Operation and Management
PLANNING AND CONTROL OF THE "COMPACT SHIYARD 2000"

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Abstract

The shipbuilding of Aker MTW Werft GmbH can look back on a tradition of more than 50 years. More than 350 ships of 27 different types had been delivered. That is a result which is being successfully continued with the modernisation of the shipyard completed in 1998 to the "Compact Shipyard 2000".

In 1998 the MTW started a joint project to develop a prototype of an integrated planning and control system. It will base on the overall concept of the compact shipyard 2000.

With respect to the project results this paper will describe the characteristics of the compact shipyard approach. It will deal with the requirements towards planning and control. The integrated planning and control architecture and the approach of using reference models for planning will be outlined. Finally will introduce the software, which was developed in the project to transfer the approach into action.

The Compact Shipyard

The strength of MTW is the capability to manufacture special and standard vessels like tankers, gas, shuttle and chemical tankers, passenger vessels, container ships, ferries and offshore-components and steel components with outside hull production.

By the modernisation of MTW to the "Compact shipyard 2000" the shipyard has developed into an ultra-modern and productive shipbuilding location of strong competence in the field of technical product innovation. Efficient manufacturing plants and a consistent orientation of productivity according to the world standard have opened the entry to new markets. After a building period of 4 years and with an investment volume of DEM 600 million the "Compact Shipyard 2000" was completed in 1998. (1)

To give an idea of the complexity of the planning and control we will start with a brief technical specification of "Compact Shipyard 2000".

The plate stock is fully automated and controlled and monitored by a stock management computer. The plates are delivered with a degree of cleanliness of 2.5 and in primed condition. (1)

Cutting hall. The code of plates and of the individual parts to be cut is applied by means of a marking station with the help of a master computer. 3 underwater plasma cutting plants (WIPC plants) working with plasma cutting torches with pollutant gas exhausters ensure cutting. The plants are provided with plasma marking devices to apply reference marks and markings as a prerequisite for subsequent assembly processes (accurate manufacture). Plate edge milling machine (CNC or DNC). Plates up to 16 m length are milled to finished size here with the corresponding preparation of welding edge (tolerance ±0.2 mm on 16 m plate length). 3 driverless transport vehicles connect a total of 23 work-stations for the material transport of plates, profiles and completed individual parts on pallets by remote control (control computers for driverless transport system). (1)
Any standard profiles of 16 m maximum length are cut in the profile cutting hall with a profile edge milling machine, two robots with air plasma are cutting plant in DNC operation and corresponding interlinking equipment. Panels and subassemblies are manufactured in the hull component production. The construction of small units from plates and profiles cut as well as small panels serves as a prefabrication station for voluminous unit construction. (1)

Straight and bent panels are manufactured on flow lines in the panel construction hall. Panels and double skin sections up to 240 t weight and 16 m x 22 m dimensions can be manufactured on the 16 m panel line. Voluminous units of flat and bent panels up to 320 t weight are welded in the voluminous unit construction hall. The hall is equipped with a unit turning and transport crane of 320 t as well as 2 assembly cranes of 32 t each and has flexible building sites. (1)

All hull sections are coated to a large extent in environment-friendly procedures in the coating hall. The coating of sections comprises separate boxes for blasting and for cleaning/coating/drying of panels and voluminous units. (1)

The centre-piece of the "Compact Shipyard 2000" is the dock hall with the building dock. The block assembly and final assembly are carried out here. It consists of the areas for block construction and the Building Dock for final assembly work. Block units are assembled in the Block construction area from voluminous units and panels up to a maximum weight of 800 t. In the building dock vessels are assembled from block units equipped beforehand. The trestle crane operating above the building dock has a lifting capacity of 800 t (1,000 t max.) with 143 m span. The dock can be subdivided into two by an intermediate gate. (1)

The basic philosophy of the compact shipyard concept is:

- Innovative ship's concepts
- Roofed production areas
- Short manufacturing times with precise observance of dates
- Short distances in production
- Minimum intermediate storage of sub-products
- Automatic production lines
- Manufacturing meeting quality standards

Planning and control of manufacturing processes, inclusive design and technological process planning, as exact as possible is a pre-requisite to make use of the high potential of manufacturing ships in a compact shipyard. Basis for that is an integrated planning and control system, which covers the preparation and performance of the whole value adding process. The goal is to reach an overall optimisation of the order processing.

