Factors affecting shipyard operations and logistics: A framework and comparison of shipbuilding approaches

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Abstract. Shipyards around the world have several differences that affect the logistics processes at each yard. The purpose of this paper is to develop a framework for mapping the key factors affecting shipyard logistics. We test and validate the framework by applying it to three case shipyards—one Norwegian and two South Korean. To develop the framework, we first identify key factors affecting shipyard logistics, based on a review of the existing literature. The framework is then applied using data from the three cases. Through a comparative analysis of the collected data, we identify and outline the main logistics differences and the key factors' main implications for the shipyards. The findings from the analysis indicate that there are important differences between the shipyards, and these have implications for their scope of planning and execution of shipyard activities, their primary focus of coordination, and their primary flows, among others. Through the framework development and comparative analysis, the paper contributes to an enhanced understanding of shipyard logistics, as well as how it is affected by internal and external yard characteristics.

Keywords: Shipbuilding, shipyard, logistics, engineer-to-order manufacturing.

1 Introduction

The shipbuilding industry is currently under strong economic pressure, and the drastic reduction in the oil price, from around 2015, caused significant changes in the global shipbuilding market. Fierce global competition has driven the margins of shipbuilding companies down, making cost-efficient operations more important than ever before. Efficient shipyard logistics—defined here as the coordination of shipyard operations related to the flow of materials through a yard up to the completion of a ship—is, therefore, increasingly significant. However, research on the topic remains scarce. Shipyards also operate under differing conditions, which affect the logistics processes at yards. Increased knowledge of the factors that affect a shipyard's logistics activities can increase the understanding of how to achieve efficient yard logistics. Norway and South

Korea are examples of two strong, but different, shipbuilding nations. Norway, with its long coastline, has strong traditions in the shipbuilding industry, which remains an important industry for the country [1]. Due to Norway's high labor costs, competing on price is difficult. Norwegian shipbuilding has focused on the low volume production of high-quality, highly customized vessels, with innovative features, for the offshore industry. South Korea, on the other hand, with lower wages and strategic government support, has become a leading shipbuilding nation through the higher volume production of large tankers and cargo carriers [2]. Accordingly, contextual factors affect how shipbuilders should approach their shipyard logistics.

The existing literature includes various studies comparing different aspects within shipbuilding. Eich-Born and Hassink [3] conducted a comparative analysis of shipbuilding regions in Germany and South Korea, focusing on how local, regional, and national factors affect global competition. Bai et al. [4] compared the information technology, production technology, and local characteristics of Chinese, Korean, and Japanese shipyards, albeit without a structured framework. Pires Jr. et al. [5] presented a methodology for shipbuilding performance assessment, based on yard characteristics, production patterns, and industrial surroundings. Colin and Pinto [6] analyzed the asset turnover of several shipbuilding companies, while Semini et al. [7] compared different offshoring strategies in ship production. Despite the range of shipbuilding studies, there is a lack of studies aimed at shipyard logistics.

This paper addresses the need for an increased knowledge of the factors that affect a shipyard's internal logistics. The purpose of this paper is to develop a framework for mapping the key factors affecting shipyard logistics. Such a framework may enable comparative analyses of shipyards and provide useful descriptions of the characteristics and challenges related to shipyard logistics. We test the framework by applying it to a Norwegian shipyard and two South Korean shipyards.

2 Research approach and framework development

Figure 1 shows the overall research approach taken in this study. The first step in developing the framework was to identify the relevant factors affecting shipyard logistics, based on a literature review. Following the factor identification, and inspired by Jonsson and Mattsson's [8] original planning environment framework, we developed the framework by establishing the factors and their respective items and content. The framework was then applied to map three different shipyards: Ulstein Verft AS (UVE), Hyundai Heavy Industries Ulsan (HHI Ulsan), and STX Offshore and Shipbuilding Jinhae (STX Jinhae). The first is a Norwegian newbuilding shipyard, and the next two are large and medium-sized shipyards in South Korea. The authors' strong relationship with the case shipyards allowed access to data through interviews and site observations, and various yard documentation and records were made available to the authors. The data collection also provided new insights that were used to revise and improve the framework. Therefore, the framework development became an iterative process with new revisions, as data from the cases were collected and analyzed. The final step was to conduct a cross-case comparative analysis, based on the mapping of the shipyards, and discuss the findings of the analysis.

