A PLANNING AND CONTROL METHOD FOR SHIPYARD PROCESSES:
A SHIPREPAIR YARD CASE STUDY

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Abstract

This paper describes a planning methodology and its application to a repair shipyard. The method includes an hierarchical model of the shipyard's resources and their workload. The model including an assignment logic of the workload to the shipyard's resources has been implemented in a software system. The system simulates the operation of the shipyard and produces a schedule for the resources and a set of performance measures, which enable the user to evaluate the created schedule. A set of scheduling experiments with data coming from a shiprepair yard have been conducted in order to validate and test the approach under different conditions.

Introduction

A major difficulty of planning the operation of shiprepair yards is that between the start and the completion time of the repair work there are typically many work changes which include added, cancelled work and priority changes. Ship repair jobs are often done to a fixed budget and is therefore a "Fixed Cost" exercise. Therefore the major requirement for the planning of a shiprepair yard is the ability to produce quickly a good schedule with a system that is flexible and adaptive to changes of production data.

The most commonly adopted approach to the planning of repair shipyards, is modeling the problem as a resource constraint project scheduling problem. This paper proposes a different approach which is based on an hierarchical manufacturing model, adapted to the characteristics and the requirements of repair shipyards. This approach is proposed as an alternative which may be more flexible and configurable than the rigid mathematical models used in the literature.

The Planning Model of the Repair Shipyard

The work described in this paper is based on the operation of an actual repair shipyard. The Production System of the shipyard to be modeled consists of six sections: the Supervisor Engineers, the Mechanical, the Naval Works, the Riggers & Painters, the Technical Support and the Quality Management Section (Figure 1). The Supervisor Engineers supervise the shiprepair activities. The Mechanical Section involves two groups of fitters with different responsibilities, one group responsible for the interior of the ship and one responsible for the exterior of the ship. This section also includes a group of workers specialized in chemical cleaning, and the two floating docks. The Naval Works section consists of five groups: the platers, the welders, the pipers, the boilers and the carpenters. The

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Riggers & Painters Section includes three groups: the riggers, the painters and the vehicle drivers and operators. The Technical Support Section includes the electricians, the firemen and the people working on the piers of the dockyard and the tugboats. Finally, the Quality Management Section includes the chemist, the foundry of the shipyard and the Quality Control section.

From a planning point of view the important parts of the sections of the shipyard are the docks, the fitters, the platers, the welders, the pipers the riggers, the painters and the electricians. Therefore the modeling and planning approach has been concentrated on these parts which are shown in boldface characters in Figure 1.

![Diagram](image)

**Figure 1.** The sections of the repair shipyard

In this work an hierarchical model with four levels has been adapted to the repair shipyard's planning problem (Figure 2).

![Diagram](image)

**Figure 2.** The four-level hierarchical model
The Factory corresponds to the entire shipyard and includes a number of Job Shops. Each Job Shop consists of a number of Work Centers, which in turn consist of a number of Resources. Job Shops correspond roughly to the sections of the shipyard, while Work Centers correspond, to some extend, to departments of the sections. The Resources included in each Work Center are a sort of "parallel processors", namely they can "process" identical Tasks. Depending upon the assignment logic or dispatching rules, a Task is assigned to one of the Work Center's Resources. In this particular application the term Resource is used for a group of workers who are typically working, according to the shipyard's rules, to a particular Task, from the beginning to the end of the Task.

Figure 3. The model of the shipyard

Table 1. Elements of the shipyard model

<table>
<thead>
<tr>
<th>Job Shop</th>
<th>Process Description</th>
<th>Work Centers</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitters</td>
<td>Fitting Jobs (interior of the ship)</td>
<td>Fitting</td>
<td>8 (each of these 8 resources includes 5 workers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Docks</td>
<td>2 docks</td>
</tr>
<tr>
<td>Pipers</td>
<td>Piping Jobs</td>
<td>Piping</td>
<td>5 (each of these 5 resources includes 4 workers)</td>
</tr>
<tr>
<td>Painters - Riggers</td>
<td>Blasting-Painting-Rigging Jobs</td>
<td>Blasting-Painting</td>
<td>5 (each of these 5 resources includes 6 workers)</td>
</tr>
<tr>
<td>Platers - Welders</td>
<td>Plating-Welding Jobs</td>
<td>Plating</td>
<td>14 (each of these 14 resources includes 6 workers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Welding</td>
<td>9 (each of these 9 resources includes 4 workers)</td>
</tr>
<tr>
<td>Electricians</td>
<td>Electrical Jobs</td>
<td>Electrical</td>
<td>5 (each of these 5 resources includes 5 workers)</td>
</tr>
<tr>
<td>5 Job Shops</td>
<td></td>
<td>8 Work Centers</td>
<td>53 Resources</td>
</tr>
</tbody>
</table>
**Work Release and Assignment**

Corresponding to the facilities' hierarchy there is also the workload's hierarchical breakdown. The Orders consist of Jobs which in turn consist of Tasks. The Orders correspond to the Factory and they are divided into Jobs which are released to Job Shops. A Job, based on its specification, can be processed only by one Job Shop and is thus released to the proper Job Shop. The Tasks that are included in a Job can be again processed only by one Work Center and are therefore released to the corresponding Work Centers. However, the Tasks can be processed by more than one of the Work Center's Resources and the assignment of a Task to a Resource is done with the help either of a complex decision making logic or a simple dispatching rule.

An Order corresponds to the entire work that has to be done for the repair of a ship. The release of Jobs to Job Shops is based on the Job specifications. Similarly Tasks are released to the Work Centers (Figure 4). For example, all the blasting and painting work on the ship is one Job which is assigned to the blasting-painting Job Shop. The Job consists of a number of specific blasting and painting Tasks, such as sand-blasting the ship's hull, painting the hull, repainting the ship's name etc. The blasting Tasks are assigned to the blasting Work Center, whereas the painting Tasks are assigned to the painting Work Center. In each Work Center there are Resources which could perform the same Tasks. Therefore the Tasks have to be dispatched to the Resources according to an assignment logic, using dispatching heuristics or a multi-criteria planning mechanism that formulates and evaluates resource allocation alternatives. An important constraint in releasing and dispatching of Jobs and Tasks is the precedence relationships among them.

