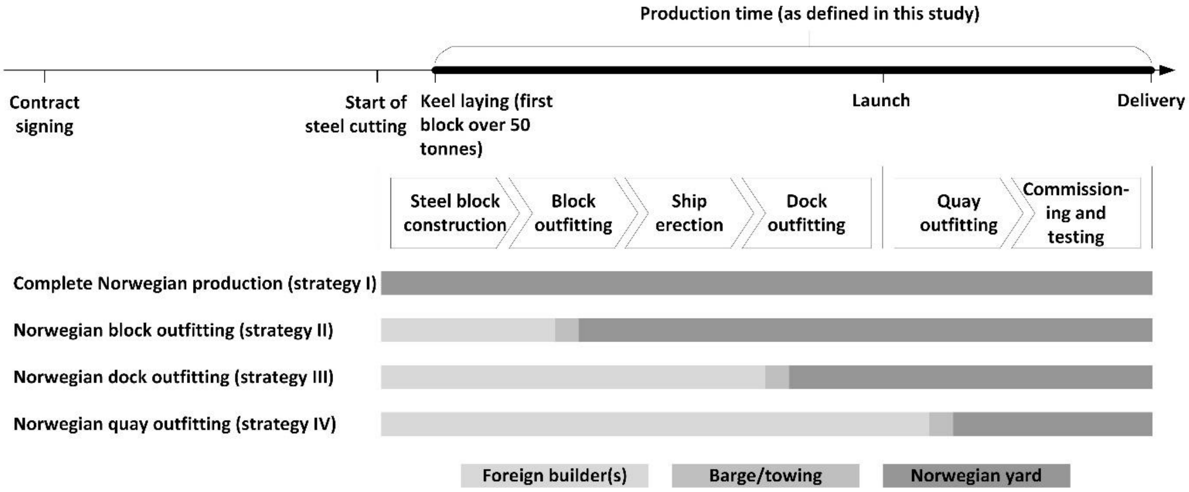

Figure 1: The lower part of the figure shows the typology of offshoring strategies for Norwegian ship production, based on different degrees of ship completion at a foreign, low-cost location before the Norwegian yard takes over, completes production, and delivers the ship (Semini et al. 2018). The upper part of the figure contains a timeline with key milestones and indicates the time span between keel laying and delivery, which is used as the measure of production time in this study.

The main purpose of the study presented in this article is to provide some quantitative evidence of the relationship between offshoring strategy and ship production performance, within the context of offshore support vessels (OSVs) delivered from Norwegian shipyards. We use production time as the performance indicator, measured as the time between keel laying[1] and delivery (see top of Fig. 1). We assess whether and how the production time of OSVs delivered from Norwegian shipyards depends on how much of the production was offshored to a foreign builder. We take into account contextual factors that are also expected to affect the production time of such ships, in particular ship size and complexity, repeat production, and the global market situation. We apply multiple regression analysis to a sample of OSVs delivered from Norwegian shipyards, which allows us to individually estimate the strength of the relationship between each of these factors and production time.

The importance of time in engineer-to-order production, such as shipbuilding, has been emphasized repeatedly (Alfnes & Strandhagen 2000; Olhager 2003; Pires et al. 2009; Stavrulaki & Davis 2010; Gosling et al. 2015; Birkie & Trucco 2016). Short delivery times can, under certain circumstances, increase the chance of winning contracts by giving the customer increased business opportunities and

---

[1] Keel laying is defined by the International Convention for the Safety of Life at Sea (SOLAS) as the stage of construction where assembly of the ship has commenced comprising at least 50 tons, or 1% of the estimated mass of all structural material, whichever less. Although yard and customer seem to have some degree of freedom in setting the keel laying date with respect to the formal definition, it implies that, usually, the keel laying date will be triggered not so long after the start of steel cutting, by the first section reaching the required weight. As OSVs delivered from Norwegian yards are usually built with offshoring strategy II, III, or IV, this would typically take place at the foreign builder (see Fig. 1), in a section or block construction hall. We use the date of keel laying rather than the start of steel cutting in our measure of production time because it is the former that is for most ships available in databases, such as IHS Sea-web.

earlier cash flows. Generally, in manufacturing, short response times are associated with lower costs and higher effectiveness. Several 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. A study in the construction sector, focusing on the total cycle time from the perception of a customer need to the satisfying of that need statistically found that reengineering the relevant business process to compress total cycle time by 40% corresponded to a 25% reduction in costs (Towill 2003).

In our study, we focus on the physical production time because we consider it to be a better measure of operational performance than the total time from contract signing to delivery. The latter also contains the period from contract signing to keel laying, which predominantly involves nonphysical processes and often strongly depends on the balance between supply and demand and other market- and business-related considerations.

Historically, there have been some previous quantitative studies of the relationship between shipbuilding strategy and performance. Lamb and Hellesoy (2002) studied the factors affecting shipyard labor productivity. Pires et al. (2009) performed data envelopment analysis to assess shipyard performance. Colin and Pinto (2009) benchmarked yards and shipbuilding regions in terms of their asset utilization, also using data envelopment analysis. None of these studies, however, specifically addressed the building of complex, technologically advanced and innovative, special ships, such as OSVs, under unconventional ship production strategies. There are important differences in product, market, process, and supply chain characteristics among different ship types and shipbuilding regions. See, for example, Bai et al. (2007) and Strandhagen et al. (2020) for comparisons of different shipbuilding regions. We are not aware of any performance studies taking into account that ships delivered from high-cost countries, such as Norway, are often partly built in low-cost countries, i.e., that production is split between two yards in different regions. Additionally, previous studies typically used yards as the unit of analysis, rather than ships. This limits the potential to link shipbuilding performance to ship-specific differences, such as size, type, and build strategy.

2. Development of hypotheses

2.1. Offshoring strategy

Although offshoring often leads to cost reductions, it might have an adverse effect on time. It has previously been argued that the use of strategies III and IV could be expected to result in somewhat longer times from contract signing to delivery than strategies I and II (Semini et al. 2018). In this article, we propose in a similar vein that strategy II can be expected to allow more rapid production from keel laying to delivery than strategies III and IV.

Strategies III and IV imply towing of a semifinished ship to the yard in Norway, which takes one to a few weeks at least and is typically part of the critical path. During towing, production on the ship itself is paused, and the Norwegian yard can only start its outfitting tasks when the hull has arrived at its premises. In strategy II, in contrast, the Norwegian yard can outfit complex blocks before all the blocks from abroad have arrived, in parallel with the construction and transportation of the blocks from abroad.

An additional factor likely to adversely impact the production time is that in strategies III and IV, the amount of structure-outfitting integration, i.e., outfitting before ship erection, is typically less than ideal from a pure shipbuilding production perspective. Generally, in shipbuilding, preerection outfitting is considered to have a beneficial effect on cost and time (Hagen et al. 1996; Bruce & Eyres 2012). Interfaces between the foreign and the Norwegian yard can also be challenging and entail the risk of prolonging the production time further, especially in strategy IV, where outfitting is initiated abroad and finalized in Norway.

In strategy II, the Norwegian yard can, theoretically, take full advantage of block outfitting and use its experienced workforce to do so. The interfaces with the foreign builder are relatively simple, as they mainly concern the construction of steel blocks. For the Norwegian yard, it also implies more direct control of progress than when strategies III or IV are used, as a larger part of the total production work is performed locally.

