Chapter 23
Shipbuilding

Kazuo Hiekata and Matthias Grau

Abstract The shipbuilding process generally consists of concept and preliminary design, basic design, detailed design, production design and production. Design information is generated in each phase to shape products and operations in the shipyard. For each process the design activities are carried out with a high level of concurrency supported by various computer software systems, though quality of products and efficiency of the concurrent development process highly depend on experiences and insights of skilled experts. The detailed design information is difficult to be shared and design conflicts are solved in a common effort by design engineers in downstream design stages. Data sharing across design sections and simulation of the construction process to predict time and cost are the key factors for concurrent engineering (CE) in shipbuilding industry. The CE process in shipbuilding will be getting more and more accurate and efficient along with accumulation of design knowledge and simulation results. This chapter gives insight into the different phases of the shipbuilding product creation process and demonstrates practical usage through typical, comprehensive use cases from design and manufacturing. Finally, it draws some expected future directions for CE in shipbuilding.

Keywords Shipbuilding · Design and construction process · Data sharing · Design knowledge · Manufacturing process · Simulation

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J. Stjepandić et al. (eds.), *Concurrent Engineering in the 21st Century*,
DOI 10.1007/978-3-319-13776-6_23

23.1 Introduction

In shipbuilding industry, the process of operation is very complex and a shipbuilding project from inquiry to delivery lasts quite long, about 2 years and more. The price of large tankers or bulk carriers is around tens of millions USD up to 100 million. Passenger ships, LNG carriers or offshore structures are even more expensive. A characteristic of shipbuilding is the huge volume of supplied material that needs to be procured and managed in addition to the design and construction process during shipbuilding projects. To present the importance of the concurrent engineering (CE) concept in shipbuilding, this chapter illustrates the ship building process first. Additionally, related works are reviewed to show problems many shipbuilders are confronted with. Moreover, several case studies are described in detail; an overview of future trends follows to conclude.

The basic shipbuilding operation is illustrated in Fig. 23.1. The detailed process can be found in [1]. The basic process is very similar to other manufacturing industries which produce products for individual customers. As for shipbuilding, two types of projects are considered for the design work. One is creating a new design model. The other is customizing past design models for the new requirements. Design and manufacturing information are required for both types of projects and often a design is reused together with the manufacturing information such as shop floor drawings, etc.

In concept and preliminary design, the basic specification is provided by the customer and the designers have to create a basic plan for the bidding. As the customer is interested in the cost for purchasing a vessel, the shipyard has to estimate the accurate cost for the delivery of the ship. A highly accurate estimation of the production is important for winning the bidding and improving the profit rate for the delivery of a ship. Skills of the estimation based on deep technical knowledge are required. Gathering data of past projects for simulations by commercial software systems are getting more and more important for accurately estimating the expected costs.

In preliminary design, designers work on key drawings such as general arrangement plan (GAP), Lines and Midship section drawings. GAP is a key drawing for defining basic dimensions, capacities and so on. A Lines drawing defines the hydrostatic performance by describing the shapes of the hull with curved surfaces. The Midship section drawing is a drawing for the most important part for the approval of the structural strength of the ship. Key performance parameters such as speed, fuel consumption, stability, basic structural plan, main engine and other key equipment are determined in addition to the three key drawings. Ship capability

Fig. 23.1 Standard design process of shipbuilding

and key performance are confirmed during the basic design process and a revised basic design will be provided for the contract. In the following detailed design phase, the detailed feature of the product is defined. As an example, the drawings developed in the detailed design phase could present handles for valves, small stiffeners, steel plates with curvature for the hull, and purchased products. There are not so many differences from other manufacturing industries in detailed design. One characteristic of shipbuilding might be that most of the parts for the ship hull and structures are made by cutting steel plates. Thus, a definition of standard parts is difficult. The number of parts is in the range of 100 k to one million for a ship, so this might also be a characteristic of shipbuilding. Depending on the construction process, the design model defined during the detailed design phase may or may not depend on the manufacturing facilities.

In production design, some of the drawings might be instructions for workers in shipyards or considerations for the manufacturing process such as margins. This phase may not include design trade-offs; this phase is a kind of planning for optimal manufacturing. The drawings do not only show shapes, dimensions and specifications of the parts, but also indicate how to make parts or fabricate assemblies. To construct a complete ship in dry docks, the whole ship hull is divided into building blocks to fit in the manufacturing facilities and capacities. Owing to the limitation of the manufacturing facilities, the production design can vary even for the same ship with the same detailed design model. The manufacturing information in shipbuilding considers the large deformation of steel structures by the welding process during fabrication.