The assignment of the shiprepair tasks to the shipyard's resources results in a schedule for each resource of the shipyard and thus a detailed plan and schedule for the critical parts of the entire shipyard is produced.

**Figure 4.** Work release and assignment
Results and Discussion

Software Implementation

The approach discussed above has been implemented in a software system with the help of Visual C++ version 5.0 (Win32 API) and it operates under Microsoft Windows 95 and Windows NT on a PC.

The system allows the user to construct an hierarchical model of the shipyard's facilities and their workload. The facilities model includes the definition of the Factory, the Job Shops, the Work Centers and the Resources. The user "fits" the workload model to the factory model, by specifying the Orders, the Jobs and the Tasks. Furthermore, the system allows the user to specify which Resources are suitable for performing each Task, the precedence relationships, the processing times and the set-up times. The system could include information on the cost for performing each Task and the processing quality. The graphic user interface is menu-driven, with win32 dialogues for guiding the user through the modeling process (Figures 5 and 6).

![Figure 5. System's user interface: Facility data input screen.](image)

A simple coding scheme could be used (based on the practice of the yard) for specifying the elements of the facilities and the workload model. As an example for the purpose of this work, the Pipers section is modeled as a Job Shop named JSPIPER, including one Work Center named WCPIPER which includes five Resources named RPIPER-xx where xx takes values from one to five. The workload for the Pipers' Job Shop consists of one Job named JBPPIPER which includes three Tasks: TP3110, TP3800, and TP3801. The four-digit numbers in the task codes are the actual codes
used by the shipyard modeled in this work.

The system uses event driven simulation to simulate the operation of the shipyard and the execution of the workload by the shipyard's resources. The simulation mechanism releases the workload to the Job Shops and Work Centers, respecting the precedence relationships which are defined by the user. In each Work Center an assignment mechanism decides which Task is going to be assigned to which Resource. Consequently, a dispatching decision is required when a Resource becomes available for processing. The assignment mechanism allocates the available Resource to a pending Task. The system simulates the operation of the production facilities either for a certain period of time (user specified) or until all the Tasks have been processed by the Resources. In either case, a detailed schedule for each Resource is produced in graphic or alphanumeric format (Figure 7).

The user has the option to select among a set of dispatching rules (Figure 6) and a multiple criteria decision making method. Furthermore, the system has the ability to consider planned maintenance in the production schedule and unexpected interrupts such as resource failures, which are statistically simulated. The schedule produced can be used for the planning of the activities of the shipyard.

![Policy File: Heurist.pol](image)

**Figure 6.** System's user interface: Selection of dispatching rule.

In case of a change on the workload or on the status of the facilities of the shipyard, the user can feed the system with the new data and reproduce an updated schedule and plan. Since a simulation run for a planning horizon of a few months takes a few minutes, it is very easy for the user any time that something unpredicted occurs, to reproduce efficiently an updated plan for the entire shipyard.
Figure 7. Schedule produced by the system: a. Alphanumeric format, b. Gantt Chart format

**Experiments and Results**

A set of experiments have been conducted in order to check the model's feasibility and produce realistic schedules for the repair shipyard. The quality of the schedule can be evaluated by the user via a set of performance measures, which are calculated by the system based on the produced schedule. The performance measures include job flow time, job tardiness, number of tardy jobs, capacity utilization etc. The job-related performance measures are calculated for each job and as mean values for all the jobs included in the entire workload. The capacity utilization is calculated for each Resource and as a mean value for each Work Center, Job Shop and the entire Factory.

For the experimentation a set of orders with different arrival times has been defined. The job due dates for the experiments have been calculated as follows:

\[ DD = A.T + k \times P.T \]

*Where* \( DD = \) Due Dates

\( A.T = \) Arrival Time

\( k = \) Constant

\( P.T = \) Processing Time of the Job

The constant \( k \) equals to \( k=1.3 \). This value of the constant results in a set of relative tight due date for the jobs. For the processing times, work and facilities related data were received from the shipyard.

A number of dispatching rules have been used for the experimentation with the model. The rules were applied for the allocation of Resources to pending Tasks for each Work Center. Each experiment includes one simulation run with the same facilities and workload data but with a different dispatching rule. Each simulation run produces a particular schedule and a set of performance measures specific to this run (Figure 8).

As was expected the EDD rule produces very good results for the mean tardiness, but performs poorly with respect to the capacity utilization. The SPT rule on the other hand, performs well with regard to the utilization. An interesting observation is that the EDD and FONPR rules produce similar results for most of the performance measures. This can be explained, considering that most of the jobs have comparable processing times and, since their due dates are calculated as functions of their processing times, the jobs with the fewer operations are the ones with the tighter due dates. Therefore the two rules result in similar assignment patterns.
**Dispatching Rules**

EDD: Task from the Job with the earliest due date is selected.

FIFO: Task from the Job which first arrives at the factory is selected.

SPT: Task from the Job with the shortest processing time is selected.

MOPNR: Task from the Job is selected which has the most operations remaining to be performed.

FOPNR: Task from the Job is selected which has the fewest operations remaining to be performed.