Several previous studies identified a negative effect of offshoring on time. Kinkel (2012) identified flexibility/ability to deliver on time as one of the most important motives for relocating production to Germany. Arlbjørn and Mikkelsen (2014) identified longer lead times as one of the main motivations for Danish manufacturers to move production operations back. And in a report by the Norwegian Board of Technology (2014), reduced shipping periods and easier response to demand changes are emphasized as advantages of domestic production. Quality problems are also repeatedly identified as an important drawback of offshoring (Arlbjørn & Mikkelsen 2014; Fratocchi et al. 2014; Kinkel 2012). For Norwegian yards, late delivery of the hull and quality deficiencies, requiring rework at the Norwegian yard, can ultimately have a negative effect on production time. Based on the Organization for Economic Co-operation and Development's (OECD) productivity statistics, worker productivity is generally lower in low-cost countries. Even though this can, to some degree, be compensated for by higher manning levels, productivity differences may also contribute to an adverse effect on time performance from offshoring.

We, therefore, put forward the following hypotheses:

H1a: Strategy II is associated with shorter OSV production time than strategy III.

H1b: Strategy II is associated with shorter OSV production time than strategy IV.

An alternative, combined formulation is that ships delivered from Norwegian yards have shorter production times when they are erected in Norway rather than abroad. Hypothesizing about the differences in production times between strategies III and IV is, however, more difficult. Strategy III has the advantage that most outfitting work is carried out under the favorable conditions prevailing at Norwegian yards. It also implies less complex interfaces with the foreign builder. On the other hand, strategy IV can take better advantage of preerection outfitting, at the foreign yard. It would also usually imply some form of ownership of the foreign yard. Although this requires deeper involvement in terms of financial and managerial commitment and increases the level of risk for the yard owners, it does give increased control over the processes performed abroad as well as opportunities to develop and improve them.

2.2. Contextual factors

2.2.1. Ship size and complexity

Shipyard performance measures, such as man-hour consumption, are usually adjusted by means of the compensated gross tonnage (CGT) concept, a measurement of a ship's size and complexity (Lamb & Hellesoy 2002; OECD 2007; Pires et al. 2009). This is based on the natural assumption that ship size and complexity affect shipyard performance. They strongly affect the amount of work needed per ship, both regarding steel structure and outfitting, and they are, thus, likely to have an effect not only on man-hour consumption, but also on production time. Therefore, the following hypotheses are suggested:

H2: OSV production time increases with ship size.

H3: OSV production time increases with ship complexity.

We consider differences between OSV types, such as platform supply vessels (PSVs) and anker handling tug supply vessels (AHTSs), to be largely taken into account by means of size and complexity, so we did not include ship type as an additional, separate parameter in our study.

2.2.2. Repeat production

Several studies have investigated the reduction in man-hours from producing successive ships of equal design in a series, typically estimated by means of a logarithmic learning curve (Erichsen 1994; OECD 2007; Pires et al. 2009). The gains from producing several ships of equal design do not only come from learning when workers become familiar with their tasks as they repeat them; they can also stem from design simplifications and the reuse of drawings and other documentation. Ship-specific managerial dispositions (e.g., reorganization of work teams and changes in incentive schemes or leadership styles) may also contribute to the series effect (Erichsen 1994). These advantages are likely to have a beneficial effect not only on man-hour consumption, but also on the production time.

In Norway, yards only exceptionally produce true series of ships, i.e., ships of equal design produced subsequently at the same yard and for the same customer. More common is the production of repeats. That is, several ships of equal standard design delivered from the same yard, yet possibly with various design modifications, different customers, different foreign builders and subcontractors, as well as interruptions by ships with other designs. Even though such a widened understanding of series production is likely to undermine quite some of its benefits, several of the above arguments should to some degree continue to hold. We, therefore, offer the following hypothesis:

H4: OSV production time decreases with repeat production.

2.2.3. Market situation

Delays in ship delivery impact the time from keel laying to delivery, and the market situation affects the occurrence of delays in at least two ways. The first effect relates to the level of global shipbuilding activity. In times of high shipbuilding activity, there is a scarcity of resources, including equipment, materials, and people. Based on the intuitive queuing-theoretical relationship between workload, capacity, and waiting times, there is an increased risk of supply side-caused delays and supply shortages. Equipment suppliers and yards may even negotiate somewhat longer production periods to cope with capacity limitations and a high number of parallel projects. The second effect stems from different levels of demand for OSV services. The demand level is typically reflected by operating rates and it is strongly dependent on the prevailing oil and gas prices (demand side). When the demand for OSV services is high, customers are eager to get their ships as quickly as possible and the actors in the shipbuilding industry are optimistic and motivated. When demand is low, however, the shipowners do not necessarily want their ships delivered, e.g., because they do not have a service contract. They may delay progress by slow decision-making and approval processes. It is also frequently common, in such periods, that shipowner and yard renegotiate and agree on a postponement of the delivery date. This relieves the shipowner from making the final payment and having to start amortizing the loan. The resulting extended occupancy of the yard and its facilities can, in some cases, also be desirable for the yard as it can help balance out its workload and cash flow situation. Hence, we argue that periods of low demand for OSVs increase the risk of customer-caused delays.

We are only aware of a few previous studies investigating the causes of delays in shipbuilding (Lin & Tan 2011; Haji-kazemi et al. 2015; Mello et al. 2015), but there are plenty in the construction literature. In such studies, supply- and demand-related factors are typically among the most important causes. In a recent review, e.g., Durdyev and Hosseini (2020) identified material shortage as the fourth and client payment delay as the sixth most frequent cause of delay in construction projects. We, therefore, propose the following hypotheses:

H5a: OSV production time increases with the intensity of global OSV production.

H5b: OSV production time decreases with the intensity of global OSV demand.

2.3. Research model

Figure 2 shows this study's research model. Previous studies identified the level of technology in the shipbuilding process (in a wide sense, also including "soft" best practices) to have a strong effect on its performance (Lamb & Hellesoy 2002; Pires et al. 2009). Based on the authors' knowledge of the yards that built the OSVs included in the study, differences in technology level among their shipbuilding processes were, however, relatively small. The Norwegian yards' technological maturity was similar, and so was the technological maturity of the foreign builders they used. Hence, we consider it reasonable to assume similar technology levels among the shipbuilding processes of the ships included in the study. Based on this, technology level is unlikely to explain a large part of the observed production time differences. It is considered justifiable to omit this factor in the model, which otherwise would have necessitated substantial additional data collection effort.

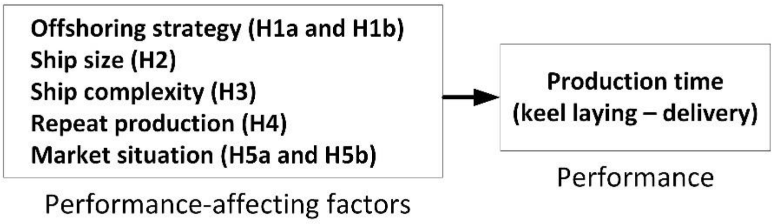

Figure 2: The research model of this study

3. Research methodology

For hypothesis testing, we performed multiple regression analysis on a suitable sample of OSVs delivered from Norwegian yards. We chose to focus on OSVs because over the past decades, until a few years ago, they constituted the majority of larger newbuildings delivered from Norwegian yards.

