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Case Studies for Concurrent Engineering Concept in Shipbuilding Industry

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Abstract. In shipbuilding process, design information is generated in each phase to shape products and operations. For each process the design activities are carried out with a high level of concurrency supported by various computer software systems, though quality of products and efficiency of the concurrent development process highly depend on experiences and insights of skilled experts. The detailed design information is difficult to be shared and design conflicts are solved in a common effort by design engineers in downstream design stages. Data sharing across design sections and simulation of the construction process to predict time and cost are the key factors for concurrent engineering in shipbuilding industry. The concurrent engineering process in shipbuilding will be getting more and more accurate and efficient along with the accumulated design knowledge and simulation results. This paper reviews shipbuilding product creation process and demonstrates practical usage through typical, comprehensive use cases from design and manufacturing.

Keywords. Industrial case studies, shipbuilding, design process, information systems

Introduction

In shipbuilding industry, the process of the operation is very complex and a shipbuilding project from inquiry to delivery lasts quite long, about two years and more. The price of large tankers or bulk carriers is around several million USD up to ten million. Passenger ships, LNG carriers or offshore structures are much more expensive. Characteristic of shipbuilding is the huge volume of supplied material that needs to be procured and managed in addition to the design and construction process during shipbuilding projects. To present the importance of the concurrent engineering concept in shipbuilding, this paper illustrates the ship building process first. Additionally, related works are reviewed to show problems many shipbuilders are confronted with and show several case studies.
Basic shipbuilding design process is described illustrated in Figure 1. The detailed process can be found in [1]. The basic process is very similar to other manufacturing industries which produce products for individual customers. Design and manufacturing information are required and often a design is reused together with the manufacturing information such as shop floor drawings etc. Decisions in design process generate

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design data and following downstream process will be proceeded based on those design data.

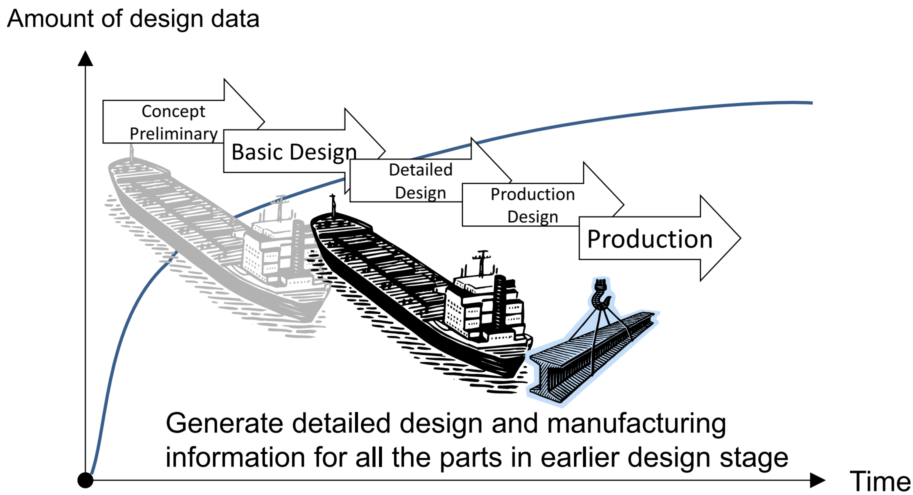

Figure 1. Standard design process and increase of design data in time history.