**Performance measures**

**MEAN TARDINESS:**

\[
MT = \frac{1}{N_{\text{comp}}} \sum_{j=1}^{N_{\text{comp}}} \max \left[ 0; T_j^{\text{comp}} - T_j^{dd} \right] 
\]

\[
= \frac{\sum_{j=1}^{N_{\text{comp}}} \left( T_j^{\text{comp}} - T_j^{\text{start}} \right)}{N_{\text{comp}}} + \sum_{n=1}^{N_{\text{inp}}} \left( T - T_{n}\text{start} \right)
\]

**MEAN CAPACITY UTILIZATION:**

\[
MCP = \frac{\sum_{j=1}^{N_{\text{comp}}} \left( T_j^{\text{comp}} - T_j^{\text{start}} \right)}{I \cdot T}
\]

where

- \( N_{\text{comp}} \): the number of completed Tasks
- \( T_j^{\text{comp}} \): the completion time of Task \( j \)
- \( T_j^{dd} \): the due date of Task \( j \)
- \( T_j^{\text{start}} \): the start time of Task \( j \)
- \( N_{\text{inp}} \): the number of in-process Tasks at time \( T \)
- \( T_{n}\text{start} \): the start time of the in-process Task \( n \) at time \( T \)
- \( T \): the time at which the performance measure's value is calculated
- \( I \): the total number of Resources

**Figure 8.** Experimental results: Mean Tardiness and Capacity Utilization vs dispatching rules

**Conclusions**

The results of this work show that the method applied to the planning problem of the repair shipyard produces adequate and easy to use results. The method requires the modeling of the shipyard's facilities and workload with the help of an hierarchical model. The results show that depending on the dispatching rule used a schedule with different performance measures is produced. Thus the user can select the appropriate rule in order to produce a suitable plan.
References

SHOP FLOOR CONTROL IN A PLATE CUTTING AREA

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Abstract

The paper describes the information system for handling all steel plates through a cutting area at ODENSE STEEL SHIPYARD. During the last years OSS' robot cell control system, ROB-EX, has been transferred to all automated and manual processes in sandblasting, primer painting, plate marking, cutting and sorting processes including material handling between operations. Equipment in numerically controlled processes are linked to a shop floor control computer for data exchange with machine programming systems, and manual processes use wireless terminals with bar-code equipment for distribution and collection of information on the shop floor. The paper describes the information system which is located in the workshop and describes how it is used step by step in the plate cutting factory logistics. The shop floor control system handles all transactions involved in producing steel elements, i.e. it supplies production information for each element in each processing step and it registers each element as it passes through an operation. The system also automatically updates the production management system with status information from the workshops and it generates production reports about machines and parts. The implementation started a few years ago and now the complete system has been running in production for more than one year with good results. The benefits achieved is a more accurate planning and control of the operation on a horizon of one or two shifts. The results have been achieved without creating extra production management procedures, and even by eliminating some procedures. The system not only provides benefits for the area it controls and monitors, but also the assembly areas, which receives plates form the cutting area, are now able to check the status of each individual element on-line. The system has been developed by Odense Steel Shipyard and The Technical University of Denmark.

Introduction

Background

This paper describes development of information systems for the shop floor. It is a further development of the introduction of automated production facilities at ODENSE STEEL SHIPYARD. Computer applications for ship design and planning are now widely used by many shipyards and numerically controlled machines and robots are a natural part of some production workshops.

In the present context, some information systems today found in shipyards are of particular interest. Machine programming systems, or off-line programming systems, generates information for e.g. cutting machines and for welding robots. The information, including NC-programs and additional data needed for the production, is generated on beforehand, according to the production plan, and stored on data servers for later distribution to individual machines.

Another type of application of special relevance in this context is the production planning and management system. It specifies the production orders for each workshop including which input
material is used for producing output parts. In addition it registers the status of all raw material, elements and assemblies.

These two types of systems have in common the dynamic exchange of information with the production activities on the shop floor. Depending on the parts being produced they deliver the data for the numerically controlled processes and they receive information about completed operations.

This paper focuses on information systems on the shop floor. One of the tasks of the information systems on the shop floor is to establish the interaction with the two types of systems described above. In addition the information systems on the shop floor shall support shop floor operations, i.e. support the production activities in the workshops.

The need for shop floor information systems

The need for information handling on the shop floor includes two main functions. First each workshop needs to interact with its surroundings and secondly the operation of each workshop can be supported by computer applications for managing and carrying out activities. Operators and foremen must retrieve the data they need for the current or upcoming production shift and they need to distribute data to individual machines. During the production run they need to collect information and generate reports for local use or for registration in a central production management system.

In a large production facility like a shipyard, and with a large number of unique parts being produced by different workshops, it can be difficult to obtain the actual status regarding each part. However, in many situations it is crucial for the planning and operation of one workshop to know the status of material produced by other workshops.

The approach for accommodating the needs

At ODENSE STEEL SHIPYARD, over a 6 year period, we have introduced so called cell control applications in different areas of the production. A system called ROB-EX has been developed originally for welding robots but has now also found its use for cutting machines and other automated and partly automated processes. Each cell controller is connected to the production management system. Since not all processes are numerically controlled, a bar-code system has been introduced for manual production processes. This is complementary to the cell controllers in order to collect data from all processes in the plate cutting area. Today the result is, that the status of all elements is collected by cell controllers and bar-codes and made available on computer terminals in the workshops which will be using the elements to produce assemblies.

The ROB-EX Cell Control system

The shop floor control system described in this paper is constructed by several cell control systems. Each cell control system serves an area of the production and thus includes functions which are mainly used locally. These functions will be briefly outlined in the following. However, the main topic in this paper is the effect reached by introducing several cell control systems in the production which will be described after this section.

Functionality of a ROB-EX cell controller

Each cell controller can link operators and machines to other areas and departments in the company. It provides information which is needed in the workshop. Also functions are needed in the workshop in order to enable local decision making. As an example, the production during one shift.
involves many NC-programs to be executed on several machines. In this case the cell controller assists
the operator to decide the allocation and sequence of jobs to the individual machines and it transfers
the right NC-programs in the right sequence to each machine. In the event that it is necessary to
change the allocation and sequence, this is easily done on the cell controller.

During the operation the cell controller automatically registers events by each machine. A
machine log is created for extraction of different reports as well as some of the event may immediately
be forwarded to e.g. the production management system.

The technology elements in a cell controller

A cell controller is constituted by several different technologies. The cell controller is
connected to different host systems and to the production equipment. For the communication, local
area networks are used as well as different types of production equipment interfaces.

The cell controller uses a database to manage large amounts of production data. Often it also
connects to other databases, e.g. it can be directly connected to the database of the production
management system.