3.1. The sample

Four shipbuilding groups stood for the majority of OSVs delivered from Norwegian yards between 2010 and 2018. The time period was chosen to obtain a large enough sample for statistical analysis, as well as to cover both high and low contracting periods.

The four groups owned and operated, in total, nine yards in Norway during the analysis period. These yards were among the largest, most active shipyards in Norway. Most of them were also part of the first, qualitative study of offshoring strategies (Semini et al. 2018), which includes a description of their typical characteristics. As explained there, the number of on-site production employees, including subcontractor personnel, depended heavily on the demand situation and varied between 0 and in the order of 1000. Each yard typically had a few hundred own employees and several hundred contracted workers in addition. Even own employees were temporarily laid off in periods of low demand.

Among the 184 OSVs delivered from these yards, we excluded 28 cases because, according to collected information, events external to production, often customer-related, led to a stop during production or a delay in the delivery of the ship after its completion. In such situations, the time span from keel laying to delivery does not constitute a purposeful measure of production performance. The sample we used for the multiple regression analysis, thus, consisted of 156 ships.

Table 1 specifies the number and types of ships built at each of the yards. It also shows the number of ships contained in the sample, including how many times each yard used each of the three offshoring strategies. The table provides an insight into the use of offshoring strategies at Norwegian yards. Group A practiced strategy IV for all the ships delivered from its five Norwegian yards (A1-A5). It used two large, fully owned foreign yards for the supply of partly outfitted hulls. Group B's yard (B1) practiced both strategies II and III regularly and it used several different external yards, from different countries, for hull supply. Group C owned two yards (C1 and C2), one mainly practicing strategy II, the other mainly strategy III. This group also used several external yards as hull suppliers. Group D's yard (D1), finally, also practiced strategy III, but it purchased almost all hulls from the same, external supplier.

The hull suppliers of groups B, C, and D typically had somewhat smaller erection areas and lower yearly volumes than group A's. Each of the three groups A, B, and D included a design company as well as one or several equipment suppliers, e.g., suppliers of technologically advanced electronic systems and solutions. Group C focused on ship production and mainly consisted of its two yards.

Thus, each strategy was practiced regularly by at least two yards. Approximately 54% of all the ships in the sample were built with strategy IV, strategy III was used in about 23.5% of all cases, and strategy II was used for approximately 22.5%. We consider this to provide a satisfactory basis for comparisons between the strategies. The correlation between offshoring strategy and yard needs, however, to be kept in mind when discussing results.

Table 1: Number and types of ships delivered from the yards between 2010 and 2018, as well as the number of ships included in this study's sample and the offshoring strategies used for them. Service operation vessels (SOVs) are included because of their similarity with OSVs, especially PSVs

Yard	Total number of ships	Types					Total number of OSVs	Included in sample	Offshoring strategies used for the ships included in the sample		
		PSVs	AHTSs	SOVs	Other OSVs	Other types			II	III	IV
A1	20	9	4	0	3	4	16	15			15
A2	19	1	3	0	8	7	12	12			12
A3	21	19	0	0	2	0	21	20			20
A4	22	7	8	0	4	3	19	19			19
A5	22	8	1	0	10	3	19	18			18
B	26	12	1	3	9	1	25	20	10	10	
C1	39	11	11	0	15	2	37	25	24	1	
C2	22	5	2	0	5	10	12	6	1	5	
D	34	12	4	3	4	11	23	21		21	
Total	225	84	34	6	60	41	184	156	35	37	84

PSVs, platform supply vessels; AHTSs, anker handling tug supply vessels; SOVs, service operation vessels; OSVs, offshore support vessels.

3.2. Data sources, variables, and measures

We predominantly collected data from ship databases, in particular IHS Sea-web and classification societies' ship registers. We also used information about yards and ships available from open sources on the Internet, such as annual reports and homepages, magazines, company presentations at conferences and seminars, and maritime forums. Furthermore, we drew upon knowledge about the yards from previous collaboration, such as research projects or student assignments. We were also in contact with them specifically regarding this study, to obtain any data still missing as well as for validation and discussion of input data and results.

Table 2 contains the main variables and measures used in this study. To represent offshoring strategy, we used two binary dummy variables (OffStratIII and OffStratIV). Because of the lack of separate official CGT coefficients for different types of OSVs, we used GT to measure ship size and lightweight/(length*breadth*depth) for complexity. The latter is a measure of a ship's compactness or density of materials and equipment. The higher this measure is, the more steel, pipes, and other materials would typically have to be prepared, assembled, and installed per cubic meter, and the more challenging this installation work is likely to be due to space constraints. For the estimation of lightweight, we used an equation developed by Ulstein International AS as a part of its parametric OSV design studies (Ebrahimi et al. 2015) and the Fast-Track Vessel Concept Design Analysis approach (Ebrahimi et al. 2018). The equation is obtained from a multivariate regression model and contains length, breadth, depth, and power as input parameters.

Regarding repeat production, we sequenced ships of equal standard design based on their keel laying dates to obtain each ship's ordinal position in the series. When two ships' keel laying dates differed by less than 2 months, they were given the same position as it typically takes more time to reap many of the benefits of repeat production. We considered the entire series, i.e., also ships that were delivered before the start of the analysis period in 2010, to determine a ship's position in the series. Since the repeat effect is likely to decrease with a ship's position in the series (Erichsen 1994; OECD 2007), we used its logarithmic transformation.

We measured the global OSV production intensity during a ship's production by the global OSV contracting level when its contract was signed, as the latter typically determines the former. Similarly, we measured the global OSV demand intensity during a ship's production by the average global OSV contracting level during that period. A limitation of using contracting numbers as a proxy of the market situation is that differences in workload among different types and sizes of OSVs are not taken into account. Nevertheless, we judged the possible increase in model predictability from more demand data not to outweigh the additional efforts needed for data collection.

Table 2: Variables and measures

	Variable type	Measure
Dependent variable		
The ship's production time (ProdTime)	Metric	Number of days between keel laying date and delivery date. Delivery date is specified in IHS Sea-web as the date when the ship status changed to "in service/commission"[2].
Independent variables		
Use of offshoring strategy III (OffStratIII)	Binary	1 if strategy III is used, 0 otherwise, according to Semini et al.'s (2018) typology
Use of offshoring strategy IV (OffStratIV)	Binary	1 if strategy VI is used, 0 otherwise, according to Semini et al.'s (2018) typology
The ship's size (GrossT)	Metric	Gross tonnage
The ship's complexity (Compl)	Metric	Lightweight/(length*breadth*depth)
The ship's degree of repetitiveness (LnPosInSeries)	Metric	The ship's ordinal position in a series of ships with the same standard design delivered from the same Norwegian yard (natural logarithmic transformation)
Global OSV production intensity during the ship's production time (ProdInt)	Metric	Approximate number of OSVs contracted globally from 6 months before the ship's contract signing date until 6 months after (based on yearly global contracting numbers and linear interpolation)
Global OSV demand intensity during the ship's production time (DemInt)	Metric	Average yearly number of OSVs contracted globally over the calendar years from keel laying to delivery of the ship

OSVs, offshore support vessels

4. Analyses

We used linear regression with the variables in Table 2 to test the hypotheses. Table 3 summarizes the main regression calculations we carried out (denoted i–viii). The table shows unstandardized regression coefficients (b) as they directly provide effect sizes in days, i.e., the expected change in production time for each unit of change in the independent variable. As a measure of the variable's unique explanatory strength, we used part correlation (pc). Part correlation specifies the strength of the relationship between a dependent and a single independent variable when the predictive effects of the other independent variables in the model are removed (Hair et al. 2014). We used .001 as the conditional significance level for hypothesis testing. The results are, however, unchanged if .01 or .05

---

[2] In some cases, topside equipment was installed after formal delivery, at a different yard, but these cases were few and the amount of work carried out after delivery relatively small.

is used. We used two-tailed testing, but the results from testing the hypotheses would have been the same if 1-tailed testing had been used.