In concept and preliminary design, the basic specification is provided by the customer and the designers have to create a basic plan for the bidding. As the customer is interested in the cost for purchasing a vessel, the shipyard has to estimate the accurate cost for the delivery of the ship. A highly accurate estimation of the production is important for winning the bidding and improving the profit rate for the delivery of a ship. Skills of the estimation based on deep technical knowledge are required. However, gathering data of past projects for simulations by commercial software systems are getting more and more important to accurately estimate the current costs. In preliminary design, designers work on key drawings such as GAP (General Arrangement Plan), Lines and Midship section drawings. GAP is a key drawing for defining basic dimensions, capacities and so on. Lines drawing defines the hydrostatic performance by describing the shapes of the hull with curved surfaces. Midship section drawing is a drawing for the most important part for the approval of the structural strength of the ship. Key performance parameters such as speed, fuel consumption, stability, basic structural plan, main engine and other key equipment are determined in addition to the three key drawings. Ship capability and key performance are confirmed during the basic design process and a revised basic design will be provided for the contract. In the following detailed design phase, the detailed feature of the product is defined. As an example, the drawings developed in the detailed design phase could present handles for valves, small stiffeners, steel plates with curvature for the hull and purchased products. There are not so many differences from other manufacturing industries in detailed design. One characteristic of shipbuilding might be that most of the parts for the ship hull and structures are made by cutting steel plates. Thus, a definition of standard parts is difficult. The number of parts is in the range of 100k to one million for a ship, so this might also be a characteristic of shipbuilding. Depending on the construction process, the design model defined during the detailed design phase may or may not depend on the manufacturing facilities. In production design, some of the drawings might be instructions for workers in shipyards or considerations for the manufacturing process such as margins. This phase may not include design trade-offs; the phase is a kind of planning for an optimal manufacturing. The drawings do not only show shapes, dimensions and specifications of the parts, but also how to make parts or fabricate assemblies. To construct a complete ship in dry docks, the whole ship hull is divided into building blocks to fit in the manufacturing facilities and capacities. Owing to the limitation of the manufacturing facilities, the production design can vary even for the same ship with the same detailed design model. The manufacturing information in shipbuilding considers the large deformation of steel structures by the welding process during fabrication.

To shorten the lead time, the whole process goes on in concurrent manner. Detailed structure or outfitting design cannot wait for the final design of the upstream process. Software systems for design and construction are implementing a lot of features and trying to provide integrated environments to facilitate the concurrent engineering process; though they used to be standalone systems such as CAD or numerical control systems. To improve the efficiency of the shipbuilding process and handle the huge number of materials, PLM, ERP and more sophisticated software are more and more used by shipyards. There is a tendency to employ new integrated information systems in shipyards although the limitations arising from legacy design data and manufacturing facilities still exists. In this paper, the general shipbuilding process is described and details of two case studies are illustrated. Finally the future trend of concurrent engineering is discussed.

1. Ship Design and Construction Process

Several efforts to improve the ship design and construction process are reviewed in this chapter. The improvements and efforts relate to the software system and the concurrent engineering concept.

1.1. Concurrent Engineering in Early Design Phase

Concept, preliminary and basic design phase are considered as early design stages. Literatures for these phases will be shown here. The purpose of the concept and preliminary design is to support the bidding process. Detailed information is not required during this design phase, nevertheless the shipyard should know the cost for the materials, man hour, major purchase equipment and the feasibility of the delivery date along with the ongoing projects. The concept and preliminary design must meet the customer's requirements and, at the same time, have to be an optimal design solution for the shipyard in terms of constructability. The shipyard has to make a design proposal considering many trade-offs in the shipyard capabilities. Speeds, fuel consumption, hydrostatic performance, selection of main engine, strength of structure and construction weight are parts of the considerations in design. International regulations by international maritime organizations and loading facilities in ports might be limitations for the design work. Even today, to achieve a balance in trade-offs, this phase of design process highly depends on the human skills. Therefore shipyards have to assign talented and capable people to the concept and preliminary design phase because this phase has a huge impact on the whole cost and schedule. Meijer [2] focuses on the pre-contract scheduling problem and captures the knowledge of experts for the process. Production scheduling tasks in the pre-contract phase are based on knowledge and experiences. The knowledge captured is, for example, detailed configurations of manufacturing facilities to optimize the turnover of the building dock.