Therefore the Aker MTW initiated in 1998 a joint project to develop a prototype of such an integrated planning and control system for the compact shipyard 2000. The project named "PLUS" (Planning and Control System for an Compact Yard) is supported by the German Government. Because of available results of previous work was it possible to keep the project duration within 20 month.

The project partners are:

- Aker MTW shipyard GmbH, Wismar
- Fraunhofer Institute Manufacturing Engineering an Automation (IPA) Stuttgart
- Project Group Rostock of IPA, Rostock
- unique information logistics GmbH, Bremen
- IMAWIS GmbH, Wismar
- Scheller System Technique GmbH, Wismar
The system will serve as common planning and control instrument for all parties involved in the process from strategic company planning to shop floor control. It will also cover the integration of suppliers and co-operating partners. To enhance reliability of plans and to accelerate the planning process a set of measures will be created using as-is-values as input for planning and simulation tools.

The projects main objectives are:

- Development of an integrated planning architecture for the compact shipyard
- Integration of all planning activities for both shipyard recourse planning and customer order management.
- Definition of a hierarchical set of so called reference models for planning, simulation and control.
- Specification and implementation of methods to capture and calculate the actual data for the reference models.
- Specification and implementation of a software tool to manage reference models and their application in planning and simulation.

**Integrated planning and control architecture**

The PLUS planning and control architecture consists of 5 levels.

**Table 1. PLUS Planning Level Description**

<table>
<thead>
<tr>
<th>Level</th>
<th>Area</th>
<th>Object</th>
<th>Horiz.</th>
<th>Goal</th>
<th>System</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perspective Planning</td>
<td>Yard</td>
<td>Ships consisting of big units (Rings)</td>
<td>1-3 Years</td>
<td>Meet customers needs (special delivery date); Dock utilisation Balanced load of resources</td>
<td>GIGROS</td>
<td>Multi-project planning using Reference Modules, Spatial resource Planning</td>
</tr>
<tr>
<td>Rough Planning 1</td>
<td>Halls</td>
<td>Shipbuilding: Sections; outfitting: Big units, systems</td>
<td>1 Year</td>
<td>Meet customers needs (special delivery date); Dock utilisation Balanced load of resources; Minimise Costs</td>
<td>GIGROS</td>
<td>Dynamic, hierarchical network scheduling; Multi-project planning using Reference Modules</td>
</tr>
<tr>
<td>Rough Planning 2</td>
<td>Manufacturing Areas incl. Indirect Areas (e.g. Design)</td>
<td>Shipbuilding: Units; outfitting: Systems</td>
<td>½ to 1 Year</td>
<td>Minimise Performance Costs</td>
<td>GIGROS</td>
<td>Dynamic, hierarchical network scheduling, Multi-project planning</td>
</tr>
<tr>
<td>Detailed Planning</td>
<td>Work-Shops; Design Groups</td>
<td>Shipbuilding: Units; outfitting: Systems</td>
<td>3 Weeks</td>
<td>Meeting internal delivery dates; Balanced Capacity Load</td>
<td>GIGROS: 4PM; SMC-&quot;Panel-Line&quot;</td>
<td>MRP, capacity planning; Material Flow Simulation</td>
</tr>
<tr>
<td>Control</td>
<td>Foreman Areas</td>
<td>Materials from Single Part up to Sections</td>
<td>1 Week</td>
<td>1. Meet schedule, 2. Balanced Capacity load</td>
<td>unique Production Control; SMC &quot;Panel-linie&quot;; 4PM</td>
<td>MRP, capacity planning; Material Flow Simulation; Network scheduling</td>
</tr>
</tbody>
</table>
The approached architecture basis on the concept of hierarchical production co-ordination. In this concept, the harmonisation of production and its activities with respect to time and content is given priority. Customer orders are handled as projects and the simultaneous production processes, their activities and the resource requirements are harmonised with multi-projects in mind. Based on this, a two-layered production co-ordination and control concept was developed. The concept consists of two layers. A decentralised independent planning and control layer for autonomous manufacturing areas (in this case Rough Planning 2 and Detailed Planning). A centralised planning and co-ordination layer (here Perspective Planning and Rough Planning 1). This integrated concept enables the devolution of decision making to the lowest possible level of operational responsibility. Therefore, the planning activities of autonomous production areas are supported by decentralised shop floor monitoring and control (SMC) systems.