We first carried out a regression calculation with all the ships and variables (regression calculation i). To identify interaction effects between offshoring strategy and the contextual factors, we additionally ran separate regressions for each offshoring strategy (regression calculations vi–viii). Because of low significance and small part correlation of the complexity variable (Compl) in all these regression calculations, we considered it the most appropriate to exclude this variable when testing the hypotheses other than H3, as this allowed improving the ratio between sample size and number of variables. To test H2, H4, H5a, and H5b, we used the regression calculation with all ships and variables except Compl (regression calculation ii). To avoid the results being influenced by irrelevant data when testing H1a and H1b, we used respective sample subsets consisting only of ships built with any of the two strategies to be compared (regression calculations iii and iv). We also performed a calculation including only ships delivered from yard B1, which allowed us to study the difference between strategies II and III without possible confounding effects from differences among the various Norwegian yards practicing these strategies (regression calculation v). Apart from this last calculation, the ratio between sample size and number of variables is always above Hair et al.'s (2014) suggested minimum of five observations per independent variable.

Table 3: This table summarizes the regression calculations performed for hypothesis testing and further analysis. R^2 = coefficient of determination; b = regression coefficient (unstandardized); p = p-value; pc = part correlation. When a variable was not included in a regression calculation, the corresponding cells are left empty.

Regression calculation	i	ii	iii	vi	v	vi	vii	viii
Sample	All strategies		Strategies II and III	Strategies II and IV	Yard B	Strategy II	Strategy III	Strategy IV
Sample size (N)	156	156	72	119	20	35	37	84
R^2	.638	.637	.604	.687	.635	.715	.617	.616
R^2 adjusted	.621	.622	.575	.674	.504	.666	.556	.591
OffStratIII	b = 61.994	b = 62.835	b = 78.559		b = 73.688			
	p = .000	p = .000	p = .000		p = .132			
	pc = .177	pc = .180	pc = .353		pc = .258			
OffStratIV	b = 107.594	b = 107.981		b = 110.355				
	p = .000	p = .000		p = .000				
	pc = .370	pc = .372		pc = .432				
GrossT	b = .013	b = .013	b = .012	b = .013	b = .018	b = .014	b = .011	b = .013
	p = .000	p = .000	p = .000	p = .000	p = .015	p = .000	p = .036	p = .000
	pc = .432	pc = .436	pc = .367	pc = .490	pc = .447	pc = .566	pc = .243	pc = .526
Compl	b = 228.210					b = 10.092	b = -93.162	b = -97.255
	p = .547					p = .988	p = .931	p = .842
	pc = .030					pc = .001	pc = -.012	pc = -.014
LnPosInSeries	b = -8.740	b = -9.553	b = -49.326	b = -5.491	b = -45.618	b = -55.845	b = -46.038	b = 11.007
	p = .248	p = .199	p = .000	p = .478	p = .138	p = .000	p = .034	p = .229
	pc = -.057	pc = -.064	pc = -.327	pc = -.037	pc = -.254	pc = -.432	pc = -.246	pc = .085
ProdInt	b = .237	b = .249	b = .585	b = .142	b = .643	b = .325	b = .959	b = .151
	p = .001	p = .000	p = .000	p = .050	p = .016	p = .044	p = .000	p = .073
	pc = .169	pc = .186	pc = .380	pc = .104	pc = .444	pc = .208	pc = .495	pc = .127
DemInt	b = -.343	b = -.350	b = -.360	b = -.360	b = -.442	b = -.134	b = -.621	b = -.457
	p = .000	p = .000	p = .000	p = .000	p = .040	p = .318	p = .000	p = .000
	pc = -.252	pc = -.262	pc = -.319	pc = -.229	pc = -.365	pc = -.101	pc = -.512	pc = -.325

Multiple regression analysis makes certain assumptions, in particular normality, homoscedasticity, linearity, and independence of error terms. We thoroughly examined the individual variables as well as the variates of all the regression calculations. We tested the normality of the error terms (standardized residuals) by means of normal probability plots and kurtosis and skewness values. To assess homoscedasticity and linearity, we plotted the studentized residuals against the predicted values as well as against each individual independent variable. A plot of the studentized residuals against the delivery date helped assess independence of error terms. We did not come across any large violations of assumptions. Therefore, we considered the assumptions underlying multiple regression analysis to be satisfactorily met. We also tested several variable transformations. Only in the case of repeat production, we considered the gains in terms of model validity (increased R2) to outweigh the extra effort required for result interpretation. Even though the effect of ship size on the production time is likely to decrease as ship size increases (curve flattens out), transforming GrossT did not notably improve R2 values. Finally, we assessed correlations and multicollinearity. We calculated Pearson correlations as well as variance inflation factors. Even though correlations are significant for some of the independent variables (see Appendix), variance inflation factors are below two in all regression calculations, thus well below Hair et al.'s (2014) recommended cutoff. Based on this, we considered the regression coefficients to be sufficiently reliable.

5. Results

Table 4 summarizes the main results from testing the hypotheses of this study.

Table 4: The results obtained from hypothesis testing

Hypothesis		Regression calculation (see Table 3)	Result
H1a	Strategy II is associated with shorter OSV production time than strategy III	iii (*N* = 72)	Supported (*p* = .000 ≤ .001)
H1b	Strategy II is associated with shorter OSV production time than strategy IV	iv (*N* = 119)	Supported (*p* = .000 ≤ .001)
H2	OSV production time increases with ship size	ii (*N* = 156)	Supported (*p* = .000 ≤ .001)
H3	OSV production time increases with ship complexity	i (*N* = 156)	Rejected
H4	OSV production time decreases with repeat production	ii (*N* = 156), iii (*N* = 72)	Rejected for complete sample (*p* = .199 > .001), supported when strategy IV is excluded (*p* = .000 ≤ .001)
H5a	OSV production time increases with the intensity of global OSV production	ii (*N* = 156)	Supported (*p* = .000 ≤ .001)
H5b	OSV production time decreases with the intensity of global OSV demand	ii (*N* = 156)	Supported (*p* = .000 ≤ .001)

H1a and H1b suggest that the production time is shorter with offshoring strategy II than with strategies III and IV, respectively. As regression calculations iii and iv in Table 3 show, the regression results provide support for both hypotheses. The expected production time with strategy II is approximately 79 days shorter than with strategy III and approximately 110 days shorter than with strategy IV. As shown in regression calculation v, when restricting the sample to ships delivered from yard B1, the predicted production time difference is similar in size. Although not significant, arguably because of the small sample size, this result provides some additional support for H1a. For an illustration of the relationship between offshoring strategy and production time when the effect of contextual factors is removed, Figs. 3 and 4 show box plots of partial residuals with respect to OffStratIII and OffStratIV, respectively.