NAPA is a software company providing a suite of software for ship design and NAPA software facilitates the utilization of 3D design models in the preliminary design phase [3]. The complex interactions, such as hydrostatic performance and compartment plan, will be calculated in the software. Each employs many types of solvers in the basic design phase [4]. CFD, evacuation simulation, structural analysis, vibration and acoustics are shown. Papanikolaou shows a multi-objective optimization of ship design case study [5]. The integration efforts for CAD system and engineering software are also active. Bons introduced the latest status of MARIN's software [6]. Hydrodynamic design tools are a kind of standalone software because of their specialized purpose. The integration of third party software framework enables specialized soft-ware tools for hydrodynamic to be applied to the early design stage. Ginnis integrate their in-house wave-resistance solver with CATIA to improve the efficiency to hull optimization [7]. As for structural design, Shibasaki utilize a 3D design model for structural analysis within an early design stage [8]. The advantages of a plenty of design and production data for the downstream process are illustrated by Nakao [9]. The quality of design model has an impact on the concurrency, quality and efficiency of the downstream process.

1.2. Detailed Design and Construction Process

All the drawings of parts will be provided in detailed design phase. The complete details of the product will be defined. Requirements for the ship operating companies are satisfied in the basic design, and the usability for the crews of the vessels depends on the quality of detailed design phase. Arrangement of small handling equipment like handles and valves is important for daily operations, so ship owners send supervisors to the shipyard to check and revise the detailed feature of vessels for improving usability. The cost for supervising work varies by the quality of the shipyard, so it is important to win an order in shipbuilding industry that the shipyard gains confidence with the customers in technological aspect though bidding price is important. The drawings contain detailed structural members, piping, pipe support and insulators, machinery outfitting, electrical outfitting and many other details. The detailed design section also work on the selection of the purchase of the outfitting equipment. Structural design and outfitting design teams work on the same hull and often have to solve the interference across the design sections. The structural design team doesn't want other team to make a hole for pipes and the outfitting team needs a hole for efficient routing of pipes or cables as shown in Figure 2.

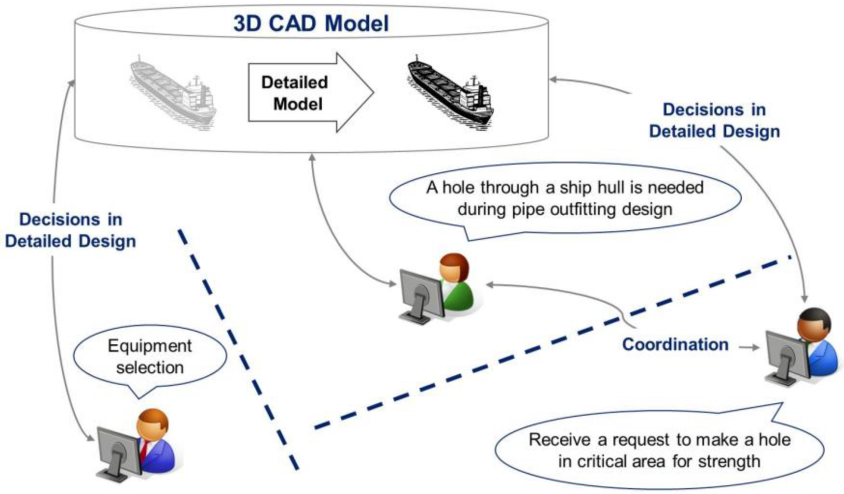

Figure 2. Detailed design process with coordination across the design sections.

After production design phase all drawings will be prepared. The drawings include not only shapes, dimensions and specifications of the parts, but also how to make parts or fabricate assemblies. To construct a final ship in dry docks, the whole ship hull will be divided into building blocks to fit in the manufacturing facilities and capacities. Because of the large deformation of steel structures by welding process during the fabrication, margins are carefully defined for each part considering the deformation. Dimensions and shapes of the parts are defined in detailed design phase, but the actual dimensions considering the deformation during the fabrication process will be shown in production design stage. Production will go on based on the production design. Basically all the procedure defined in the production design phase will be completed in production, then the final product will have finished. Problems may be occurred even in the production process. Ideally, the production section just constructs a ship based on the information defined in the prior stage. However, there are still many factors to fluctuate the schedule of the shipyard. Delays in production schedule according to weather conditions, late delivery of purchases and unexpected problem in resource or facility often happens in practice. Moreover reworks caused by the inconsistency and mistakes in detailed or production design stage will also happen in the production phase. Carrying and installing large equipment into the ship building blocks is done in complicated procedure because of the limitation and the transitions of work area along with the progress of production.