The cell control system is used by operators and foremen in their daily work. Therefore the
user interface is based on either graphic terminals placed in the workshop or handheld computers
which are wireless connected to the network.

The cell controller may contain calculation programs for e.g. machine calibration. In general it
can be used for any type of information processing or analysis which is needed on the shop floor.
Typically the operator needs some analysis or calculation in connection to the daily work, or a large
amount of data is collected and analysed on the shop floor, and only the analysis result is forwarded to
other departments.

The cell controller can also be used for manual and automatic control of production activities.
E.g. some operations for setting up a machines and downloading the NC-program may be completely
automated or the cell controller can be used for manual remote control of several production
machines.

Not only production equipment is found on the shop floor. Different types of identification and
measurement systems may also be found. Therefore the cell controller also integrates e.g. bar-code
systems and vision measurement systems.

The users of cell control

The philosophy of ROB-EX cell control is to make a system for the shop floor workers. It is a
system specifically made for operators and foremen, see Figure 1.
Figure 1 The ROB-EX cell control systems is used by operators in the workshops

Results achieved with cell control

The ROB-EX cell control system has been in use at ODENSE STEEL SHIPYARD and other shipyards for several years. The first version was installed in production in 1993. Since then new functions have been added as well as new computer platforms and production processes are supported.

The system has brought several benefits to the users. First of all the cell control systems have enabled local decision taking and increased the possibilities for local action taking. By collecting information automatically the operators use the cell controller to form a general view of the situation very rapidly. In effect they are able to make decisions right when it is needed and based on the right information. Furthermore, the functions on the cell controller also mean that carrying out the new actions, following the decision, is done very rapidly. The cell controller assists the workers in the workshop to achieve high responsiveness to changes and disturbances. As a result, they are able to make the reality meet the goals due to the increased manoeuvrability.

The result can also be seen on the increased utilisation of production equipment in a production environment where many different parts are produced, a significant fraction of time is used for changeover and setting up for a new production run. By quickly arranging and starting the work, the cell controller is able to make more efficient use of the equipment. A cell controller may in some degree be an alternative to investment in new machines and production space due to increased utilisation of existing equipment.

Finally, one of the consequences on introducing cell control on the shop floor is that the operators become more involved in the complete production process - which in itself has a positive effect on productivity and quality.

Further developments of cell control

The ROB-EX cell control system is a result of development by ODENSE STEEL SHIPYARD and by a research collaboration with The Technical University of Denmark. This approach combines a practical side with a theoretical side - and we continue to use an approach where academic research and industrial development joins efforts in the realisation of new systems. ODENSE STEEL SHIPYARD works with universities on improving the cell control applications and also in new areas such as the coordination between multiple production cells.
Deployment to other processes

The development of ROB-EX cell control started in connection with welding robots. ROB-EX means: robot execution system. Its main task was to support the execution phase of the robots in the production when the planning and programming had been performed in the technical departments.

The new processes

These so-called new processes was only new with respect to cell control. The production had been using numerically controlled equipment for plate and profile cutting for years. From 1995 to 1998 the ROB-EX system was introduced in the plate and profile cutting area at ODENSE STEEL SHIPYARD.

However, this area contained also a number of manual processes for post-cutting operations and material sorting. Therefore a new bar-code system was introduced in all non-numerically controlled operations for data collection.

Material flow management and monitoring

The introduction of cell control and bar-codes in the plate cutting area took place over a period of time. During this period the systems were mainly used for distributing NC-data to each machine or machine group and for generating production reports. Similarly the manual operations used the bar-codes for reporting progress of the production.

The manual operations and the numerically controlled operations are interconnected in terms of the material flow. The steel passes through several of these operations. Once each operation is equipped with either cell control or a bar-code system it is possible to monitor the progress of the steel on its way through the operations.

The plate cutting facility at OSS

The plate cutting area is producing steel plates and profiles for several assembly lines, see figure 2. It is receiving raw plates and profiles from the steel stockyard and it produces elements which are delivered in a sorting area or directly to the assembly lines.

The elements produced in the plate cutting area

The elements produced in this area are all contours which are cut out of the raw steel plates from the steel suppliers. Out of each raw steel plate one or several elements are cut. Figure 3 shows a typical element. Note that the element also contains a marking consisting of an identification code including a bar-code.
Figure 2 Plate cutting area

Figure 3 A plate element produced in the cutting area
The processes in the plate cutting area

The processes and the material flow of the plate cutting area are shown in figure 4. The diagram shows the main processes only. In total the area includes some twenty processing stations.

Figure 4 The main material flow and processes of the cutting area

Steel from stockyard → Material entry → Cutting → Post cutting operation → Sorting → Elements to assembly areas

Cutting

Figure 4 shows how the steel from the stockyard passes through a steel entry line and continues through one or more cutting machines. Some elements must pass through a post cutting operation. Eventually the elements ends up in the sorting area. From the sorting area the material is delivered to the assembly lines.

The steel entry line consists of several steps. First the steel plates are sand-blasted and surface treated with primer paint. Following that each plate is marked with identification code and a bar-code. Finally the plates are transported and stacked automatically to an area where they can be picked up by cranes depending on the cutting process the plates must undergo.

The cutting operations are manually or numerically controlled and the process used is either plasma or flame cutting. During the cutting operation the elements are marked with new unique identification codes including bar-codes. Figure 5 and 6 shows the cutting machines.

Some elements have to undergo post cutting operation, either because the cutting machine was unequipped to perform the complete process or because the process failed. The post cutting operation includes additional cutting or machining. Finally the elements are gathered and sorted by assembly in the sorting area.
Figure 5 Numerically controlled plasma cutting of plates

Figure 6 Manually controlled cutting machine
Information system overall architecture

This section describes the main systems involved in the shop floor control. Figure 7 identifies the systems and shows how they are connected.

Production management system

The production management system holds a record on each element and assembly of the ship. It also defines that elements are cut from raw plates and that the elements are joined in assemblies. The production management system defines the process plan for each element. Similarly it can keep track of the status of each element.