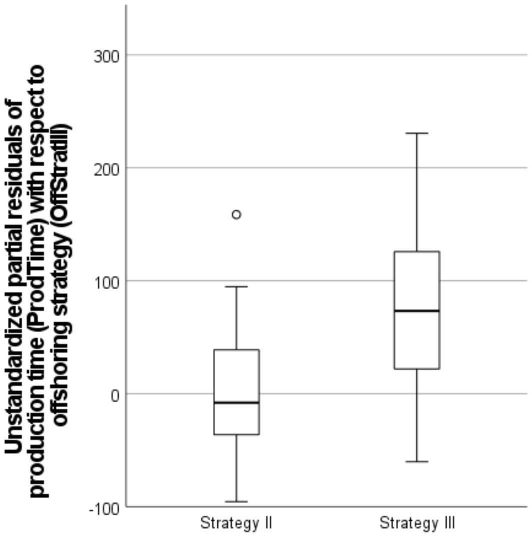

Figure 3: Box plot of partial residuals with respect to offshoring strategy(OffStratIII) obtained from regression calculation iii, used to test H1a

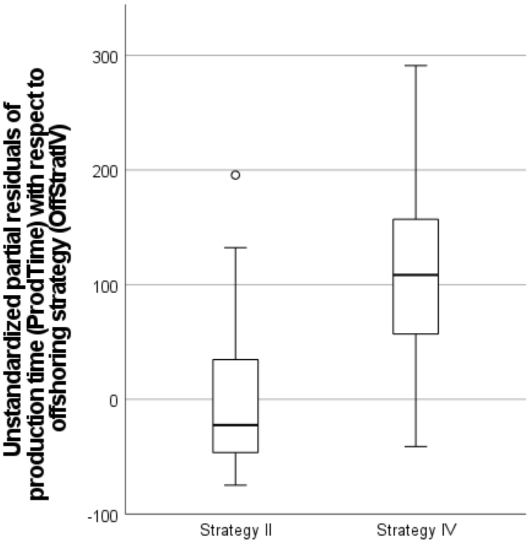

Figure 4: Box plot of partial residuals with respect to offshoring strategy (OffStratIV) obtained from regression calculation iv, used to test H1b

The results support H2: ship production time is strongly linked to ship size. The regression coefficient is in the order of two weeks per additional 1000GT (see regression calculation ii). For illustration of this relationship, Fig. 5 shows the corresponding partial residual plot.

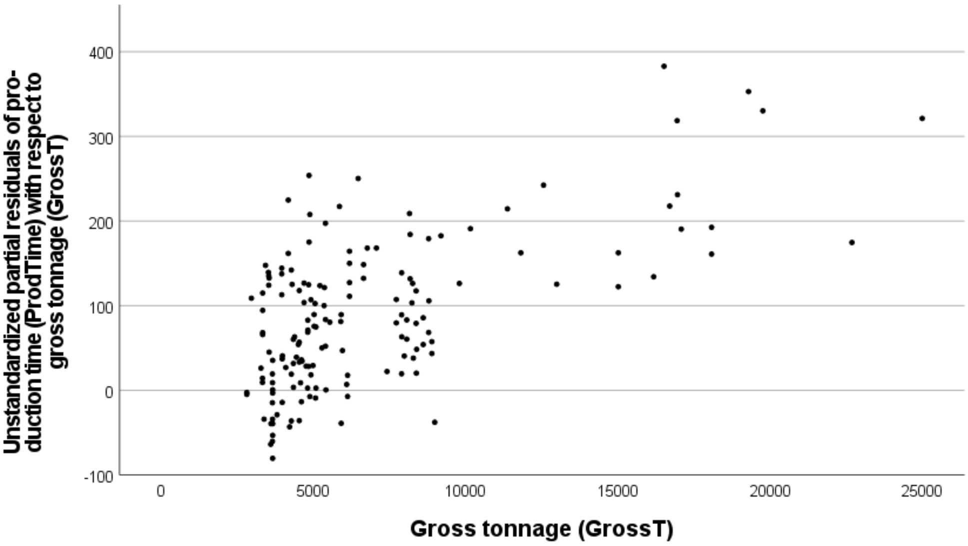

Figure 5: Partial residual plot with respect to gross tonnage (GrossT) obtained from regression calculation ii, used to test H2

Based on regression calculation i, the complexity variable is not significant. H3, which predicts a positive relationship with production time, must be rejected. The regression coefficient is small. Based on its value, the expected difference in production time between the least and the most complex ship in the data set is only approximately 3–4 weeks (other variables kept constant).

H4 suggests that the production time decreases when ships of equal standard design are delivered repeatedly from the same yard. As regression calculations ii and iii show, this hypothesis must be rejected for the complete sample, but it is supported for the sample consisting of ships built with strategies II and III. Based on the regression coefficient obtained in the latter case, the effect size is approximately 54 days between ship number 1 and ship number 3, and another approximately 48 days between ship number 3 and ship number 8. For an illustration of the relationship between repeat production and production time of ships built with strategies II or III, Fig. 6 plots the partial residuals with respect to LnPosInSeries (obtained from regression calculation iii) against each ship's position in the corresponding series of ships with equal standard design delivered from the same yard.

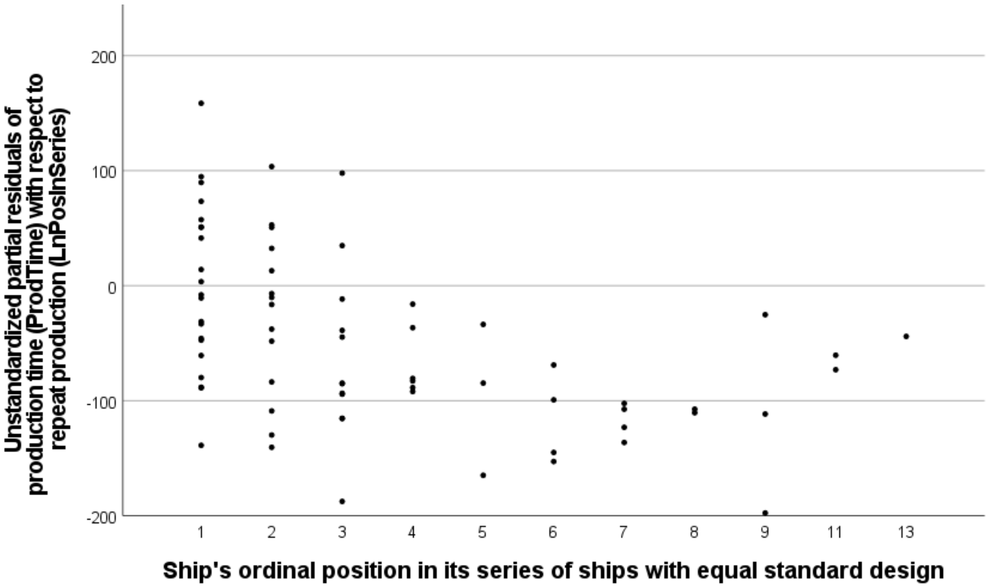

Figure 6: This plot provides an intuitive illustration of the relationship between repeat production and production time for ships built with offshoring strategies II and III, when the effect of other contextual factors is removed. It shows partial residuals of production time (ProdTime) with respect to the repeat production variable (LnPosInSeries) on the Y axis, plotted against the ships' respective positions in their series of ships with equal standard design delivered from the same yard on the X axis.