The downstream process such as detailed design, production design and production should be straight forward in concurrent manner, but the coordination is still required.

2. Case Studies

Historical data and simulation technology are potential solutions for the problems caused by the complexity of the design and production process. Two case studies about data management and simulation are shown in this chapter.

2.1. Data Management in Production Process

Recently, some accuracy evaluation systems using measured data of assemblies obtained from laser scanners are proposed. Laser scanners measure the whole surface of the members as point cloud data. Measured data can be used for evaluation, checking the accuracy of shipbuilding blocks [10] or surfaces of shell plates [11]. The measured data and evaluation results have much information content, so these data are expected to help to discover knowledge about the manufacturing process. However, in most shipyards, the search and reuse of evaluation results is difficult because large amounts of accuracy information are stored without an adequate data management.

It is recommended to employ a data management system using measurement data and accuracy evaluation results of shipbuilding assemblies gauged in the manufacturing process.

The proposed system has three functions: (1) accuracy evaluation, (2) accuracy data accumulation, and (3) search and reuse of accuracy data. The objective of this study is to build a method for identifying knowledge, know-how and techniques in the field based on the data managed by the developed system and evaluated by the three dimensional measured data in the ship construction process. The overview of the whole system is shown in Figure 3. All types of data stored in the database and, as well, the metadata is assigned to them. Any data stored in the system can be reachable efficiently thanks to the metadata

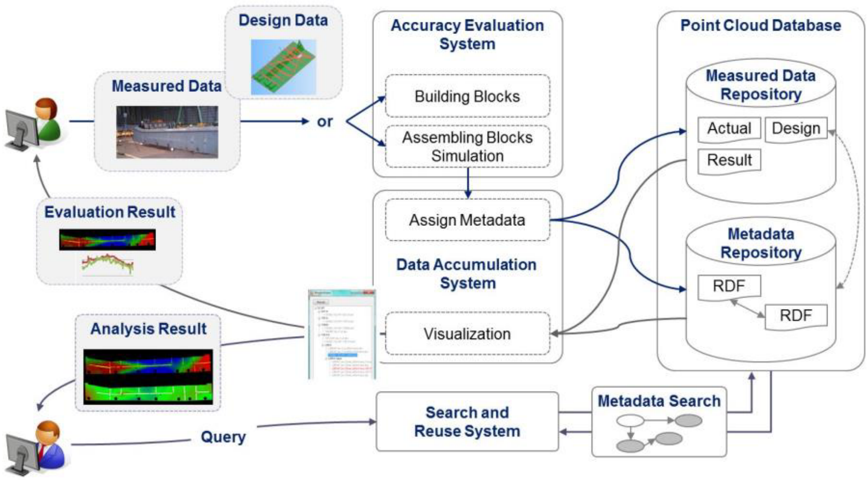

Figure 3. Overview of data management system.

In the accuracy evaluation system, the accuracy of assemblies is evaluated as gaps between measured data and design data. In the accuracy data accumulation system, measured data, design data and evaluation results are stored. The metadata is attached to each data in RDF format [12]. Measured data can be retrieved by using RDF metadata. Search results are shown with metadata to facilitate the users to work on the measured data and accuracy evaluation results easily. Some evaluation results stored in the proposed system are shown in Figure 4. This figure gives an overview of the shipbuilding blocks and the deformation of internal structural members calculated from accumulated measured data by laser scanners. The vertical axis of the graph is offset along with the depth of blocks and the horizontal axis corresponds to the width. Two measured data are retrieved in a three months interval, however the same tendency of the deformation can be found. The findings obtained by these comparisons can be utilized for redesign of the manufacturing process.

The accumulation of the data will enable shipyards to do this kind of analysis easier and avoid uncertainties in the production process.

