Integrated Design and Production Planning for Ship Block Assembly and Construction
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1. Summary

This white paper was originally submitted to The Royal Institution of Naval Architects.

The block assembly process is a critical source of optimization in ship construction. Advanced shipbuilding companies concurrently utilize diverse manufacturing facilities, machines, and production methods to assemble blocks of multiple ships at the same time, in different shops, or across the world. To increase competitiveness and productivity, shipbuilders must rely on flexibility and accuracy of their production planning and scheduling systems. Key considerations are shop and resource management, on-time completion, availability of sequenced sub-assemblies, and readiness of materials to be processed. However, to really optimize the process, the shipbuilder must integrate these considerations directly into the design process.

This paper addresses the utilization of the 3D shipbuilding CAD system, starting with the design phase and continuing through final construction, to manage the collaboration with materials availability, bill of materials management, and scheduling of the block assembly construction process. It will discuss how an integrated system concept can drive both design engineering and production from a single CAD model, and manage progress and workload of complex production facilities like panel or curved block assembly shops that have to handle mixed ship types. Additionally, the paper will look at how a design-to-production CAD model can provide better ways to optimize production accuracy through weight calculation and management, and measurement of the as-built assembly.
1.1. Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>APS</td>
<td>Advanced Planning &amp; Scheduling System</td>
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<tr>
<td>BOM</td>
<td>Bill of Material</td>
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<tr>
<td>PLM</td>
<td>Product Life Cycle Management</td>
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<td>PO</td>
<td>Purchase Order</td>
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<tr>
<td>S3D</td>
<td>Intergraph Smart™ 3D CAD Software</td>
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<tr>
<td>SPC</td>
<td>Intergraph SmartPlant® Construction Management Software</td>
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<td>SPMat</td>
<td>Intergraph SmartPlant Materials Management Software</td>
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<tr>
<td>SPR</td>
<td>Intergraph SmartPlant Review 3D Simulation/Review Software</td>
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<tr>
<td>SPF</td>
<td>Intergraph SmartPlant Foundation e-Engineering Integration Hub</td>
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<td>WP</td>
<td>Work Package</td>
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<td>WBS</td>
<td>Work Breakdown Structure</td>
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<td>WPR</td>
<td>Work Package Review</td>
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2. Introduction

Prior to the existence of parallel or concurrent engineering concepts, the shipbuilding industry formed unique processes which execute design, production planning, and production for hundreds of thousands of parts simultaneously. The basic unit for design, material purchasing, fabrication, and assembling tasks is the ship block, and these tasks and processes must be executed for a block not only consecutively, but also simultaneously, to optimize total production time. This is particularly critical for large shipyards that execute multiple projects concurrently.

Shipbuilding has similarities with plant industries from a product point of view. However, the production processes of shipbuilding are very different, because shipbuilding processes deal with multiple ships at the same time at the work center level. Productivity of the shipyard depends on design and production data to be efficiently generated and properly utilized, using legacy data and standard 3D CAD data to cover basic, detail, and production design, and to deliver data to the production department in a short period of time.

Production planning aims to bridge design and production using 3D CAD data, production scheduling, and production-related knowledge after contracting. Total efficiency of the shipyard is closely related with how a shipbuilding company makes a quality production plan. A shipyard’s competitive advantage comes through evaluation, simulation, and optimization of alternative process design, process planning, and scheduling.

This paper addresses an application of a 3D CAD system, combined with an information management core, which optimizes block assembly from an integrated system perspective and allows large shipyards to effectively manage multiple projects simultaneously. The authors will discuss how the integrated system approach can be applied using the process shown in Figure 1.
3. Key Considerations in Ship-block Production Planning and Process Management

The first step in integrating the design cycle with the production planning and fabrication cycles is to understand the shipbuilding-specific needs for planning, fabrication, and process control.

3.1 Hull Fabrication and Process Planning

Block production can be divided into fabrication units, which include plate and member cutting data and a process for assembling the parts. Manufacturing design information includes the selection of processing mechanisms, machine, jig, and assembly sequence, as well as conditions and parameters for these fabrication and assembling processes.

Block division and shop drawing creation are key components of process planning. The block division involves macro-level process planning for deciding block configuration, assembly base, and process order. Shop drawing creation includes the issuing of working instruction information for cutting/fabrication and block assembling. Shop drawings, profile sketches, nesting information, and bill of materials are some basic deliverables for the manufacturing department to execute their job.

To achieve continuous improvement for these processes, it has become a necessity for each department involved in design, planning, and production to have tools for creating and evaluating alternatives using a 3D product model. The process planning and scheduling system should be integrated for optimized production planning. Application areas using 3D CAD in process planning are as follows:

- Fabrication process data creation through 3D CAD part geometry data.
- Assembly process information creation through 3D CAD part and relationship between parts.
- Scheduling for process planning, considering load balancing among work centers (bays) based on planning time period.
- Selecting and reassigning of block within a bay for load balancing.

