TOTAL PROCESS SIMULATION IN SHIPBUILDING: SIMULATION AIDED HULL ASSEMBLY PLANNING

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ABSTRACT
Shipbuilding processes in Western Europe are primarily characterized by its result: unique ships built on customer-specification. This character pushes the limits of conventional planning and control methodology. The application of simulation aided production planning as a means to improve process control of multifaceted shipyard processes is therefore subject of research. In general the capacity limiting resource of a production system requires the best control and the production flow of the adjacent processes should be brought in balance with this bottleneck. For shipbuilding, this is the erection site (slipway, dock), at which the hull assembly takes place. Improving shipbuilding process control by simulation starts therefore at modelling this resource. The paper presents the status of an ongoing research effort showing that hull assembly and total shipbuilding processes can be modelled and that simulation in this context is a powerful means to improve process control within the maritime industries.

Keywords: production simulation, assembly planning, ship production, virtual manufacturing

1. INTRODUCTION

The shipbuilding industry is a labour intensive industry which is operating in a global and extremely competitive market. The shipbuilding process involves numerous production steps of many parts and their assemblies, far-reaching interactions with suppliers and a large volume of manhours to design and construct the large and complex structures. The price of these structures is determined by the laws of supply and demand, compromising between the level at which a shipyard is prepared to accept a contract and the level the customer is prepared to pay. The resulting price however is subject to many influences and is not very transparent in the market because of the small series size typical for shipbuilding. The necessary margin for shareholder's satisfaction and company's continuity must be obtained by having an acceptable cost level. As material cost is essentially fixed by the requirements of the ship's specification, significant reduction in construction cost can only result from improvement in production efficiency, both at the yard as well as at the subcontractors. Thus, the shipbuilders' financial situation depends on the achieved production efficiency. To meet this, improvement of process control is a requisite.

However, the complicated character of the shipbuilding process, especially in the case of one-off ships, pushes the limits of conventional planning and control methodology. Due to this, it is a challenge for all partners (shipyards and suppliers) within the total ship production process to make a feasible planning that is as optimal as possible and by which a suitable utilization of resources is achieved.

A means to improve process control is the application of simulation. This technique enables to manually investigate alternative production scenarios for the total shipbuilding process in advance. With this, products and processes can mutually be brought in balance and processes can be geared to one another resulting in smooth logistics of materials and components and properly levelled utilization of workstations as a consequence.

The study reported in this paper is aimed at enabling simulation of ship assembly processes on the hull erection site, with the goal to improve the corresponding process control. The paper presents the preliminary results of an ongoing research programme showing that multifaceted total shipbuilding processes can be modelled and that simulation in this context is a powerful means to improve process control within the maritime industries. The paper starts with a brief overview of ship production and hull assembly processes including the most important dependencies and details of process and product. Next, shipbuilding process control and the need for simulation is presented. This is followed by a description of the current simulation developments and applications in shipbuilding. It continues with the status of the development of the hull assembly simulation model. An application of simulation in planning is included in the results section. The paper ends with conclusions relative to the applicability of simulation in shipbuilding processes.

2. INTRODCUTION IN SHIPBUILDING

2.1. Physical decomposition of ships

Every ship can be considered as an autonomous system that offers the capability to fulfil the tasks required for its mission. On the one hand, every ship has to have the capability to float, sail and manoeuvre. On the other hand, a ship has functionalities that are integrated in the ship's standard systems, which are cargo or service related. Therefore, it can be said that every ship consists of a floating body subdivided into compartments that holds the systems, see Figure 1 for an example. These are all made up from elements classified as parts (steelwork) or components.