Off-line programming

The off-line programming system generates NC-programs for the cutting machines. The NC-programs may be executed on different machines, however special post processing of data from the off-line programming system may be required for certain machines. The NC programs generated also contains data which controls the marking equipment mounted on the cutting machines.

PC for reporting

From any PC on the local area network it is possible to obtain production reports from the plate cutting area.

ROB-EX Cell Controller for numerically controlled machines

The ROB-EX cell control system has already been described in an earlier section of this paper. The control system for the plate cutting area described in this paper involves two cell controllers. One cell controller is used to control the steel entry line and another is used to control all the cutting machines. Each of the cell controllers are connected to the equipment for direct communication with the equipment controls.

The bar-code system

The bar-code system consists of a base station and a about a dozen bar-code terminals. These terminals are battery powered and are using wireless communication to connect to the base station. The handheld terminals consist of a visual display, a small keyboard and a bar-code reader.
Figure 7 Information system overall architecture

Operation scenario

This section demonstrates a typical operation scenario of the cell control and bar-code applications in the cutting area. It explains how the systems, described above, work in different stages of the production process, also described above. The description focuses on how different transactions are handled by the cell control and bar-code systems as the steel passes through the processing steps.

Steel entry

The foreman uses the cell controller to define a list of plates to be introduced from the steel stockyard to the cutting area through the steel entry line. The cell controller keeps track of all the plates currently being processed on the entry line.

At this stage each plate is identified and the cell controller for the steel entry line automatically notifies the cell controller for the cutting area that plates are on their way. Then, the cutting cell controller automatically retrieves the NC-programs needed for each of the plates. In this way the cell controllers collaborate and coordinate activities according the actual status on the shop floor.

As the steel undergoes sandblasting, primer painting and marking with identification code, the cell controller makes sure that the processes are adjusted to each plate and that the plate is marked with the correct identification code.
Finally the cell controller also supervises an automatic material handling system, and it controls
the automatic delivery from the steel entry line to a certain position in the cutting area, depending on
the further processing.

At this stage the plates are changing status from being ‘in stock’ to be ‘ready for cutting’. This
is automatically reported to the production management system which then can generate reports on
the status of individual plates or on the total amount of plates entered to the cutting area over a period
of time.

**Cutting**

The plates are transferred from a plate stack to the cutting machine by crane. The plates are
identified by the code applied in the steel entry line. According to the plate identification the NC-
program for cutting the plate is transferred automatically from the cell controller to the cutting
machine controller. The cutting process may now begin. The cutting machine is equipped with
marking equipment and during the cutting process the raw plate is marked with new identification
codes for each of the element cut out if the raw plate.

The cell controller continuously monitors all the plates being processed on the cutting
machines and the progress of the work. Once a raw plate has been cut into one or more elements the
cell controller automatically registers the completion. At this stage, the raw plate no longer exists and
may be marked as such in the production management system. Instead each of the elements cut out of
the plate are now registered as having completed their first operation.

Some of the elements just produced have post cutting operations to be performed. Either
because the process plan requires that they undergo manual processing after cutting or because the
cutting process failed and the element must be reworked or repaired. In this case the bar-code systems
is used to identify these elements and register their next operation.

**Post cutting**

Typically the post cutting operation is a manual process. Therefore the bar-code systems is
used for data collection. Once the post cutting process is completed each element is identified and
registered as completed in the production management system.

**Sorting**

After the elements have been produced they are gathered in the sorting area. Elements are
sorted by assembly. Once all the elements for a particular assembly are checked in the sorting area by
bar-code, they are registered as ‘ready for assembly’ in the production management system. At this
stage the elements are ready to be transported to the assembly areas.

**Production reports**

Throughout the process described above the cell controllers and the bar-code system collect
information on each element as they pass through the operations. The collected data is stored in a local
database on the cell control system. Some of the information is immediately reported also to the
production management system.

The collected information is used to produce production reports of different type. Typical
reports contain information about the number of plates processed by a machine or a group of machines
over a specified period of time. The foreman responsible for a machine group needs to know the
amount produced on his machines during his shift, whereas the production manager typically want a
day-by-day report with a weekly summary of the total production.
Other reports may be used to analyse the logistic in terms of work in progress levels and lead-
time of the elements. Also the quality performance may be indicated by the number of redirected
elements to unplanned post cutting operations.
In terms of the machine utilisation the collected data also shows the distribution of work
between the individual machines and the accumulated processing time of the machines.
Finally, specific enquiries on particular elements are possible. Perhaps an operator want to
locate an element or want to find out which machine produced the element.

Benefits achieved by using the shop floor control system

The introduction of the shop floor control system described in this paper has had a significant
impact on the daily operation of the cutting area. In addition the system has also provided a much
better service for the areas which receives the elements produced in the cutting area.

Benefits for the operation of the cutting area

One main benefit achieved is the automatic data collection and report generation. Without
adding any extra work procedures (actually some manual procedures have even been eliminated) a
number of high quality production reports are now created automatically. In addition these reports are
generated immediately as events in the production occur. The presence of detailed information with no
delay provides a good base for more efficient management of the plate cutting area.

As an example, it is very easy to keep track of work in progress, element by element, and
based on that decide on how to organise the production activities within a shift. And during a shift it is
possible to see the status and progress, take action accordingly and see the result in the reports.

The shop floor control system has also been able to eliminate some paper based procedures by
handling the information electronically. The electronic handling of the data also mean that more
flexibility is achieved e.g. in re-distribution of NC-programs between machines when production
changes require cutting operations to be moved from one machine to another.

Benefits for the assembly areas

One major benefit for the area which receives elements from the cutting area is that the
responsible foremen in the assembly areas can be notified immediately when the elements are
produced. Elements needed for a particular assembly are reported ready in the sorting area without
delay. Furthermore, the foreman can also check for each element, i.e. find out their progress in the
cutting process and thus take the actual status of the material into account when planning the assembly
operations.

This feature of the shop floor control system saves time for the preparation of the flowing
assembly operations because they very quickly can obtain the information they need about the
elements for each assembly.