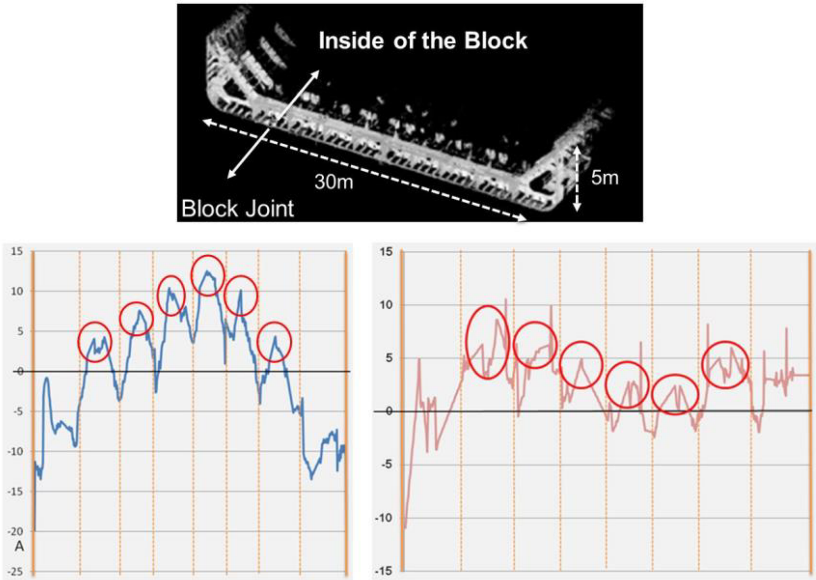

Figure 4. Deformation in Fabrication Process.

2.2. Simulation of Production Process

Simulation technique is crucial to predict the following process. This case study proposes a methodology to evaluate organizational performance based on the research of [13]. The developed system defines workers, facilities, activity models and production strategy. The evaluation of organizational performance is done through the following processes: (1) create the enterprise model and strategy, (2) calculate work plan by optimizing the weights of each strategy, (3) compare the basic scenario to the scenario when a situation changes. The system proposes a work plan by genetic algorithm. The plan minimizes the total cost in doing the work activities considering the weight of each production strategy. The proposed methodology is applied to some sample scenarios in a fabrication shop. Results show that the methodology can evaluate organizational performance successfully by analyzing the work plan. In addition, the methodology also evaluates the effect of improving organization and sudden trouble quantitatively. Figure 5 shows the overview of the proposed method.

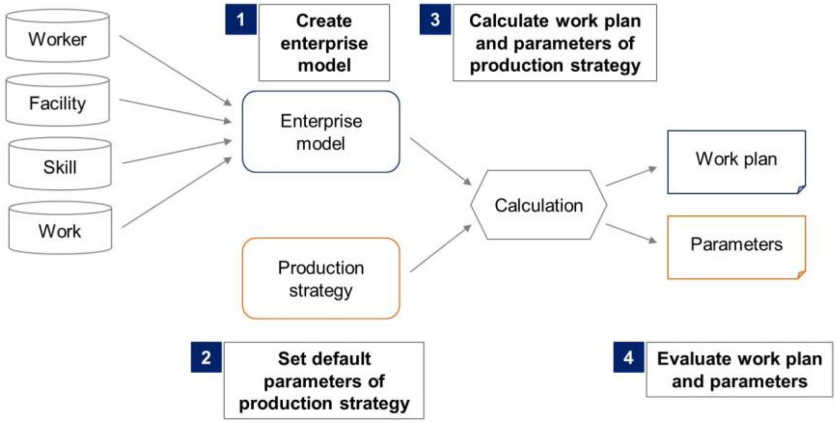

Figure 5. Deformation in Fabrication Process.

Initially, an enterprise model is developed based on the workers and facilities in an organization including the different work activities and skills set and the production strategy is made by setting each parameter. Next, the optimal work plan for the enterprise model is calculated by designing the parameters of the production strategy. Finally, the organizational performance is examined by evaluating the optimal work plan and parameters of the production strategy.

The skill set is a class of skills needed to perform the various activities in an organization. Workers, facilities and tasks in some activities are defined by the skills in this set. The organization model is composed of workers, facilities and their capabilities or skills. Workers and facilities are defined by their costs and the presence or absence of skills in the set.