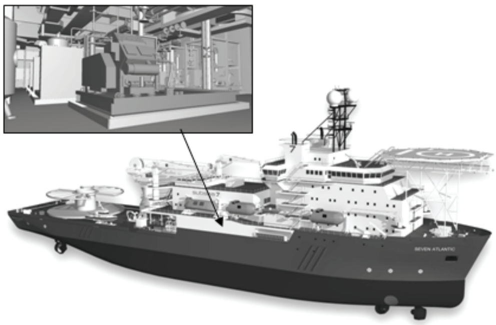

Figure 1: Yard number 713 with a typical compartment including volume and routing components

The hull, superstructures and deck houses are built up from steel parts, consisting of conserved structural steel material. The hull represents a steel assembly system of very many parts that provides the structural strength which makes it possible for the ship to fulfil its tasks. In general, every hull consists of three parts; the stern (aft), midship and stem. For hydrodynamic reasons, the first and the latter have curved forms, the rest of the hull is the widest part, almost prismatic, and quite voluminous.

Components cover the so called volume and routing components. Volume components include mechanical equipment, outfitting material, interior elements, and all other equipment necessary for ship operation. The routing components represent the infrastructure connecting with each other the power generation, consuming and/or processing volume components. These consist of piping, ducting, cabling and secondary steelwork to mount them to the ship structure. Currently, almost all systems and components are supplied to a shipyard and the integration, hook up and commissioning is arranged by the yard. This is not necessarily the case for the turn key supplies with full responsibility assigned to the supplier.

2.2. Work breakdown structure of ships

The presented physical decomposition and customized nature of ships make the shipbuilding process very complicated. Every ship taken in production represents a challenging planning and control task because the internal activities of a shipyard require the production of a large number of individual parts and their assembly in a meaningful order. Beyond that, a large number of systems must be integrated in an order that matches the order of the internal yard activities. Therefore, proper organization and a convenient product taxonomy play a very important role in shipbuilding.

In spite of the one-off character of shipbuilding, shipyards have adopted group technology (Storch 1988) for the organization of their current steelwork practices, which are considered to be leading during the production of a ship. By focussing on methods to improve the organization of work, “one-off” production can be structured such as to reap the advantages offered by mass production (Kihara and Yamamoto 1968). This can be arranged through standardisation of the production processes by means of employing many different kinds of constructions subdivided in a number of similar subassemblies (group production). The advantage of this is that it is possible to employ a repetitive process for the production for every group in a “few” successive simple activities which are subdivided in work steps. This subdivision of work and specialisation in production allows efficient organisation and work simplification (steeper learning curves) and provides the parallel with mass production.

With regard to the hull assembly process, only the upper two levels of the work breakdown structure (WBS) of ships need to be introduced. Figure 2 presents the upper level as the ship and the second level as the section level. This means for the hull assembly process, with regard to the steelwork, that the ship is erected by subsequently placing and connecting sections. Because of the application of the group technology philosophy, the section dimensions, weight, and assembly time of every section are in harmony with the other sections.

The presented WBS is shipyard specific, ship dimensions and yard setup can be reasons for an extra assembly stage where sections are combined into blocks that are then integrated to form a ship. The main advantage for these shipyards is that this shortens the lead time of the ship on the assembly site, providing a better allocation of the most expensive resource(s) on a shipyard. The lower levels of the WBS exist of subassemblies and parts.

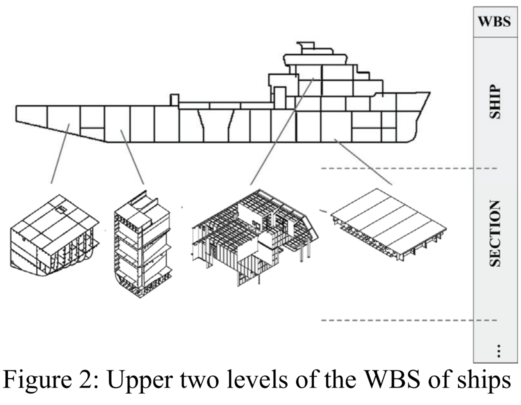

Figure 2: Upper two levels of the WBS of ships

2.3. The hull assembly process

The highest level of the WBS hierarchy presents the product ship that is erected during the process called hull assembly, which is described in this section. Material inputs for the process are pre-outfitted sections, small parts like brackets to mount the sections to each other, and outfitting material.