Conclusion

This paper has described an information system for control and management of production
activities on shop floor level in a plate cutting area at ODENSE STEEL SHIPYARD. The shop floor
control system handles the exchange of information between the shop floor and the technical and administrative systems. It also supports the operation on the shop floor.

The shop floor control system is built up by several cell controllers, as used by e.g. robot cells elsewhere in shipyards. By using the same concept and open technologies it has been possible to reuse the technologies from the robot systems. For the same reason it has been possible over a period of time to build a highly integrated and homogeneous system.

By combining several cell controllers and a bar-code systems a shop floor control system covering the entire plate cutting area has been established. The results achieved are increased efficiency in the plate cutting activities and less disturbances in the coordination of the delivery of steel elements to assembly areas.

Acknowledgements

This paper has described a highly integrated information system constituted by many contributions. Therefore the author wishes to acknowledge colleagues from the Cell Control Centre of the Automation Development Department at ODENSE STEEL SHIPYARD which by their expertise in different technologies have played an instrumental role in the realisation of the cell control and bar-code systems described in this paper.

Also colleagues from the company Maersk Data who are involved in the off-line programming of cutting machines and the local area network installation, and colleagues working with the production management system are acknowledged for their role.

Finally, the users and production management who initiated and supported these developments are acknowledged for their role.

References


Rationalization in Shipyard Industry and Equipment Engineering

It can be observed for quite some time now that strict realization of technical innovations in working processes and tools contributes greatly towards rationalization, which in turn affords significant competitive advantages for both shipyards and shipyard suppliers.

In the field of Pipe production, integration of design, preparation, fabrication and installation has furthered great potentials in saving costs and finally led to "industrial" prefabrication of pipelines.

The success of such efforts has become visible now and the experiences gained can be evaluated and summarized as follows:

The consequent integration of virtually all working processes for realization of a pipeline system, whether it is in the field of shipbuilding, in chemical or petrochemical plants or in underground installed supply lines, is the decisive way towards rationalization. To this end, computer-aided data processing systems are equally important as direct processing tools.

Nature, extent and the time of data collection play an important role with respect to the cost-saving potentials. This applies in particular to equipment engineering, a field that is yet dominated by handicraft.

**EDP systems suitable for shipyard industry and equipment engineering must:**

1. start early in the production process and
2. be easy to operate and
3. be of sturdy design and
4. be able to store data strictly structured and
5. be flexibly adjustable to changing requirements and
6. be based upon accepted and future-oriented standards.
The fundamental configuration of a system can be derived from these requirements:

On Site  Work Prep.  Design

Production Control

Pipe Production / Prefabrication

PPC System,
Accounting Sys.,
Material management,
others

This system is realized by the PipeFAB- Productfamily!
IsoFAB

Software Isometrics: Easy, fast and wherever you want!
- The Straight Way To Create Isometrics!

One way is the automatic production of pipeline isometries from a constructed product specimen by means of a CAD system and the subsequent processing of data in PipeFAB.

But the immediate computer-aided input of the Pipe course by the designer is frequently required.
**IsoFAB supports the design by**
- very easy and fast handling
- complete independent in use
- automation of routine functions
- direct database support
- with PipeFAB automatic creation of all fabrication data inclusive material- time- and cost information

**IsoFAB - functions (Windows Version)**
- Sketching of non-scaled isometry by clicking pixels with the mouse within a pre-selected drawing frame, or by direct input of coordinates.
- Assignment of Pipe class, diameter and semi-finished products by selection from the components data base.
- Insertion of fittings and other components by selection from the data base, and clicking the point of insertion with the mouse.
- Completion of isometry by semi-automatic dimensioning of lengths and angles.

**In addition**
- Processing the display by Zoom / stretch and compress functions.
- Insertion of auxiliary geometry by drawing with the mouse
- Completion of text with or without relation to individual elements of isometry
- Input of additional information (name of operator, date of preparation etc.)
- Automatic sectioning of line isometry into single isometry

IsoFAB is available with the waterproofed and shockresistant UniDAT OutdoorPC. It can be used in all conditions on site.

**PipeFAB**

**Workflow Management For Pipe Production – Creation Of Isometrics, Calculation Of Production Costs And Management Information**

PipeFAB was developed to rationalize the application and organization of production data for piping systems. All information are held in a relational databases. Pipe geometries are keyed in or taken directly from a CAD system: everything else is done virtually automatically. Connections to NC machines are available.

PipeFAB organises your materials and working times, calculates costs and provides our workshop with all the production documents required.

PipeFAB can not only be integrated into existing CAD and PPC systems, but also functions fully independently.
Fabrication in the part lists, sawing and flame cutting lists, bending lists, working schedules, manufacturing lots, disposition lists etc. are made available at the outputs. A bending collision check is carried out. All outputs are also available as machine-readable files.

PipeFAB makes the main functions, and in particular those for preparation and output of manufacturing data available in a complete system.

A calculation of all costs of material and production time is done!

While information on material and geometry is first linked in a data base with IsoFAB or an integrated CAD system, these linkages are evaluated by PipeFAB.

IsoFAB is usable being a stand-alone system and offers all functionalities for creating isometries founded on the database. It also includes the data transfer to PipeFab and printing of the bills of material.

PipeFab is usable being a stand-alone system too and includes the entire functionality of IsoFab. In addition to that PipeFab offers all logical conditions for fabrication (working processes and organisational processes, advance times, prices of material and times, available machinery, order and optimization criteria, information on tools etc.)

PipeFAB contains all logical requirements of the production process (workflow information, working times, available machines, criterias for optimization, tools information and many more). All needed results are created automatically by calculations on the base of these informations and catalogues.

As a result all required data are to be printed out as lists or NC programs.

**The Data Base**

According to program technology, all modules of the FABRICATION product family are based upon a relational data base (preferably ORACLE), where all required information is stored.
The PipeFAB products are prepared to be integrated with all other ORACLE-based applications. This is the more important, the more comprehensive the existing EDP environment (PPC, CAD, accounting software etc.).