Both variables concerning the market situation have statistically significant p-values (regression calculation ii), so H5a and H5b are supported. For each of these variables, we calculated the expected difference in production time between the highest and the lowest value in the sample. For the intensity of global production during the ship's production time, it is approximately 127 days, for the intensity of global demand approximately 140 days. The results for the market variables vary quite strongly among the strategies, however (regression calculations vi–viii).

6. Discussion

6.1. Offshoring strategies III and IV are associated with longer production time than strategy II

The analysis provided support for the hypotheses suggesting that offshoring strategies III and IV are associated with longer production time than offshoring strategy II. The results suggest that OSVs can be produced several months faster when their hulls are erected at the Norwegian yard rather than the foreign builder. This is interesting, because it provides empirical evidence of the importance of manufacturing and build strategy choice in determining shipbuilding performance, as argued for by

Clark and Lamb (1996). It also adds to the general body of knowledge on the implications of production offshoring, supporting the finding of Arlbjørn and Mikkelsen (2014) on the adverse impact of production offshoring on production time and extending it to the context of shipbuilding in Norway. A reasonable implication is that domestic ship erection can be an effective means for Norwegian yards to cut production time and improve competitiveness in situations where time is critical and workforce and facilities are available. If the ship can be put into operations several months earlier, the economic gains may be substantial, although they must be weighed against a potential cost increase from doing more steelwork in Norway.

Because of the correlations between offshoring strategy and yard, some of the identified differences in production time between the offshoring strategies may be caused by other yard characteristics, such as yard-specific capabilities, capacities, practices, policies, and organization. One such yard characteristic is the size of the erection area, which is not necessarily a direct consequence of offshoring strategy choice. The yards that constructed the hulls of the ships built with strategy IV had the largest erection areas, whereas those building ships with strategy II had the smallest. A large erection area allows construction of several hulls in parallel and short berth occupancy is not critical. This is typically reflected in somewhat longer time spans from keel laying to launch. It can give important advantages in terms of flexibility to carry out tasks in the right sequence and whenever most appropriate, it allows more balanced use of key resources and lower peak manning levels per project (e.g., less crowded ship), and it can provide economies of scale. When the erection area is small, hulls are erected sequentially and short berth occupancy is decisive for the shipyard's capacity, even though it might not be optimal from a cost perspective. The size of the erection area is, therefore, likely to explain some of the differences in production time between the offshoring strategies.

As explained in Section 2.3, differences in the technological maturity of the Norwegian yards included in the study are considered small and, therefore, unlikely to play a dominant role in explaining the identified time differences between the offshoring strategies. Some support for this assumption was obtained by limiting the analysis to yard B1 and comparing strategies II and III without possible confounding effects of differences between the Norwegian yards. As shown, the expected production time difference between the two strategies is similar in size to that obtained from the calculation including all the yards that used strategies II or III. Even though the sample of ships is small when limited to yard B1 and the difference not significant, this finding provides support for the direct influence of offshoring strategy on production time.

6.2. Role of contextual factors in explaining production time variability

Our study identified ship size to be strongly related to production time (H2 supported). This finding is in agreement with the intuitive notion that a higher workload in terms of man-hour consumption usually also translates into a longer production time. The result is interesting in as much as it provides quantitative, empirical evidence of this relationship. Our analysis indicates that, other things being equal, an increase in ship size of 1000GT can be expected to increase the production time by approximately two weeks. The result adds to the understanding of how ship size affects production parameters, which has so far been centered on man-hour consumption (Lamb & Hellesoy 2002; Pires et al. 2009). It may, however, be worth mentioning that the effect size (regression coefficient) we found cannot be directly compared to the rules of thumb used at yards of the relationship between ship size (or weight) and production time, as the latter typically assume this relationship to be proportional and independent of other factors.

The analysis rejected H3, which predicted an effect of ship complexity on the production time. It is a well-established notion that more complex ships normally require more work, reflected in the use of the compensated gross tonnage concept in shipbuilding performance measurement. As explained, one would usually expect this to affect the production time as well. The low explanatory strength of complexity in our sample is, therefore, somewhat surprising. One possible explanation could be that complexity is not well captured by the chosen measure, as it does not incorporate factors such as the shape of the hull, the general arrangement, and the type of on-board equipment and its level of newness. Another explanation may be that differences in complexity among OSVs are relatively small. Developing and testing measures of ship complexity that can accurately predict its effect on production provide an interesting path for further research, which is also motivated by the limitations of the compensated gross tonnage concept.

Hypothesis H4 was supported for ships produced with strategies II and III. For these strategies, the results are in agreement with previous literature on the effect of ship production in series (Erichsen 1994; OECD 2007). The contribution of our study is that it contains empirical evidence of this effect on production time, including the size of the effect, whereas previous studies have focused on the effect on man-hours. The finding is also interesting because it provides strong indication that several of the benefits of series production also appear in its wider interpretation of producing similar ships. Given the average production time of all nonrepeats (ships that were the first in their series) produced with strategies II or III of approximately 447 days, the incremental savings were approximately 12% from ship number 1 to ship number 3 and another 11% from ship number 3 to ship number 8. The identified repeat effect on the production time of OSVs delivered from Norwegian yards is, thus, somewhat smaller than the series effect found on man-hours in OECD's study, encompassing a larger number and variety of ships and yards (OECD 2007). Yet, it is very close to the effect on man-hours Erichsen (1994) found in his study of ships delivered from Norwegian yards during the 1970s and early 1990s.

For ships built with strategy IV, the data do not show a repeat effect. One likely explanation is, again, the size of the erection areas at the yards that constructed their hulls. When erection areas are large, short berth occupancy is usually not critical, and often several hulls are built in parallel. In such situations, erection time is not in the same way determined by workload as it typically is at yards with small erection areas. Reduced man-hour consumption from producing repeats does, therefore, not necessarily translate into shorter production time. An additional reason likely to have undermined some of the potential repeat benefits in strategy IV is that the amount of outfitting performed abroad tended to be increased when producing repeats. Such a practice allowed saving costs and compensating for a lack of resources at the Norwegian yard.

The analysis provided support for the hypotheses suggesting a relationship between the market situation and the time from keel laying to delivery. This finding is interesting as it emphasizes the close interlinkages between market and production in the Norwegian OSV shipbuilding segment, both on the demand side and on the supply side. It supports the idea that high global demand for OSVs implies shorter production times, whereas high global production activity has the opposite effect. It is consistent with Durdyev and Hosseini's (2020) study on delay causes in construction.

7. Implications, limitations, and further work

7.1. Implications

First, it seems reasonable to conclude that the results suggest that domestic ship erection can be an effective means for Norwegian shipyards to cut production times. Having the equipment and capability to erect ships can give Norwegian yards the flexibility to choose among several strategies. When time is critical, being able to produce OSVs with strategy II can give the yard a competitive advantage, provided that extra costs and risks are not prohibitive.

Second, yards should adequately consider the benefits for production from reusing existing standard designs in the specification process with the customer. Based on our results, there are considerable gains to be made, even with design modifications and supplier changes.