![Co-ordination concepts for one-of-a-kind production](image)

**Figure 1. Co-ordination concepts for one-of-a-kind production**

The vertical integration of the planning levels is realised by joining the co-ordination level with the production area control level via closed control loops. This integration process is supported by a revolving planning concept. That means, planning and control activities will be started not by time intervals but by events. In figure 1 the chosen harmonisation approach is arranged in the order of co-ordination concepts for one-of-a-kind production.

**Supporting IT**

The planning system architecture is build out of the following systems (see Table 2).

<table>
<thead>
<tr>
<th>System</th>
<th>Task</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;GIGROS&quot;</td>
<td>Object oriented, hierarchical network planning, Resource planning in a multi-project situation, Project monitoring and control</td>
<td>NT; SQL-Server</td>
</tr>
<tr>
<td>&quot;PS-System&quot;</td>
<td>Material Requirement Planning, Bill of Material, Feedback</td>
<td>UNIX; ORACLE</td>
</tr>
<tr>
<td>&quot;Production Control&quot;</td>
<td>Detailed Scheduling, As-is-data (due dates), Physical work progress, Checklists</td>
<td>NT; SQL-Server</td>
</tr>
<tr>
<td>&quot;Punel-Linic&quot;</td>
<td>Material flow simulation and optimisation</td>
<td>NT; MS-Access</td>
</tr>
<tr>
<td>&quot;RAMOS&quot;</td>
<td>Resource and activity management on shop floor level</td>
<td>NT; SQL-Server</td>
</tr>
</tbody>
</table>
The planning and control of complex manufacturing processes such as shipbuilding requires support of the reuse of knowledge during order processing. Therefore all involved planning systems are designed to handle this kind of information. The concept to gather and reuse such experience and feedback data is called reference modules.

**Figure 2. Approach of Reference Modules**

The reference modules support the planners creating a new planning model by providing them with standard objects. The classification of a reference module is done according to certain product attributes which lead to different process parameters. The reference modules library is a hierarchical set of modules with respect to the common product structure.

**Figure 3. Reference Module Hierarchy**

Therefore the system architecture must also follow an hierarchical approach to be able to make use of the different reference modules of different levels.
The definition of a reference module for a new project is done by, first selecting one from the library according to selection attributes, and then describing it using parameterise attributes. Each reference module is linked to standard planning elements in one or more of the planning systems.

**Table 3. Matching of Reference Modules and Planning Elements**

<table>
<thead>
<tr>
<th>System</th>
<th>Standard Planning Element</th>
<th>Reference Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project co-ordination system &quot;GIGROS&quot;</td>
<td>Project-Version; Capacity Demand; Network; Sub-Network; Part-Network; Activity; Type-Curve</td>
<td>Ship; Ring; Assembled Section</td>
</tr>
<tr>
<td>MRP-system &quot;PS-System&quot;</td>
<td>BOM; Work Order; Accounting structure</td>
<td>Single Section: Panel</td>
</tr>
<tr>
<td>Production Control System &quot;Production Control&quot;</td>
<td>Product-Activity Relations; Work Order Responsibilities</td>
<td>Assembled Section: Single Section</td>
</tr>
<tr>
<td>Shop floor monitoring and Control system &quot;Panel- Line&quot;</td>
<td>Processes</td>
<td>Panel</td>
</tr>
<tr>
<td>Shop floor management system &quot;RAMOS&quot;</td>
<td>Task; Type-Curve</td>
<td>Assembled Section: Single Section</td>
</tr>
</tbody>
</table>

As an example how to use reference modules we would like to describe the scheduling and resource allocation on the perspective planning level of a new ship to build. The responsible planner selects an appropriate reference module for the ship in question using the configuration management of the GIGROS system. This leads to related big units (ring), which then have to be parameterised. According to the selected reference modules the rough planning system creates a project with all its elements.

**Figure 4. Reference Modules and Project Items**

The GIGROS system is designed to handle this kind of hierarchical approach because of its internal data structure. Product data, process data, and resource data are structured in such a way to support the Top-down approach which is typical for one-of-a-kind-production.
The next step is to adopt the automatically created project according to the actual shipbuilding project. Order processing in the shipbuilding industry requires project models with at least hundreds of production activities and their corresponding technological and chronological inter-dependencies. Therefore, the GIGROS Network Editor allows the representation and the definition of a selected project in an activity-oriented network.

Figure 5. Networkplan Editor

In order to guarantee a clearly arranged representation (essentially defined by the number of crossings of interdependencies) an heuristic for the arrangement of activities has been integrated through which the number of crossings are minimised. (2)

With the help of this module the planner adds and removes activities and activity relations or creates new sub-nets to detail the reference project.