This method is evaluated in the fabrication process of simple panel structures in the case study. The process model is shown in Figure 6. The simulation scenario is that 11 workers using 6 facilities are working on making 10 panels. The result is also shown in Figure 7 in Gantt chart format. The weight vector for strategy in assigning the activities to workers is also obtained. This simulator shows that the job allocation strategy will change from cost saving to first-in first-out to keep the delivery date in case of the resource shortage.

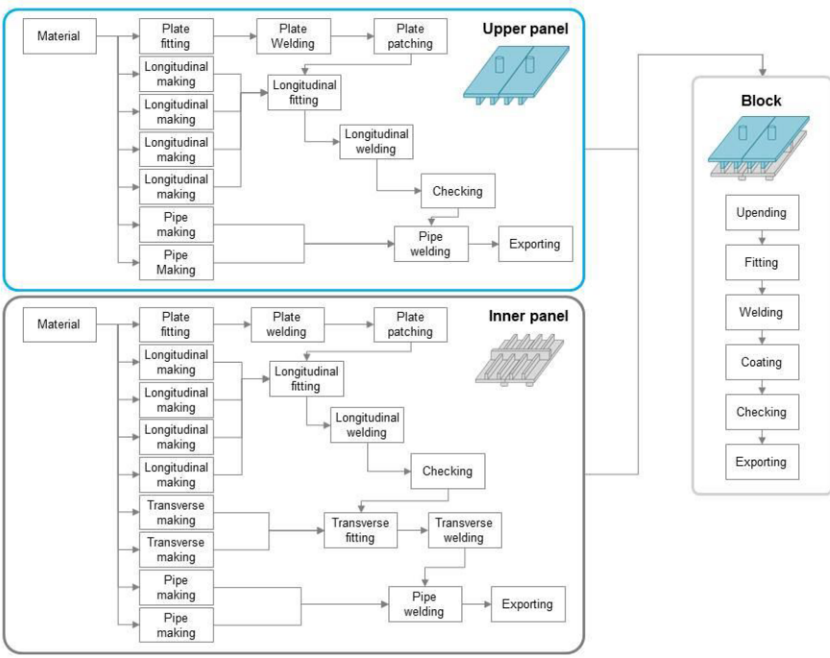

Figure 6. Process Model for Fabrication of Simple Panel Structure.

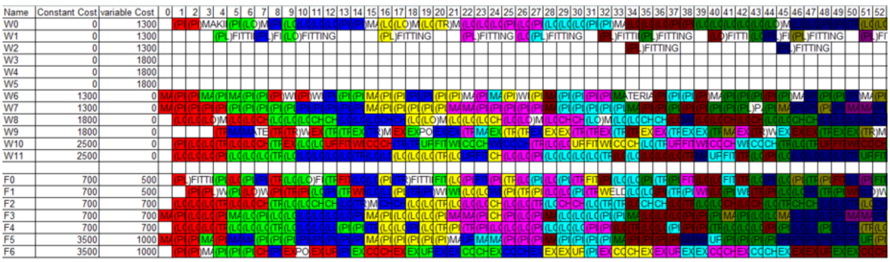

Figure 7. Calculated Schedule by Proposed System.

3. Future Directions for Concurrent Engineering in Shipbuilding

The design engineers have to consider complex and concurrent processes of shipyards. The same situation can be seen in the following basic design phase. To manage and predict the complex and concurrent shipbuilding process, basically two types of efforts are proposed for the early design stage. The first approach is to accumulate design and construction experiences. In the early design phase, design engineers work based on similar projects. The designers identify the differences between the past design and the new requirements and estimate the impact on the new design. The second approach is simulation. Production scheduling and performance measures of the ship (such as fuel consumption) are vital for bid creation Whereas during the concept design phase the focus is set on production scheduling, ship performance is the key topic in the preliminary design phase. The basic design focuses on defining the parameters for the product to meet the requirements. Though the trade-offs of design parameters across the design sections are taken into account in the prior stage, negotiations based on the actual design start in this phase.

The case studies show how to use the accuracy measurement data and simulation results. For the concurrent engineering deployment in shipbuilding, data accumulation and analysis and simulation technique will be key technology.

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