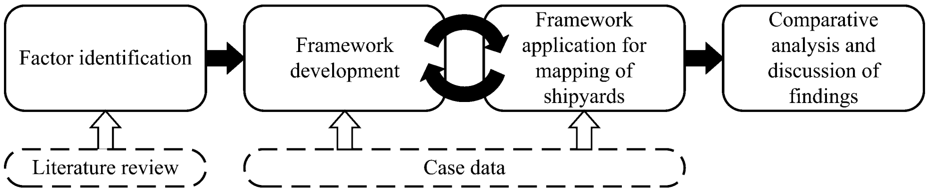

Fig. 1. The paper's research approach.

From an operations management perspective, shipyards are different from traditional manufacturing systems, due to the distinct characteristics of their production environment. Following Buer et al.'s [9] definition of production environment, we define a shipyard logistics environment as the sum of internal and external factors that affect shipyard logistics processes. Based on the literature, we include four factors: yard characteristics, product and market characteristics, process characteristics, and supply chain characteristics. Each factor consists of several items.

As shipyards are different from traditional manufacturing systems, we treat yard characteristics as a separate factor. First, a yard's facilities and available equipment influence both the activities that can be carried out and how they can be carried out. Second, shipbuilding is the production of large-scale products that require a certain amount of physical space and number of workers. Although shipbuilding is typically characterized as production in a fixed-position layout, several options exist within that main layout type, eventually affecting how material flows through a shipyard. Finally, a yard's logistics is affected by its levels of process automation and information technology (IT) in terms of IT systems to support logistics processes.

A production environment's product and market characteristics typically include the placement of the customer order decoupling point, product volume and variety, level of customization, and product complexity. However, the description of a shipyard requires items that are adapted to the shipbuilding context. Shipyards can vary based on the types of vessels they produce, as different types may require different material handling equipment or different organization of the activities at a shipyard. The vessel type can also indicate the complexity associated with building it. The number of vessels produced per year and whether a shipyard typically produces one-offs or a series of several ships per order are additional aspects that affect shipyard logistics.

A yard's process characteristics include the main shipbuilding processes it performs, as processes may be outsourced to other yards. There are also different possible building practices for outfitting operations in shipbuilding, i.e., the installation of a ship's equipment in its hull. As the hull is typically constructed by joining hull blocks together, outfitting may be done on single blocks before they are joined to erect a ship. Outfitting after ship erection reduces accessibility to the point of installation, as the hull is then a closed structure. The final item within this factor is the throughput time, i.e., the total time from production start to ship completion.

Shipyards may differ greatly in how their supply chains are organized. The degree of vertical integration has been found to have a particularly significant impact on shipbuilding productivity [10]. Thus, it is included as an item within supply chain characteristics. A shipyard's supply network, in general, may also influence its logistics and is, therefore, included as a second item within this factor.

The framework is shown in Table 1. In addition to the four factors included in the framework, different organizational, social, and cultural factors may affect shipyard logistics. These factors include labor costs and productivity [2, 5], organizational structure [11], and characteristics of the workforce [2]. They are particularly relevant when comparing shipyards in different countries, but they are not included as distinct factors in the mapping framework. Similarly, economic factors, such as the shipbuilding company's financial performance and eventual government support [2, 5], while relevant factors, are not included in the framework at the current stage.

Table 1. Framework for mapping factors affecting shipyard logistics.

Factors	Items	Content	Ref.
Yard characteristics	Yard facilities	Main production facilities, docks, and quays.	[6]
	Yard equipment	Main yard equipment for material handling.	[5]
	Yard size	Total number of shipyard workers, total yard area.	[10]
	Yard layout	Shape and direction of material flow through the yard.	[2]
	Automation level	Level of automation of shipbuilding processes.	[6]
	IT level	Level of IT systems infrastructure and integration.	[5]
Product and market characteristics	Vessel types produced	Tankers, bulk carriers, cargo/passenger ships, fishing vessels, and offshore vessels.	[12]
	Customization	Degree of customization.	[13]
	Total production volume	Average number of vessels produced per year.	[9]
	Order size	Average number of similar ships per customer order.	[9]
	Type and size of market	Type and size of the market the shipyard competes in.	[2]
Process characteristics	Throughput time	Average throughput time of a customer order.	[9]
	Main shipbuilding processes	Main shipbuilding processes performed at own shipyard.	[7]
	Building practices	Degree of advanced outfitting.	[12]
Supply chain characteristics	Supply network	Characteristics of the supply network.	[5]
	Vertical integration	Shipyard's integration with hull yard, ship designer, main equipment suppliers, and shipowner.	[10]