After building the project structure it must be scheduled. To cope with complex one has to determine the start- and due-dates for activities. This is supported by our hierarchical network scheduling approach. Activities on higher levels provide time-frames for the sub-nets on a lower level. Scheduling of sub-nets is possible only within this given frame. Thus a support of partially autonomous and decentralised production areas is provided.

The deterministic scheduling is a prerequisite to the consideration of a project in the decision supporting modules. In order to achieve an event-driven production co-ordination, the function "scheduling" can be performed both project oriented and under consideration of the feedback data. If there are project inconsistencies i.e. not allowed loops or time limits the function "fault analysis" undertakes the error search process. (2)
The planning of the new ship also have to consider the resource availability and allocation in the multi-project situation of a shipyard. Capacity demand as well as available capacities are more or less subject to change in course of time. The task of the resource planning is to align capacity demand and available resources. GIGROS supports to determine the availability of resources as well as the estimation of demands and its temporally distribution with its interactive capacity planning module. (3)

![Graph](image)

**Figure 6. Interactive Capacity Planning**

The planner uses the resource demand profiles derived from the reference modules and adopt them according to the actual situation (e.g. decreasing budget because of the learning effect). Analysing functions identify time periods (days, weeks, or months) were critical over- or underloads are occurs.
Whereas the Capacity Diagram supports capacity-oriented overviews and analysis the Dynamic Gantt Diagram offers functionality for time-oriented decisions. The diagram presents each time the production activities of the momentary capacity level, their current time positions, "current" buffers and total buffers. The diagram assists graphically and interactively the shift of activities and the modification of activity duration.

The short example showed, that the planning expert is able to integrate a new shipbuilding project into the yards master plan in short time and reduced effort when using the reference modules.

**Conclusion**

The described approach and the tools developed the PLUS project are currently in the status of pilot installation and testing and the Aker MTW Shipyard. The results so far are very promising because the time to prepare plans and their reliability has increased since the implementation of reference modules. The shipyards management expects the planning quality to be enhanced through this experience and knowledge feedback method.

The crucial point is the clustering of the reference modules and the definition of related planning data. The suitable mechanisms for that are implemented and the quantity of relevant data and therefor the quality of the reference modules will increase in the course of time.

The PLUS project focuses on the scheduling and resource planning. The potential of the reference module approach should be used to enhance the cost budgeting and controlling also.

The same goes for spatial resource planning. In contrast to human and machine resources, production activities can have a two-fold assignment to spatial resources (i.e. production premises such as halls). Between spatial resources and production orders time assignments are necessary such as those between orders and machine resources. An additional assignment is required to fix the location of the order within the production premises. In order to support these kinds of planning activities the Spatial Resource Management Module was developed and unique will enhance it with reference module functions in the near future.

**References**

1. Aker MTW Shipyard GmbH: The Compact Shipyard; WorlWideWeb publication http://www.akermtw.de/Seiten/Art08/MTW_T.htm

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A SIMULATION BASED SCHEDULING FOR AN INTEGRATED HULL, OUTFITTING AND PIPING WORK AT DOCK STAGE

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Abstract

A simulation based scheduling algorithm for pre-erection stage and erection stage has been proposed, in which three dimensional spatial scheduling problem is converted to two dimensional one and thereby two dimensional nesting algorithm can be utilized.

Introduction

In shipbuilding industries, design, process planning and scheduling works are performed concurrently and are highly inter-related as shown in Fig 1.

![Diagram showing the inter-relations among Design, Process planning and Scheduling]

**Fig 1.** Inter-relations among Design, Process planning and Scheduling

In order for the dates of key events such as keel laying, launching and delivery to be kept, the master schedule should be evolves to schedules at dock stage, pre-erection stage block assembly stage and cutting/fabrication stage as soon as practical. Especially those at dock stage and pre-erection stage are necessary to set due dates for assembly blocks. Schedules at dock and pre-erection stage are prepared based on initial design information and the block division.

Scheduling at dock and pre-erection stage involves spatial scheduling problem and has three decision variables:
The locations of pre-erection blocks in the pre-erection area (Spatial Allocation Issue)
The start times and completion times of pre-eresion work (Temporal Allocation Issue)
The resources used by work (Resource Allocation Issue)

Since these three decision variables are highly interdependent, it is necessary to deal with these variables in one framework.