3.1.1. Cutting and Fabrication Scheduling

The fabrication process utilizes the exact geometry of a part as generated in the 3D CAD model, along with properties about how the part should be constructed. Properties include the pre-treatment of plates as they are primed for construction, and cutting and bending data of parts that are nested. Additionally, the 3D CAD output provides information about secondary operations such as twisting, knuckling, rolling, and grinding. Load balancing tasks are also needed to optimize efficiency of each work center (bay) by reassigning plates or cut parts to different machines.

3.1.2. Assembling Process Planning

The assembly planning process is composed of decisions required to optimize assembly creation. The decision process is based on assembly unit, assembly method, assembly bay, assembly man-hours estimation, and assembly order selection. Generally, assembly unit and assembly order selection tasks should consider weld posture, weight and size limitation, and minimization of turnover (T/O). Assembly order has two levels: assembly tree hierarchy and assembly order in the unit. 3D CAD can support automatic and manual creation and evaluation of alternatives.
3.1.3. Load Balancing Between Work Centers

The assembly bay (work center) should be selected depending on the assembly unit’s characteristics. Companies normally employ selection rules to decide on the best assembly bay and optional bays based on the bay type (flat or curved block), crane capacity, block size, turnover availability, and weight and gate size. Alternative bay is provided as an option in the case where the best bay’s load is too high, and when the bay allocation must be changed for the blocks. Working time information per alternative bay has to be provided to scheduling system.

A man hour (MH) function covers the calculation of fitting and welding MH for each block. Calculation factors include ship type, attachment type, weld posture, thickness, and welding foot length.

3.1.4. Block Assembly Scheduling and Load Balancing

Block assembly scheduling includes setting, welding, and accuracy checking on a moving bay of flat block or a fixed bay of curved blocks. Usually the bay area is a critical resource for scheduling because block sizes are normally big and bay area sizes are limited in a shipbuilding company.

3.2. Execution Planning

Shipbuilding industry Bills of Material (BOM) are evolving as ship designs (initial, detailed, and manufacturing) have become more detailed. Production schedules are prepared based on estimated material information such as weight, welding length, and joint length of reference ship. However, many factors cause the situation to change rapidly, and it has become imperative that the execution level scheduling should be performed by each workshop’s manager who knows the most up-to-date issues and status in the shop.

3.3. Production Process Control

The goals of production process control are on-time delivery of the contracted ship, optimized resource allocation for the ship construction process, and maximized throughout shipyard facilities. The ship construction process faces ever-changing factors such as design changes, design errors, delay of upstream processes, late arrival of materials, and delay of current processes. The quality process control system has to cope with these kinds of challenges.

To achieve an effective process control system, the work package definition, design delivery planning, BOM activity, and material acquisition date should be frozen. Based on the BOM’s material information, detailed material amounts and unit costs of production can be used to make cost estimations. And finally, efficiency and productivity of the ship construction can be measured by the executed data per work package.

A work package is an optimized management unit for ship construction based on a Work Breakdown Structure (WBS) and is usually decomposed to zone, discipline, stage, and skill for ship construction workers. The work package contains not only the work amount, target man hours, and work schedule information, but also drawings, material, machine, and workers in order to apply scheduling, design, material, and process monitoring tasks. A work package roughly covers one month of work and can be divided into sub-packages of several work steps. Of course, a work package unit may differ depending on the management unit of a company. [1]
4. Integrated Solution for Production Planning

Since the 1990s, computer integrated manufacturing has been applied in shipbuilding. Since the time when shipyards in Japan wrote their own CAD systems, CAD for shipbuilding has evolved and advanced with the availability of information technologies.

In more recent years, shipbuilding companies have begun to employ PLM systems to further optimize their processes. A number of issues remain to be resolved. The following sections highlight those issues and their solutions.

4.1. Assessing Block Assembly Strategy

The ship design process progresses from basic design to the final generation of deliverables. During that design cycle, many factors affect the design and necessitate the ability to make rapid changes to the CAD model. A particular challenge is facilitating change to production planning. The CAD tool can be used to optimize the production process by assessing the following:

- Block and assembly management based on work location.
- Size, weight, and orientation.

4.1.1. Managing Strategy Based on Work Location

In today's design scenario, a ship can be designed in one part of the world and built in another. It is also possible for blocks of the same ship to be built at different shipyards, and those shipyards most likely have different production capabilities and schedules. Therefore, block and assembly size and weight cannot always be defined in advance. Rapid change must be easy.