**Utilization of existing data**

If a relational data base if already available, it is possible to connect all PipeFAB modules directly. Any missing partial information can be subsequently added if required.

It is a rule that almost any enterprise holds great parts of required data available: They are stored in different formats (ASCII, text files, Excel tables, Word documents etc.) are distributed over a number of departments/workplaces, or they are stored in different data bases.

Experience has shown that by far the greatest part of these data can be automatically transferred into the relational data base by means of minor auxiliary programs.

Such auxiliary programs (scripts) are, in part, already available, or they can be easily established and adapted to individual requirements by CARETRONIC or by a staff member of the enterprise (system administrator).

Every kind of material catalogue can be transferred to the database. Customers pipe class definitions can be integrated. All information of customers catalogues (material, fittings, identification numbers, prizes and many more) are useable.

PipeFAB is prepared to read the IsoFAB data and to calculate the complete range of fabrication data of these isometrics.

**3D Measuring And RoboFIX Are Parts Of**

**The Overall Strategy Of The PipeFAB System**

**Advantages of the method are:**

- Considerable savings in time because repeated transports between plant and workshop are no longer necessary
- The preparation of production models (basket, box, wire) can be dispensed with
- Saving of the entire material for the preparation of models (avoidance of scrap)
- Continuous and consecutive processing of any number of pipes on board ship and direct data transfer to the workshop
- Inclusion of the fitting pipe data into the shipyard's general EDP processing (material management, time, costs, etc.)

**Result:**

1. Considerable rationalization in the complete pipe production process
2. A speedy return of investment realizable already after having built less than 3 ships
3D Pipe Measuring

Treatment Of Fitting Pipes

As is the case with any type of fabrication, it can happen in the fabrication of piping systems that the manufactured and assembled system differs from the theoretical design. This may result from dimensional inaccuracies in pipe production (sawing, welding, bending, flanging, etc.), installation, as well as from the environment of the system (walls, ceilings, foundations, etc.).

As a rule, so-called "fitting pipes" are provided to compensate the overall dimensional inaccuracies by summing up all individual tolerances. Their task is to compensate differences between the design and the reality of a piping system. To this effect, their geometry is determined taking into consideration the real conditions in the ship. This means in fact that the course of the fitting pipe is only determined after the remaining part of the piping system has already been manufactured and fitted.

In principle, there are several methods available for the processing of fitting pipes.

The pipes already designed are:

- manufactured on site taking real conditions into account. Should documentation be required, it will be prepared subsequently on the basis of the sketches and charts established on site,
- manufactured in the workshop according to a model made in the plant, and documentation is prepared subsequently,
- prefabricated following manual determination of the situation in the plant and input of the data into the EDP, and being provided with extra length, adapted in the plant and completed. Here, the "as built" documentation is prepared subsequently as well,
- directly corrected to the dimensions which are automatically determined by means of 3D measuring and integrated into the normal process of workshop fabrication. The required documentation is prepared automatically.

State Of The Art

Until now it has been common practice for a steel model (either wire model or box model) of the pipe course to be made, which also demonstrates the positions of the flanges which are to be connected.

These are transported from the plant to the pipe workshop for further processing and/or manufacture. Or individual pipe components (partially prefabricated) are transported to the plant where they are cut, bent, if required, and completed by tack welding.

Both methods have a great number of common negative characteristics:

- Welding within the plant,
- transportation of welding equipment and residual materials,
- increased expenditure due to work regulations (flying sparks, ventilation, accident prevention, etc.),
- partly multiple transport of the material,
• accumulation of waste material (scrap),
• hardly avoidable distortions of the pipe, missing "as built" documentation.

Altogether, these methods are therefore too time-consuming and too expensive.
SCOPELINK

SCOPELINK is an electromechanical device for the determination of pipe course coordinates. It allows automatic measurement of all pipe coordinates within a plant, manufacturing of the pipe in the workshop and preparation of the "as built" documentation with reproducible accuracy.

To this end, the course of the pipe to be manufactured is modeled directly in the plant between two connection points (e.g. between two flanges), using plug-in components. This model is then evaluated on site by means of a portable computer.

*Special features of the patented system are:*  
- easy three-dimensional modeling of the piping course immediately on board ship by means of plug-in components,  
- simple shaping of fitting pipes of different nominal widths using the same components, including direct control of the actual outer pipe diameter,  
- universal use of the system for differing pipeline courses by different combination of only three types of components (fixed and variable length components, variable angular components),  
- quick connection to existing fixed points (flanges or the like) by means of universal adapters,  
- easy handling by locking the components with bayonet catches,  
- extremely sturdy design of all components as well as of the portable computer for use on board ship (humidity, knocks, temperature, etc.),  
- undisturbed integration of the measuring transducers for lengths and angles into the device and direct output of the processed values to the computer,
immediate judgement of the measured values directly on site in a connected computer, including a suitability test for construction (usability of the available tools, bending collision, selection of materials, etc.)

This ensures that a simultaneous visualization of planned Pipe courses and computer-aided measuring of the associated Pipe coordinates can be realized directly within the plant to be piped.

The systems to be piped can thus be defined right within the ship taking into consideration the existing marginal mechanical conditions and manufacturing tolerances in terms of suitability for fabrication, and the required manufacturing data can be transmitted to the workshop.

**Brief Description Of The System**

The measurement of lengths and angles is performed by means of integrated measuring transducers which are mechanically connected with the device, and transmit the required individual values for section lengths and individual angles via an internal bus system to a portable computer for evaluation.

The connection of the device to the fixed points (fixed Pipe ends, machine connections, etc.) to be considered in the plant in each case is made by means of universal adapters, which are rigidly connected to the existing fixed points (e.g. flanges or sleeves). To this end, twisting angles (flange position) and angles of departure # 90° within the range of ± 5 degrees are taken into consideration.

The Pipe course between the fixed points is built up by facility segments. The following types of segments are available for Pipe laying: transition flanges for the range DN 40 to DIN 400, straight segments of fixed lengths, straight segments of variable lengths and bent segments with adjustable angles.