After welding and grinding, sections are pre-outfitted with prefabricated routing components and secondary steelwork. On-section (pre-)outfitting is done because of better accessibility and shorter transport lines to allow greater efficiency compared to on-board outfitting. Furthermore, it is of advantage when the onboard activities are minimized as much as possible, because many parallel processes involving many parties take place on the ship normally. An accurate assembly of sections is therefore a prerequisite, because that precludes rework during hull erection.

The hull assembly process starts with the mile stone event “lay keel” (Figure 3). This event implies the first section to be laid on the hull erection site. Before this event can happen, the erection site must be emptied and cleaned. This site preparation for erection happens immediately after the launch of the predecessor ship. During the erection of the predecessor, the assembly of the sections of the next ship is well under way. Therefore, it is possible to build up a small section stock which enables shortening the lead time of the ship on the erection site, resulting in a better allocation of the capacity limiting resource(s) on a shipyard.

Figure 3: Keel lay event (left) and erected bottom sections during outfitting (right)

After the first section is laid on the erection site, the planned subsequent sections can be mounted to this first section. Special attention is paid to the accurate alignment of sections. Once a section has been welded to the ship in formation, another section can be attached to this section. The first section is a midship bottom section, followed by other bottom sections to create a complete deck area (Figure 3) as soon as possible, which simplifies possible outfitting processes that can only be done when such a deck area is complete. Before this deck is closed off by mounting the next layer of sections, all components which are planned to be positioned on this deck and which cannot or are difficult to be carried onboard later, are placed in the right compartment (Figure 4).

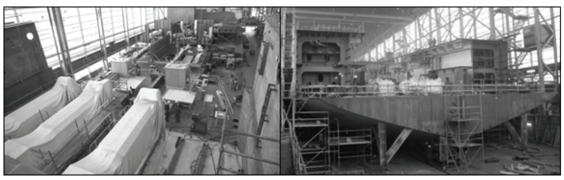

Figure 4: Main engines (left) and big equipment positioned during hull assembly (right)

When two sections are welded to each other, routing components can be connected with the help of fitting pieces. After positioning of equipment, these can be connected to the piping infrastructure by mounting measure pipes in between. Pulling of electrical cables, followed by the connection to equipment, is done after the ship in formation has reached a certain progress where it is worth starting pulling full cable lengths over long distances.

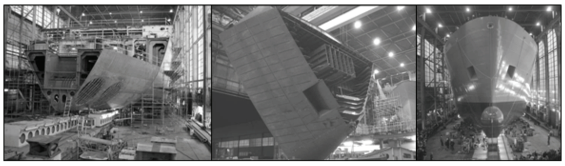

Figure 5: Ship during erection with scaffolding (left), transport of section to the ship in assembly (centre) and fully erected ship just before launch (right)

Figure 5 shows that the accessibility of the ship decreases with its progress, outfitting processes require therefore relatively more and more time as the erection process progresses. Scaffolding and gangways are applied on the inner and outer side of the ship to keep its accessibility as good as possible. Sometimes, it is required to cut extra holes in bulkheads to guarantee safe and practical work conditions.

If all processes involving heat are completed on the bulkheads and decks adjacent to a tank, pressurising of this tank can start. When this is completed for a compartment and all grinding processes are done, this compartment can be conserved. Distortion of an existing paint system should be precluded, but this is not always possible.

The output of the hull assembly process is the erected ship that thereupon can be launched when the hull is painted and all under water components like thrusters and rudders have been installed. After the launch, the ship is brought to the so called outfitting quay and all assembly processes from now on fall under the completion stage.