The objectives these scheduling system pursue are due-date satisfaction, maximum utilization of spatial and non-spatial resources and minimization of waiting time. Typical constraints include crane availability, man-hour availability, physical adjacency of coupled objects for operational efficiency and minimum required clearance between blocks.

**Network representation of erection sequence**

In our model, nodes represent erection activities of blocks and arcs are used to represent physical joints between blocks. Therefore the attributes of arcs are joints length and possible status of joints such as fitting, welding or inspection.

Some of the arcs used to represent the sequence of erection are directional and pitch, which is the minimum period of time to accommodate next erection block, is added to attributes additionally. Keel laying activity and launching activity will be added to block erection nodes.

**Erection sequence generator**

The role of erection sequence generator is to determine the directions of directional arcs and to calculate the earliest starting time (EST) and the latest starting time (LST) of erection of each block. See Fig 2.

**Spatial scheduling at pre-erection stage**

Most of pre-erection block which consist of cargo holds have same length and relatively short working period of time compared to those which consist of engine room, after body and fore body. In addition, their shapes are rectangle. Furthermore their orientations are fixed since the Goliath crane has no rotational function. This facts hints us to design bays with same widths to accommodate the length of pre-erection blocks and the spatial load of each bay at a given time can be represented by one variable, occupied length. This simplifies spatial scheduling from three-dimensional problem to two-dimensional one. See Fig 3. As we can see, spatial scheduling problem now converted to two-dimensional nesting problem of rectangles on the rectangular working plates, one dimension is length and the other is time.
Fig 2. Erection Sequence Generation
Nesting strategy

Nesting strategies we adopt are:
-Nesting order is based on not time but area (width x time). It is natural to place a bigger rectangle first.
-Maximize free rectangular space. The concept of the free rectangle set is similar to the prime convex area used for finding a good path in robot path planning (1, 2). For the simple understanding of maximal free rectangular space, see Fig 4, where maximal free rectangular spaces are defined as (R1+R2+R3), (R2+R4+R6-R8), (R2+R3+r4+R5) and (R7+R8).

Scheduling procedure

Scheduling procedure we propose involves the following steps:

Step 1
Generate a erection sequence based on process planner's requests and major milestones imposed by production planner.
Fig 4. An Illustrative Free Rectangular Space

Step 2
Calculate ENT and LNT for pre-erection work based on those for erection and standard working period of each pre-erection block at pre-erection stage.

Step 3
Assign rectangles to the appropriate bay

Step 4
On each bay, nest the rectangles according to the nesting strategies. Whenever the placement has been occurred, ENT and LNT of each shall be updated.

Example

In order to explain the algorithm proposed, let's take a simple example. The process planner determines a block division shown in Fig 5.

Fig 5. Block Division
In addition, \( A_1 \) and \( C_2 \) are assigned as the keel laying block and the final erection block, respectively. Fig 2 shows the initial input network model, where seven erection blocks are modeled as nodes. Joints \( J_{A1B2}, J_{B1B2}, J_{A2B1} \) and \( J_{C1C2} \) are to be directed arcs and their directions are predetermined due to the topological relations.

Joints \( J_{A1B1}, J_{B1C1}, J_{A2B1} \) and \( J_{A2C2} \) are also directed arcs since they represent erection method, which directions will be determined by erection sequence generator.

The constraints imposed by process planner are:
- The docking period is 40 days.
- The latest dates for the constructions of zone 1, 2 and 3 are 30 days, 20 days and 10 days respectively.

Fig 2 shows the proposed erection sequence, where EST and LST of each erection blocks are assigned to each erection block.

Table 1 shows information for pre-erection scheduling.

Fig 6 shows a final result.

<table>
<thead>
<tr>
<th>P.E. Block Name</th>
<th>Size ((L \times B))</th>
<th>P.E. Period</th>
<th>Shortest</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_1 )</td>
<td>22 \times 10</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>( A_2 )</td>
<td>22 \times 18</td>
<td>26</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>( A_1 )</td>
<td>22 \times 10</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>( B_2 )</td>
<td>22 \times 10</td>
<td>17</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>( B_1 )</td>
<td>22 \times 4</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>( C_1 )</td>
<td>22 \times 10</td>
<td>22</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>( C_2 )</td>
<td>22 \times 4</td>
<td>17</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.** Input data Pre-erection stage for Scheduling.

Fig 6. Final Scheduling Result
Conclusion

This paper proposes the way of converting three dimensional spatial scheduling problem to two dimensional one and thereby provides the possibility of minimizing scheduling failure.

References