3 Framework application: A comparison of shipyards in Norway and South Korea

Norway's high cost levels affect performance, especially in labor-intensive production, by driving up product costs through higher direct and indirect labor costs [14]. A consequence of this is the offshoring of most steel-related tasks to countries with lower cost levels [7]. Therefore, Norwegian yards primarily perform the more advanced outfitting tasks, such as the installation of machinery and deck equipment, electrical systems, and accommodation, while the steel structure is built in lower-cost countries [7]. With these high cost levels, there is also a need to focus on high value-added and knowledge-based products, making access to competence and innovation vital. Norway's maritime industry is supported by a network of maritime clusters, and proximity to customers, suppliers, competitors, and research institutions provides benefits that compensate for the high labor costs [14]. Organizational, social, and cultural factors also have implications for the Norwegian shipbuilding industry. Examples include the flat and informal organizational structures, autonomous employees, a skilled workforce, and the small local communities [14]. These locational characteristics provide Norway with a competitive advantage in the production of highly customized products of high quality and with innovative features. This has enabled Norwegian shipbuilders to be global leaders in the market for highly specialized offshore vessels. The performance of Norwegian shipyards has been affected by fluctuations in the oil and gas market, which has forced them to pursue, and adapt to, alternative markets [15].

After entering the shipbuilding industry in the 1970s, South Korea has strengthened its position as a leading shipbuilding nation through lower wages and a national strategic focus [2]. The country's shipbuilding industry has benefited from the large domestic production of steel and a strong marine equipment industry [16], and their large shipyards have dominated for the past decade [2]. South Korean shipyards produce a variety of different ship types, with the main types being larger vessels, such as container ships and various tankers [16]. South Korea's dominance in the shipbuilding industry is a result of advanced technological developments, innovation, and governmental research and development support, in addition to the potential to compete on price. However, the fierce global shipbuilding environment also challenges South Korea, and with many shipyard's struggling to stay in business, the national industry is currently seeing significant restructuring, through several mergers between shipbuilding companies.

Table 2 shows the mapping of the three case shipyards after the application of the framework. The main differences and their implications for logistics are discussed in section 4.

Table 2. Framework application on the three case shipyards.

Items	UVE	HHI Ulsan	STX Jinhae
Yard facilities	Pipe fabrication, outfitting, painting; quay (208 m), 1 graving dock.	Steel and pipe fabrication, assembly, outfitting, painting, pre-erection, erection; quay (7.4 km), 10 graving docks.	Steel and pipe fabrication, assembly, outfitting, painting; pre-erection, erection; quay (1.8 km), 2 graving docks.
Yard equipment	2 main traveling cranes (250 tons), 4 dockside and quayside cranes.	9 goliath cranes (max 1,600 tonnes), 33 transporters.	4 goliath cranes, 6 transporters.
Yard size	Around 75,000 m^2 and 300 shipyard workers.	Around 6,320,000 m^2 and 15,000 shipyard workers.	Around 1,000,000 m^2 and 1,000 shipyard workers.
Yard layout	L-shaped, with material flow directed towards hull in dock or at quay.	U-shaped from steel entry through fabrication, assembly, and erection to docks and quaysides.	

Level of automation	Mostly manual operations, with some automation of fabrication.	High automation of steelwork and block assembly. Mostly manual operation on painting, outfitting, and ship erection.	High automation of steelwork and medium automation of block assembly. Mostly manual operation on painting, outfitting, and ship erection.
IT level	IT systems used for all business processes but with a low level of integration between systems.	IT systems used for all main business processes. High level of integration in the design phase. Low integration at the production site.	
Vessel types produced	Offshore support vessels (PSV, OCV, SOV) and passenger ships (ROPAX, cruise).	Large size commercial carriers, offshore platform systems, and support vessels.	Tankers, gas carriers, cargo carrying vessels (container ships, bulk), and LNG bunkering.
Customization	Very high.	Very high.	Very high.
Total production volume	2 vessels per year.	70 vessels per year.	10 vessels per year.
Order size	Few—between 1 and 2.	Several—up to 20.	Several—up to 10.
Type and size of market	Mainly offshore, cruise, and passenger markets.	Maritime transport market and offshore market.	Maritime transport market.
Throughput time	20 months.	10 months.	12 months.
Main shipbuilding processes	Outfits complete hull structures in dry dock and at quayside.	Performs all main processes at own shipyard (integrated yard).	Performs all main processes at own shipyard (integrated yard).
Building practices	All outfitting work performed on closed hull.	Pre-outfitting of hull blocks.	Pre-outfitting of hull blocks.
Supply network	Hull production at a yard in Poland. Mostly local equipment suppliers.	Domestic and foreign suppliers of steel. Partly outsourced hull block construction. Two engine suppliers. Several domestic suppliers of other equipment.	
Vertical integration	Medium. Vertical integration with ship designer. Partnership with hull yard in Poland.	Very high. In-house ship design. Vertical integration with main equipment suppliers.	Low. Some in-house design-activity.