2.4. Process control

As far as their assembly processes are concerned, a shipyard is in a subordinate position vis-à-vis its suppliers, because it heavily relies on their performance in terms of efficiency and reliability. A well prepared plan, which takes into account all facets of the complex product and a limited amount of resources, to meet the project goals and to keep to this planning during production, is therefore, a prerequisite for a well-executed project.

This plan consists in general of several schedules which are drawn up during different stages of the project. The master schedule offered to a shipowner within the budget proposal can be seen as part of strategic scheduling as it contains estimations of the lead time of the main activities (based on an available slot on the erection site) and the delivery of the main components.

Based on the offered budget proposals, the "future" shipowner defines a short list with most competitive shipyards that are requested to provide a detailed proposal. This includes a detail planning that can be seen as a plan on tactical level, which brings the many shipbuilding process steps in the right temporal and spatial order. As already mentioned, the erection site (dock, slipway) is the most expensive resource which needs to be allocated as efficiently as possible. The available slot on the erection site is therefore part of the master schedule, but it is also the starting point for determining the detail planning. In general the process starts by tracing the erection relations between sections and big components which cannot or are difficult to be carried onboard. The corresponding hull assembly schedule then forms the basis for deriving all other production and delivery schedules. On operational level, the detail plan is fine tuned with the actual progress and available transport possibilities.

Hengst (1999) emphasizes the importance of the erection schedule as follows. When a shipyard has one erection site, the shortest possible delivery time of subsequent ships is amongst others determined by the launch date of the ship in formation on that site. Its allocation partly determines the delivery time and inherently the shipyard's competitiveness. Every shipyard strives therefore to shorten the erection time, which is a "bottleneck" where all ships needs to get through.

It is a real challenge for all partners (shipyard and suppliers) within the total ship production process to make a feasible and "optimal" planning in which a suitable utilization of resources is achieved. Because the erection schedule forms the basis for deriving this integrated planning, obtaining an "optimal" erection schedule is a prerequisite. The application of simulation can be used to achieve this, because this technique enables to investigate alternative production scenarios for the total shipbuilding process in advance, both on the strategic as well as the tactical level. On the operational level, it can be applied to aid in fine tuning of the tactical plan to actual production situations. With this, products and processes can mutually be brought in balance and processes can be geared to one another with smooth logistics of materials and components and properly levelled utilization of workstations as a consequence.

3. HULL ASSEMBLY SIMULATION

3.1. Simulation in shipbuilding

Simulation to control shipbuilding processes has in recent years been applied with success in the steel building area, prefabrication and sub construction assembly processes. The main result of this experience is the universally applicable Simulation Toolkit for Shipbuilding (STS) of the Flensburger Schiffbau-Gesellschaft (FSG). FSG and DUT are co-founders of *Simulation Cooperation in the Maritime Industries* (www.SimCoMar.com), a bundling of efforts in the area of simulation in ship production. Goals of this cooperation are the further development of the STS, knowledge exchange in applying simulation and joint research. The actual cooperation partners are DUT, FSG, Shipyard Nordseewerke, the Technical University of Hamburg-Harburg, the Center of Maritime Technologies (all three in Germany), and the University of Liege – ANAST (Belgium).

The shipyard independent STS is a class library developed in eM-Plant of Siemens-UGS-Tecnomatix, a simulation package based on the discrete event simulation principles. The STS contains a wide variety of simulation functions needed for modelling the production processes of companies in the maritime industries. The tools can easily be implemented in all kinds of simulation models and they can be adapted to certain tasks and specifics by adjusting their parameters (Steinhauer 2005). The development of the STS is part of SimCoMar's goals to be able to simulate the total ship production process. At Delft University of Technology (DUT), several simulation projects at Dutch shipyards have been executed based on the STS, see for example Kaarsemaker (2006) or Kaarsemaker (2007).