With the availability of 3D CAD tools that allow for large-scale modification, the ship modeling may begin very early in the design process. In cases where a ship owner oversees the overall design requirements but delegates the detailed design and construction to multiple shipyards, the design process may start before the construction location is known. A sample decision process is shown in Figure 2.

![Figure 2: Assessing block assembly strategy.](image-url)
In this scenario, the basic design is dictated by the ship owner and initial block definition is developed early in the process to start managing split locations. Several shipyards will work on this construction. As the production phase moves closer, Shipyard A falls behind on a different project, and several blocks must be moved to Shipyard B. Using rule-based automation for checking production properties, the CAD system checks the weight of the block versus the capacity of the target workshop at each yard. The following example shows this process.

First, the weight of the block is computed by the software, as shown in figure 3.

![Figure 3: Block weight calculation.](image)

Second, the weight of this block is compared to the weight limit of the primary shop in each shipyard:

- Shop 1 in Shipyard A has a weight limit of 220,000 kg.
- Shop 1 in Shipyard B has a weight limit of 200,000 kg.

When the planner runs an automated rule to check the block weight against the capacity of Shop 1 in Shipyard B, the check provides a warning to indicate that this block exceeds the weight limit for Shop 1 in Shipyard B. Based on this validation, the designer can either move parts out of this block, or modify the block size to meet the weight requirement.

### 4.1.2. Optimizing Cost Based on Physical Properties

Of the many physical properties that can affect the way an assembly moves through the shipyard, size, weight, and orientation have the biggest impact on cost. For example, orienting a block to minimize the number of overhead welds will reduce the difficulty of welding, thereby reducing welding man hours and optimizing cost [2].

The shipyard’s knowledge of construction best practices can drive the CAD system to automatically choose the best orientation and sequence for each assembly, based on rules. For example, the side shell block shown in Figure 4 is analyzed by the software.

![Figure 4: Target structure (side shell) to choose orientation.](image)

The production planner runs an automated rule on the side shell panel to assess the optimized assembly orientation of the panel. Because the primary orientation of this panel is vertical, a large percentage of the welds required to assemble the panel are currently overhead, which makes the welding more difficult. The automated check notifies the user to consider re-orienting the assembly, and the user runs a command to automatically orient the assembly based on the majority of the plates that make up the panel, as shown in Figure 5.

![Figure 5: Finding the best orientation.](image)
Likewise, the software automatically determines the orientation of all assemblies in the block, until the block construction method has been fully optimized. The final orientation is shown in Figure 6.

![Figure 6: Final orientation of assembly.](image)

After the assembly sequencing is known, the weld orientation and length data that are stored for each weld are uploaded to the PLM system and can be used to estimate cost.

### 4.2. Integrated BOM Management

Management of the BOM at various levels of the design is critical not only for optimization of the ordering and utilization of materials, but as an enabler of efficient and powerful integration of design and production.

This section of the paper introduces several important functions among various application fields of integrated BOM management.
4.2.1. BOM Editing and Management

For the last few years, important research of integrated BOM has been conducted. Shipbuilding companies have acknowledged the importance of BOM within product lifecycle management (PLM) implementation, which covers ship design, production, material management, and process control. [3]

A BOM creation and editing capability is one of the main functions needed to facilitate generation of a new BOM from a reference BOM, or from 3D CAD model data, for various purposes. As an example, the BOM editing and comparison function of the integrated design system is shown in Figure 7.

*Figure 7: Multi-BOM viewer between model and BOM, and comparison between system and assembly.*
4.2.2. Nesting BOM Creation and Management

Nesting is the process that makes a connection between raw material (plates and bars) to parts that will be fabricated, as shown in Figure 8. After the manufacturing information has been generated for the parts via the 3D CAD system, and the parts are grouped together on a sheet of plate, the nesting BOM can be generated.

Figure 8: Work processes of parts manufacturing.
XML files of the parts that will be nested are transferred to the nesting system. Subsequently, the nesting system runs the nesting process after grouping parts by block. The process is shown in Figure 9.

*Figure 9: Integrated BOM with nesting system.*
Figure 10 shows the progression of data as it moves from the 3D model to nesting. First, we see the result of 3D CAD manufacturing design for an assembly; the right pane shows the system hierarchy which is composed of deck, shell, stiffeners, etc. The next step in the process is to view the nesting results in a graphical view. Then, the drawings, reports, and final results are imported into the integrated BOM management system.

Figure 10: The model progresses from CAD to nesting.
The integrated system can display nesting information through its BOM management functionality. One of the most important functions of the tool is to run comparisons between different BOM types for the same ship. For instance, the assembly BOM may be compared against the cutting BOM or system (pre-nesting) BOM to verify whether all the parts of the block exist in both BOMs. Figure 11 shows the nesting BOM viewer in the integrated BOM management system, as well as the comparison view between the model and nesting data.