4 Discussion

One of the main differences between the three yards studied concerns the shipbuilding processes performed at each yard. UVE mainly performs outfitting operations, with the other main shipbuilding processes performed at a partner yard. From a logistics perspective, UVE can keep its focus on the outfitting operations. However, as ships spend only a part of the total construction time at UVE's yard, it must operate with a tighter schedule, as there is less room for flexibility in the planning and execution of the outfitting activities performed at their yard. HHI Ulsan and STX Jinhae, on the other hand, are fully integrated yards, and must coordinate the whole range of shipbuilding processes and handle the logistics activities related to these processes.

Another main difference is the large variation in production volumes between the yards. While they all build customized vessels, UVE is more focused on building highly specialized vessels, in a market with lower global demand, than the South Korean yards. While UVE mostly produces one-offs, the South Korean yards build series of several ships. One implication for logistics is the total number of ships being built at the respective yard at any given time. Having up to 20 ships at the yard at a time requires significant interproject coordination, i.e., coordination between projects. UVE mainly has to focus on intraproject coordination, i.e., coordination within each shipbuilding project, as each project makes up a higher share of the total sales value.

The yards' production volumes are naturally linked with their capacity in terms of the number of docks, number and lifting capacity of cranes, and the yards' sizes. Producing tens of ships per year requires the facilities and space of a different magnitude compared to the production of only a handful of ships. As HHI Ulsan and STX Jinhae, both integrated shipyards, perform all the main shipbuilding processes, they need equipment and transporters that can handle and move hull blocks. For instance, yards of the size of HHI Ulsan typically have around 500 hull blocks located at different areas of their yard, and every day more than 100 blocks are transported. UVE, on the other hand, only performs outfitting operations on complete hulls. It does not need heavy-duty material handling equipment, as there is no transportation of hull blocks. The heaviest material handling process at UVE is the lifting of equipment by tower cranes for installation on ships in the dock or at the quay. Accordingly, UVE's main concern regarding layout-related issues is how to improve productivity in their outfitting operations. The primary flow that UVE has to plan and control to perform outfitting operations is the flow of workers to and from the dock or quay and on and off the ship being built. The South Korean yards are, to a larger extent, concerned with planning and controlling the flow of blocks and larger ship structures around their yards.

5 Conclusions, limitations, and further research

This paper has proposed a framework for mapping the key factors affecting shipyard logistics. Yard characteristics, product and market characteristics, process characteristics, and supply chain characteristics have implications for a shipyard's logistics, and this has been illustrated through mapping three shipyards by applying the framework. The factors' key implications for shipyard logistics include the scope of planning and execution of shipyard activities, the primary focus of coordination (intraproject versus interproject), and the yards' primary flows.

The low number of cases is one of the paper's limitations. A larger number of cases would enhance the generalizability of the results. Moreover, the presented framework is focused on the shipbuilding industry and the shipyard environment and is currently a first version that needs additional work to be developed further. Future work should consider comparing shipyards with the production environments in other industries.

Nevertheless, the paper contributes to an enhancement of the understanding of shipyard logistics, as there is a lack of related research in the shipyard logistics area, and addresses how logistics challenges are affected by internal and external yard characteristics. The results of this paper can help shipbuilders understand the internal logistics environment and support them in selecting and designing appropriate logistics planning and management systems. The paper offers a guide to further research, which should aim to investigate the main logistics challenges in different shipyard contexts, with the specific objective of developing a typology of shipbuilding logistics. The future work on shipyard logistics should also address how the need for digitalization and the use of Industry 4.0 technologies differs, based on shipyard logistics differences.

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