Third, within the context of OSVs delivered from Norwegian shipyards, our study provides evidence of the importance of the market situation for the production process. Both the supply side and the customer side frequently and strongly seem to impact this process and the time it takes to complete it. For shipyards, this underlines the importance of understanding and predicting, preparing for, and adapting to the market situation. Specifically, knowing the market can help predict and prevent supply-related problems and delays. It can also help balance workload and capacity by predicting and adapting to customer side influences.

According to Pires et al. (2009), the main determinants of time spent between keel laying and delivery are the level of preerection outfitting, the size of blocks to erection, and the precision of steelwork. It seems reasonable to conclude, based on our findings, that for certain types of ships and shipbuilding environments, other factors are likely to play an important role as well. Within the context of OSVs delivered from Norwegian yards, offshoring strategy and the market situation seem to be two such factors.

7.2. Limitations and suggestions for further research

Although our study provides valuable new insights into how offshoring strategy relates to time, it does not provide a holistic assessment of the various strategies' performance implications. There is a need to compare costs and other performance attributes as well, even though it will likely be more difficult to access the required data. Ultimately, differences in production costs would often play a more dominant role in offshoring strategy decision-making than some months' savings in production time. From a cost perspective, we expect strategies III and IV to outperform strategy II because of lower factor costs and economies of scale at the foreign builders, although this is purely a speculation at this stage. Further research is also required to assess the performance implications for the complete shipbuilding project, including its nonphysical processes, such as engineering and purchasing.

The present study provides quantitative, empirical evidence of how time consumption varies with offshoring strategy, but its research design does not allow concluding with causality. Based on our knowledge about the yards involved in the study, the Norwegian yards' technological maturity was similar, and so was the technological maturity of the foreign builders they used. Nevertheless, differences in yard-specific factors, such as capacities and capabilities, vertical integration, building methods, planning approaches, and organization, may explain some of the identified time variability among the offshoring strategies. In our data, such factors may be correlated with offshoring strategy, without necessarily being a direct consequence. This motivates the need for studies explicitly accounting for a more comprehensive and detailed set of performance-affecting factors.

In order to identify factors likely to affect ship production time, qualitative case studies may be performed, such as the one presented in Moyst and Das (2005). Data can be collected by means of questionnaires, interviews, and site visits. Case studies also permit an explicit investigation of the causes that have led to the observed time differences between the offshoring strategies, and whether they are a direct consequence of offshoring strategy choice or not.

Although in our study, ship size, offshoring strategy, repeat production, and the two market factors included as independent variables could explain a large portion (over 60%) of the variability in production time, inclusion of additional factors is expected to further increase the explanatory strength of the model as well as reveal correlations. A particularly interesting question in this respect is, in our view, how much of the unexplained variability is due to production-related factors and how much to design-related factors. Extending the set of independent variables requires, however, more yards and ships to be included in the sample, which brings along the notorious challenges related to data access discussed previously (Lamb & Hellesoy 2002; Semini et al. 2018).

In this study, the majority of the data were collected from publicly available sources. This put some restrictions on the level of detail of the measures we used. They may, therefore, not fully capture the constructs they are supposed to represent. Offshoring strategy, for example, may be even more appropriately operationalized by means of two independent, continuous variables: one for the degree to which structural work is offshored, the other for the degree to which outfitting is offshored. The product- and market-related factors may also be operationalized with more sophisticated and fine-grained measures if the necessary data can be accessed. For example, Grabenstetter and Usher (2013) proposed a product complexity equation for flow time estimation in engineer-to-order environments containing seven factors.

Our study makes several contributions to the literature on the relationship between strategy and performance in shipbuilding. We are not aware of any previous studies quantitatively assessing how offshoring strategy relates to shipbuilding performance. Our study concentrated on OSVs delivered from Norwegian yards, but offshoring is also practiced in other countries, such as Germany, the Netherlands, Japan, and South Korea. The theoretical arguments that led to our hypotheses are likely to hold, to a certain degree, also for other special ships delivered from yards that practice offshoring, even though such extensions of the scope first and foremost remain opportunities for further work. The various offshoring strategies' performance should also be compared to that of building ships entirely at one yard, which is the most common approach in a global perspective.

To the best of our knowledge, our study is also the first to focus on ship production time as the performance measure and provide quantitative, empirical insights into how it relates to the build strategy as well as product and market characteristics. It, thereby, initiates an important extension of the theory on shipbuilding performance to the concept of time, which should be followed up by similar studies for other ship types and shipbuilding regions.

Finally, we are not aware of any previous scientific studies applying statistical techniques to measure shipbuilding performance based on data about ships, although this is necessary if ship-specific factors are to be adequately accounted for. Our study shows how multiple regression analysis can be applied to ship data for strategy benchmarking. A single yard may use the approach to quantify the effect of an investments or strategic change while keeping the effects of other performance-affecting factors constant. The approach may also be useful to compare the performance between several yards. Best-performing yards may be identified to work out best practices and transfer them to other yards. Such benchmarking studies may be particularly relevant for companies owning a network of yards. Company-internal studies would typically allow access to much more comprehensive data, including detailed cost-related measures, than what is publicly available for the comparison of independent, often competing, shipbuilding companies. Nevertheless, also national and international studies should be carried out and can give new insights.

Acknowledgments

We would like to thank a number of people for various contributions to the present study: Jørund Kolsvik for data collection and analysis at a very early stage of the study; Clara Patek, Nina Grøsvik Ådnanes, Runa Lunde Tobro, Logan Reed Vallandingham, and Giuseppe Fragapane for data collection, processing, and validation; Clara Patek also for numerous relevant discussions as a part of a related study she carried out for her master thesis; Jose Jorge Garcia Agis from Ulstein International for repeatedly extracting updated OSV contracting numbers from IHS Sea-web; numerous other representatives from the involved shipbuilding companies for their time and willingness to validate, comment, and discuss the study, its input data, and its results; and our academic colleagues Erlend Alfnes, Jo Strandhagen, and Arnulf Hagen for interesting discussions on topics of relevance to the study. We also thank the anonymous reviewers for their valuable comments, which have been very helpful in improving the quality of the article.

This work was supported by the Research Council of Norway and the industrial partners in the SUSPRO and the Manufacturing Network 4.0 projects (Research Council of Norway grant numbers 225356 and 247637).

References

ALFNES, E. AND STRANDHAGEN, J. O. 2000 Enterprise design for mass customisation: The control model methodology, *International Journal of Logistics: Research and Applications,* 3(2), 111-125.

ARLBJØRN, J. S. AND MIKKELSEN, O. S. 2014 Backshoring manufacturing: Notes on an important but under-researched theme, *Journal of Purchasing and Supply Management,* 20(1), 60-62.

BAI, X.-P., NIE, W. AND LIU, C.-M. 2007 A comparison of Chinese, Japanese, and Korean shipyard production technology, *Journal of Marine Science and Application,* 6(2), 25-29.

BIRKIE, S. E. AND TRUCCO, P. 2016 Understanding dynamism and complexity factors in engineer-to-order and their influence on lean implementation strategy, *Production Planning and Control,* 27(5), 345-359.

BRUCE, G. J. AND EYRES, D. J. 2012 *Ship Construction,* Amsterdam, the Netherlands: Elsevier.