The segments in each case are plugged together as required by the planned course. During plugging, the segments are mechanically interlocked by means of quick-acting couplings. This is performed in defined positions to each other, so that unambiguous values are measurable both for lengths and angles.

Connection of the necessary segments and adjustment of the bent segments to the required bending angle are made manually.
The measurement of the lengths and angles is performed automatically by means of the integrated measuring transducer. Variable straight segments are fitted with linear displacement transmitters and variable bent segments with angle transmitters. Each of the segments used processes the measured values by calibration and transmits the actual lengths and angles via a bus system to the standard output interface.

The required hardware is integrated in the individual segments ("intelligent segments") and is also electrically interconnected by simple plugging of the components.

Clip-on segment rings facilitate a direct collision check of the planned piping course by comparing its actual outer diameter with the surrounding pipes, components or other parts of the plant. Consideration can be given to branching pipes (fittings) by using additional devices.

Once the measurement is complete, the device is disassembled and is again available for the next measurement.

**Further Measuring Methods**

Further measuring methods can be used, varying and depending on the individual case. These are 3D laser scanner for model wires or model pipes or photometric methods, which can be supplied by Caretronic as well and be integrated into the shipyard's system.

**UniDAT OutdoorPC**

The further processing of the actually measured Pipe data is performed by a connected portable computer, the outdoor PC UniDAT. This computer combines the functionality of an efficient office PC with the protection from humidity and knocks and blows occurring during harsh daily operation (work environment in the plant and/or ship).

The computer is protected according to IP 56 and can be operated without keyboard and mouse. The database as well as the respective measuring software is installed on the operating system Windows 95 and/or
Windows NT. Isometries can be prepared everywhere, independently and directly supported by the database. The data are transferred via network and radio telephone into the company's own system environment.

Availability of the PipeFAB software in the shipyard's EDP system is the prerequisite for the calculation and output of data meeting the manufacturing requirements and for triggering the machines.

RoboFix Tacking Device

General

It is the task of the tacking device to define the flange positions required for Pipe production, so that prefabricated Pipe sections can be connected in the device with the flanges by means of tack welding. In addition, the tacking device allows checking of the Pipe course.

The tacking device can directly use the Pipe coordinates calculated by means of PipeFAB or determined by one of the 3D measuring systems.

Working Process

The Pipe data are loaded into the control computer of the tacking device either by means of a disk or via network connection. The control computer verifies that the permissible geometrical data are observed and performs a collision check in comparison with the device.

The 3D flanges of the as yet unloaded tacking device (without Pipe and real flanges) are then moved by means of an electric motor into such position to each other as if measured in the ship / at the building site. At the same time, the screen of the control computer shows the course of the fitting Pipe in a 3D display.

The screen display shows:

- The spatial course of the Pipe in the device
- The designation and position of the Pipe sections
- Reference dimensions to verify the Pipe course in the device

The "real" flanges of the Pipe are now screwed by means of the quick acting couplings onto the 3D flanges of the device. Subsequently, the prefabricated Pipe sections are positioned and fixed according to the screen display. The Pipe course can then be checked.
against the reference dimensions and corrected if required. The weight of the Pipe sections is held by external supports so that the accuracy of the system is not impaired.

The final step is to connect the Pipe sections by tack welding. In order to make for better accessibility, the tilting frame can be tilted manually by ±30°.

In case of overload of the 3D flanges, e.g. due to excessive overhanging lengths, the flanges give in without being destroyed, and a message is given. Once the overload has been removed, the 3D flanges are repositioned by the control electronics.

Technical Description of the Components

Basic Frame

The basic frame is intended to accommodate the tilting frame and the electrical enclosure as well as the tool cabinet. It is a welded steel construction. The passable areas are covered with checkered plates or gratings. Alignment is effected by means of leveling feet.

The working area before the tilting frame is safeguarded by side rails. The front and rear side of the workroom are fitted with light barriers which signalize the presence of persons in the danger zone to the control and activate the safety stop as soon as the area of the device is entered.

Tilting Frame

The tilting frame accommodates the 3D flanges as well as the linear guides with the movable cross beam. The actual working area is located within the tilting frame.

In order to make for an unhindered access to the workroom, the tilting frame can be tilted by ±30° from the vertical. This ensures that the fitting Pipe sections can be positioned in the device, even though geometry may be unfavorable. Fixing is made by means of two locking bolts, the position of which is monitored by the control. The tilting frame is supported by means of ball bearing pillow blocks on the laterally arranged stays.
The U-shaped horizontal carriers of the tilting frame hold the linear guides of the cross beam. The channel section is open on the side away from the workroom, so that the guides are protected from mechanical impact.

The control ensures that the positioning of the flanges and cross beam as well as entry to the working area are possible only when the tilting frame is fixed.

A safety circuit ensures that both the tilting frame and the flange can be readjusted only while in unloaded state.

**3D Flanges**
Essentially, the 3D flanges serve two purposes:

- Alignment of the flange level in each direction of an imaginary hemisphere
- Location and centering of the flanges to be tacked

The 3D flanges consist of rotary plates mounted one behind the other. The rotary plate on the Inlet side is connected with the tilting frame and/or cross beam, while the rotary plate on the outlet side is fitted with the adapter plate which receives the flanges.

The rotary plates are equipped with drive mechanism for the rotary movement as well as with angle transmitters. The drive mechanism use automatic overload protections and are self-locking.

**The control ensures that**

- positioning can only be effected when the brakes are released
- the workroom can only be entered when the brakes are applied (otherwise alarm)
- the brakes are applied in case of failure of the AC mains supply.
PipeFAB - The Production Management System

CAD → ERP / MRP
Accounting -Systems, Material -Management

PipeFAB ORACLE*

IsoFAB
Isometric input in the office on a PC or portable via OutdoorPC

RoboFiX
Tacking, welding of flanges on bended pipes

SCOPELINK
Measuring of fitting pipes on board