Experiences from all involved shipyards show that the steel building processes, from pre-manufacturing up to hull erection, are suitably applications of process simulation. But at this time, there is still a lack of simulation applications in the area of the more complex shipbuilding processes such as erection, outfitting and supply chain processes.

3.2. Strength of simulation in shipbuilding

The strength of simulation, especially in shipbuilding, has been shown in various projects. In spite of that, proving its direct financial advantage is often beyond the bounds of the possible because a shipbuilding project is never the same and consequently it is not possible to run the same project with and without the use of simulation. The gained experience within SimCoMar shows that the main benefit from applying simulation is the possibility to accurately test, evaluate and communicate (an almost unlimited amount of) future production scenarios in the computer before they become reality. This relates to the set-up of new production facilities as well as the normal day-to-day building of new ships in existing facilities.

3.3. Requisites for simulation

In theory, it is very easy to state that it is reasonable to run through the total production process of a ship in a computer simulation. It's also true that model development and maintenance is speed up by the STS, but a disposal simulation model can be created very quickly. A good simulation tool and programmers are of course main requisites for simulation, but the correctness of input and output data is at least as important.

Important influences on the success of a simulation project are; an extended analysis of the "is"-state, clear objectives and a good preparation. A simulation model is as good as its preparation and its results are in accordance with the quality and form of the input data. A consistent data-infrastructure that is continually kept up-to-date is needed, but unfortunately, data-readiness for simulation is still a rarity.

The main benefit from applying simulation is doing "unlimited" scenario research to reach an "optimal" plan. Therefore, product data needs to be available in an early stadium. This is in general a problem in current ship production practice, because detail engineering information gets out at a very late stage (concurrent engineering). A product data-generator to assess the missing data to enable simulation at an early stage is therefore a requirement.

Careful model validation takes a lot of time, but this is needed to achieve a valuable simulation model. In spite of a well-validated model, a right interpretation of simulation results is required. The results of a simulation are statistical values of a random check, all constraints and simplifications of the model have to be considered. Thereby, simulation can't guarantee an optimal solution.

3.4. Simulation of hull assembly processes

The current status of the development of the simulation aided hull assembly planning tool is that the extended analysis of the "is"-state and the collection of validation data is in progress. As already mentioned in the last section, these are the most time-consuming activities concerning the creation of a simulation model.

Analysis of the "is"-state implies the introduction to the production processes and facilities of the process under study. In other words, the collection of material flow diagrams, process parameters, dimensions of production facilities, but also the collection of necessary product, process and project data. As written before, product data needs to be available in an early stadium. This is for the hull assembly process not a problem, as best estimates for these data are already made during budget proposal (before the ship is sold).

Collection of validation data implies in first instance that the process parameters (capacities of resources) are checked for correctness. This can be done by timing activities and work steps, but also by verifying registered working hours and production progress. With these data, the simulation model can be calibrated. After that, the calibrated simulation model can be run in parallel to reality to improve its veracity.

3.5. Result

A basic hull assembly model of the FSG erection site has been made available to the SimCoMar community. This model, presented in Figure 6, is structured with the STS. It can therefore easily be adapted to be a basic for the creation of a specific model for another shipyard, for example the IHC Merwede shipyard in Hardinxveld-Giessendam.

Figure 6 presents besides the top view of the hull erection model, the layout of a simulation model modelled with the STS. This object library enables to model truly the facility (site and crane) and (sub-) product (sections and ship in assembly). In the figure are marked furthermore the methods which take care of starting actions and control the elements in the model. The general tools are shown in the upper left corner, these take care of:

- coordination and synchronization of the events
- administration of the model
- the operating calendar and shift times
- personnel definition and administration
- periodical summarization of statistics
- managing means of transport and the transports