CLARK, J. AND LAMB, T. 1996 Build strategy development, *Journal of Ship Production,* 12(3), 198-209.

COLIN, E. C. AND PINTO, M. M. O. 2009 Benchmarking shipbuilders' turnover of main assets, *Journal of Ship Production,* 25(4), 175-181.

DURDYEV, S. AND HOSSEINI, M. R. 2020 Causes of Delays on construction projects: A comprehensive list, *International Journal of Managing Projects in Business,* 13(1), 20-46.

EBRAHIMI, A., BRETT, P. O. AND GARCIA, J. J. 2018 Fast-track vessel concept design analysis (FTCDA). *Proceedings*, 17th International Conference on Computer and IT Applications in the Maritime Industries, Bertram, V., Editor, Pavone, May 14–16, Hamburg, Germany, Technische Universität Hamburg-Harburg.

EBRAHIMI, A., BRETT, P. O., GASPAR, H. M., GARCIA, J. J. AND KAMSVÅG, Ø. 2015 Parametric OSV design studies - Precision and quality assurance via updated statistics. *Proceedings*, 12th IMDC Conference, IMDC 2015 Secretariat, Editor, May 11–14, Tokyo, Japan, IMDC 2015 Secretariat.

ERICHSEN, S. 1994 The effect of learning when building ships, *Journal of Ship Production,* 10(3), 141-145.

FRATOCCHI, L., DI MAURO, C., BARBIERI, P., NASSIMBENI, G. AND ZANONI, A. 2014 When manufacturing moves back: Concepts and questions, *Journal of Purchasing and Supply Management,* 20(1), 54-59.

GOSLING, J., TOWILL, D. R., NAIM, M. M. AND DAINTY, A. R. J. 2015 Principles for the design and operation of engineer-to-order supply chains in the construction sector, *Production Planning & Control,* 26(3), 203-218.

GRABENSTETTER, D. H. AND USHER, J. M. 2013 Determining job complexity in an engineer to order environment for due date estimation using a proposed framework, *International Journal of Production Research,* 51(19), 5728-5740.

HAGEN, A., EIDE, P., GRIMSTAD, A., HUKKELBERG, Ø., LØNSETH, M., STEINVEG, M., WAAGBØ, K., HANSON, J. O., HOKSNES, O., KALLMYR, N., SANDØY, S. I., SETERVIK, H., SPORSHEIM, H., BLØ, H., AUNE, M., HAUGE, M., MELVÆR, T., RIMMEN, O., SOLHEIM, S., UDBERG, R., RINGSTAD, A., LANGELAND, H., PETTERSEN, K., SELJESETH, K., SLETTEBAKK, S., VOLDNES, B., SØVRE, A. E., LYSÅ, P. Å. AND HERMANSEN, G. 1996 *Tidligutrustning,* Trondheim, Norway: Marintek.

HAIR JR., J. F., BLACK, W. C., BABIN, B. J. AND ANDERSON, R. E. 2014 *Multivariate Data Analysis,* Harlow, England: Pearson.

HAJI-KAZEMI, S., ARICA, E., SEMINI, M., ALFNES, E. AND ANDERSEN, B. Detecting early warning signs of delays in shipbuilding projects. *In*: Umeda S., Nakano M., Mizuyama H., Hibino H., Kiritsis D., von Cieminski G., Editors, *Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth. APMS 2015. IFIP Advances in Information and Communication Technology*, vol 460. Cham, Switzerland: Springer.

KINKEL, S. 2012 Trends in production relocation and backshoring activities: Changing patterns in the course of the global economic crisis, *International Journal of Operations & Production Management*, 32(6), 696–720.

LAMB, T. AND HELLESOY, A. 2002 A shipbuilding productivity predictor, *Journal of Ship Production,* 18(2), 79-85.

LIN, C. L. AND TAN, H.L. 2011 A study on causes of delays in the shipbuilding industry in Taiwan, *Journal of Taiwan Society of Naval Architects and Marine Engineers,* 30(3), 157–169.

MELLO, M. H., STRANDHAGEN, J. O. AND ALFNES, E. 2015 Analyzing the factors affecting coordination in engineer-to-order supply chain, *International Journal of Operations & Production Management,* 35(7), 1005-1031.

MOYST, H. AND DAS, B. 2005 Factors affecting ship design and construction lead time and cost, *Journal of Ship Production,* 21(3), 186–194.

NORWEGIAN BOARD OF TECHNOLOGY. 2014 *Made in Norway? How Robots, 3D Printers and Digitalization Can Open up New Opportunities for Norwegian Manufacturing,* Oslo, Norway: Norwegian Board of Technology.

OECD 2007 *Compensated Gross Ton (CGT) System*, OECD Directorate for Science, Technology, and Industry: Council Working Party on Shipbuilding. www.oecd.org.

OLHAGER, J. 2003 Strategic positioning of the order penetration point, *International Journal of Production Economics,* 85, 319-329.

PIRES, F. C. M., LAMB, T. AND SOUZA, C. M. 2009 Shipbuilding performance benchmarking, *International Journal of Business Performance Management,* 11(3), 216-235.

SEMINI, M., BRETT, P. O., HAGEN, A., KOLSVIK, J., ALFNES, E. AND STRANDHAGEN, J. O. 2018 Offshoring strategies in Norwegian ship production, *Journal of Ship Production and Design,* 34(1), 59-71.

STALK, G. AND HOUT, T. M. 1990 *Competing against Time: How Time-Based Competition Is Reshaping Global Markets,* New York: Free Press.

STAVRULAKI, E. AND DAVIS, M. 2010 Aligning products with supply chain processes and strategy, *The International Journal of Logistics Management,* 21(1), 127-151.

STRANDHAGEN, J. W., JEONG, Y., WOO, J. H., SEMINI, M., WIKTORSSON, M., STRANDHAGEN, J. O. AND ALFNES, E. 2020 Factors affecting shipyard operations and logistics: A framework and comparison of shipbuilding approaches. *In*: Lalic B., Majstorovic V., Marjanovic U., von Cieminski G., Romero D., Editors, *Advances in Production Management Systems. Towards Smart and Digital Manufacturing. APMS 2020 IFIP Advances in Information and Communication Technology*, Vol 592, Cham, Switzerland: Springer.

SURI, R. 2010 *It's About Time: The Competitive Advantage of Quick Response Manufacturing,* New York: Productivity Press.

TOWILL, D. R. 2003 Construction and the time compression paradigm, *Construction Management and Economics,* 21(6), 581-591.

Appendix

Table 5 shows bivariate correlations between the variables included in the study, based on the total sample of 156 ships.

Table 5: Bivariate correlations between the variables included in the study (N = 156)

	ProdTime	OffStratIII	OffStratIV	GrossT	Compl	LnPosInSeries	ProdInt	DemInt
ProdTime	1	-.151	.443**	.587**	.114	-.238**	.326**	-.390**
OffStratIII	-.151	1	-.602**	-.198*	.055	.187*	-.147	-.121
OffStratIV			1	.135	.042	-.136	.172*	-.021
GrossT				1	-.102	-.235**	.212**	-.153
Compl					1	-.131	.222**	-.180*
LnPosInSeries						1	.060	.186*
ProdInt								.040
DemInt								1

* Correlation is significant at the .01 level (2-tailed)

** Correlation is significant at the .05 level (2-tailed)