Figure 11: BOM, Model, and Nesting Information Viewer.
4.3. Work Package Review for Production Planning (WPR)

4.3.1. Automatic Creation of Work Package from BOM

Figure 12 shows the tool configuration within the integrated system. As a bridge between the 3D modeling system and construction (production) management system, automatic work package creation, which is managed by the tool, will give users the benefit of substantial time savings.

*Figure 12: CAD – work package creation – work package management.*
Automatic creation of a work package utilizes BOM information, along with routing and work center information, to create the contents of a work package for the plate cutting or block assembly production process. As shown in Figure 13, work packages can be created in batch, and related drawings and documents can be linked to the work package automatically or manually.

Figure 13: Create work package and Autolink drawings.
As a work package management system, SmartPlant Construction (SPC) provides a fully integrated filtering functionality to handle model, parts, work type, work center, and schedules. Figure 14 shows the work package searching function operating on the model.

*Figure 14: Search work packages by model viewer.*
4.3.2. Work Schedule Micro Adjustment Function per Bay Using Work Load Leveling

From the perspective of the workshop manager, there is a need to have multi-project-based work package searching and reviewing functions as illustrated in Figure 15. For example, a panel assembling process line may have blocks from different projects for a given week, and both projects must be considered in the load.

Figure 15: Multi-project work package loading.
The tool supports load analysis and load balancing on a bay and can be set automatically or adjusted manually to achieve optimal bay operation. After importing schedule data from Microsoft Excel, Primavera, or an in-house intermediate scheduling system as shown in Figure 16, the system provides production controllers the ability to micro-manage schedules according to the ever-changing production environment. [4]

Figure 16: Importing schedule information into the work package and adjusting schedule by editing the Gantt chart.
4.3.3. Work Step Definition and Contents

The work package includes information about the components that make up the assembly, and also contains the work steps which are sub-level tasks for the assembly construction process. These include fitting, welding, and accuracy checking. A work step has man hours (MH) as its primary unit of measure and is calculated from CAD and other resourcing data. This is shown in Figure 17.

![Figure 17: Components unfolding for a work package.](image-url)
4.3.4. Progress Checking and Monitoring

If the user enters executed work steps daily for each work package, progress of the whole project, block, discipline, and stage can be calculated and evaluated using 4D simulation and printed reports. Figure 18 depicts the progress of the assembly process with red highlights on two different dates.
4.3.5. Link with Material Management System

The work package also needs to have material information for the plates cutting process, and this is accomplished through the interfaced material management system. The materials system checks the availability of required materials and handles material reservations. With materials information from the complete project execution life cycle residing in a single database, organizations can establish information for quick and effective decision support as well as early warning systems. Figure 19 shows a sample connection between SPC and SPMat.

**SmartPlant Construction:Materials**

![Material Reservation and Availability Checking](image)

**Figure 19: Material reservation with material system.**
4.4. Block Assembly Sequence and Spatial Planning Simulation on Bay

Finally, assembly simulation can be performed using the assembly order selected from the process planning stage. This enables the planner to review and check for collisions, as shown in Figure 20.

*Figure 20: 3D visualization for assembly sequence.*
Spatial planning for ship blocks within a bay is a critical criterion that must be taken into account to utilize work space efficiently, because it directly relates to productivity. The Convex Polygonal Approach is one of the solutions for block spatial planning optimization. [5]

Block location 3D simulation on a bay may be used to verify 2D-based block location setting results. An example is shown in Figure 21. If collision occurs, manual modification of block location or allocation of the block to another bay can be used to resolve the problem.

3D motion simulation with schedule information can check the availability of the solution from the Convex Polygon Approach’s results.

Figure 21: 2D-based blocks spatial planning (sample).
5. Conclusion

This paper shows the potential of 3D CAD in optimizing ship design and production planning. The resulting business advantages are shorter delivery time, more accurate task management, and better control of the production process that is enabled with better information sharing.

Integration of the 3D CAD and PLM system enhances the efficiency of the block assembly process, which can be a bottleneck in most shipyards. The integrated system can more efficiently support the planning and management of ship and offshore constructions, resulting in increased productivity, accelerated project completion, and reduced risk. By seamlessly integrating design, procurement, fabrication/assembly and site materials, the integrated system can facilitate improved planning, efficient information exchange for better communication, and enhanced engineering and construction work processes.

Using current information from various sources such as 3D models, 2D engineering tools, materials management, and project control and scheduling systems, the integrated system ensures accurate and timely decisions can be made from the best available information. All necessary information is factored in to develop precise and flexible work packages to better manage labor and materials in the shipyard.
6. References