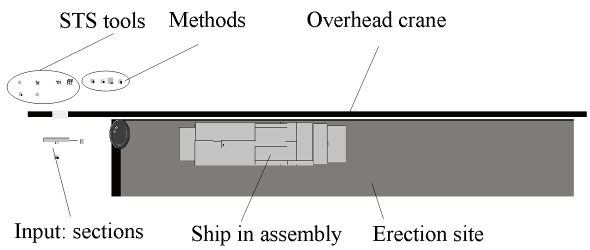

Figure 6: Top view snapshot of the basic SimCoMar hull erection model during a simulation run

Not shown in this figure is the statistics object that arranges the periodical summarization of resource statistics and the aggregated representation in work load diagrams. This is enabled by the STS tools which automatically tape all events (process steps, requests, transports, etc.) into tables. Based on these data, it is possible to visualise the results and then to evaluate them. The possibilities of a simulation model like this can be illustrated with an example regarding the workforce. Its composition (without suppliers) is simplified as given in Table 1.

Table 1: Composition workforce

Designation	Site	Shifts	Numb.
Constructing	…	…	…
Welding method 1	…	…	…
Welding method 2	…	…	…
Scaffolding	…	…	…
Quality checking	…	…	…
Grinding	…	…	…
Tank pressurizing	…	…	…
Painting	…	…	…
Aligning / Transport	…	…	…
Total			+/-100

This table can be explained as follows. During certain shifts, the workforce exists of approximately 100 employees of whom a certain number have certain designations who work at certain locations. The simulation model takes into account that when an activity requires two employees with the designation constructing during a dayshift, that the activity won't be executed when there is only one available and vice versa of course.

Via the statistics object, the workload diagrams as presented in Figure 7 can be created. This possibility to visualise results enables evaluating the balance between the production and employee schedules, with other words: resource levelling. Besides, representing progress or stage of assembly, or which section and components are worked on is possible as well. This knowledge combined with a view as in Figure 7, enables verifying what is going on at that moment in the simulation model.

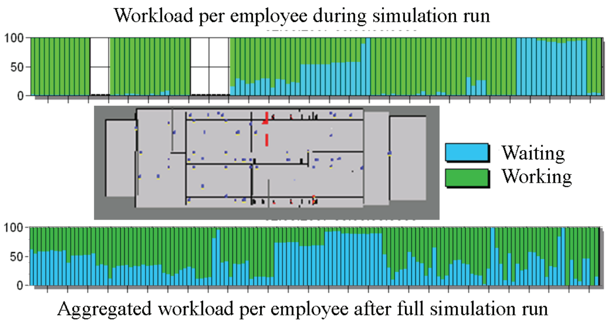

Figure 7: Workload per employee, also represented in the top view of the model, during and after simulation run

The combination of resource performances, comparison of planning with a simulated production realisation and the possibility to trace every part in the simulated production enables searching for reasons for delays and disturbances, which normally are not obvious because of all dependencies in the process. From these, conclusions can be drawn regarding improvements to production planning and resource management (Kaarsemaker (2006)).

4. CONCLUSIONS

Presented is the status of an ongoing development of a simulation aided hull assembly planning tool. Currently, the extended analysis of the "is"-state and the collection of validation data is in progress, these are the most time-consuming activities concerning the creation of a simulation model.

Presented is a basic simulation model of an erection site, which comprises the whole production process concerning steelwork. After adjustment, this model can be used for the erection site (Hardinxveld-Giessendam) under research. Furthermore, the functionality of the model needs to be extended to include the big components that are part of the erection process. With the output that is possible to generate, it is assumed that the model could be fully validated, verified, and synchronised with reality, all extremely important for the success of the model.

The coming half year is reserved to continue the development of the simulation aided hull assembly planning tool. Conversely, because of the results up to now and the experience gained from other simulation projects, it can already be concluded that it is feasible to model hull erection processes on a high level of detail in the form of a simulation tool and that this techniques can be of benefit for the improvement of production control at any shipyard.

ACKNOLEDGEMENTS

Some phrases from Section 3.1 to 3.3 were also presented in Kaarsemaker (2007).

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