In this section, the general shipbuilding process is described. Also, the characteristics and differences of shipbuilding are noted. To shorten the lead time, the whole process proceeds in a concurrent manner. A detailed structure or outfitting design cannot wait for the final design of the upstream process. Software systems for design and construction are implementing a lot of features and trying to provide integrated environments to facilitate the CE process; though they used to be standalone systems such as CAD or numerical control systems. To improve the efficiency of the shipbuilding process and handle the huge number of materials, PLM, ERP and more sophisticated software are more and more used by shipyards. There is a tendency to employ new integrated information systems in shipyards although the limitations arising from legacy design data and manufacturing facilities still exists.

23.2 Related Work

There are a lot of software systems supporting the shipbuilding process. The latest efforts for employing CE in shipbuilding are described here.

23.2.1 Problems in Scheduling in the Early Design Phase

The concept, preliminary and basic design phases are considered as early design stages. The literature for these phases will be shown here.

The purpose of the concept and preliminary design is to support the bidding process. Detailed information is not required during this design phase, nevertheless the shipyard should know the cost for the materials, man hours, major purchase equipment and the feasibility of the delivery date along with the on-going projects. The concept and preliminary design must meet the customer's requirements and, at the same time, have to be an optimal design solution for the shipyard in terms of constructability. The shipyard has to make a design proposal considering many trade-offs in the shipyard capabilities. Speeds, fuel consumption, hydrostatic performance, selection of main engine, strength of structure and construction weight are parts of the considerations in design. International rules of international maritime organizations and loading facilities in ports might be limitations for the design work. Even today, to achieve a balance in trade-offs, this phase of design process highly depends on human skills. Therefore, shipyards have to assign talented and capable people to the concept and preliminary design phases because these phases have a huge impact on total costs and schedule.

Meijer et al. [2] focuses on the pre-contract scheduling problem and captures the knowledge of experts for the process. Production scheduling tasks in the pre-contract phase are based on knowledge and experiences. The knowledge captured is, for example, detailed configurations of manufacturing facilities to optimize the turnover of the building dock.

23.2.2 Utilization of Engineering Software in the Early Design Phase

As just described, design engineers have to consider complex and concurrent processes of shipyards. The same situation can be seen in the subsequent basic design phase. To manage and predict the complex and concurrent shipbuilding process, basically two types of efforts are proposed for the early design stage.

The first approach is to accumulate design and construction experiences. In the early design phase, design engineers work based on similar projects. The designers identify the differences between the past design and the new requirements and estimate the impact on the new design.

The second approach is simulation. Production scheduling and performance measures of the ship (such as fuel consumption) are vital for bid creation whereas during the concept design phase the focus is set on production scheduling, ship performance is the key topic in the preliminary design phase. The basic design focuses on defining the parameters for the product to meet the requirements.

Though the trade-offs of design parameters across the design sections are taken into account in the prior stage, negotiations based on the actual design start in this phase.

NAPA facilitates the utilization of 3D design models in the preliminary design phase [3]. NAPA is a software company providing a suite of software for ship design and operation. The software suite for ship design covers the early stages of the design process, such as concept design, preliminary design and basic design. The design spiral in the early stage of ship design has a huge impact on overall performance and, furthermore, on the construction costs of the ship. Designers can easily elaborate the candidate for the basic design of ships using the NAPA software by varying some major design parameters. NAPA employs 3D models and the effect of changing the hull shape is calculated based on the current 3D design model. Complex interactions, such as hydrostatic performance and compartment plan, will be calculated in the software. Each software package employs many types of solvers in the basic design phase [4]. Computational fluid dynamics (CFD), evacuation simulation, structural analysis, vibration and acoustics are shown. Papanikolaou shows multi-objective optimization of a ship design case study [5]. This research does not consider the production process; however, a software tool for simultaneous evaluation of key measures is proposed and applied to a realistic case study. The simulation approach proved to be helpful for early design.

Integration efforts for CAD system and engineering software are also active. Bons has introduced the latest status of MARIN's software [6]. Hydrodynamic design tools are a kind of standalone software because of their specialized purpose. The integration of a third-party software framework enables specialized software tools for hydrodynamics to be applied to the early design stage. Ginnis integrates an in-house wave-resistance solver with CATIA to improve the efficiency to hull optimization [7]. As for structural design, Shibasaki utilizes a 3D design model for structural analysis within an early design stage [8]. The key is data conversion from CAD to a solver for structural analysis. There are many translators for data formats; however, the quality of the converted data is often not enough. It has been proven that, in an early design stage, a customized 3D design model can be reused for structural analysis with only few adaptions. The advantages of a large amount of design and production data for the downstream process have been illustrated by Nakao et al. [9]. According to their survey, quality and efficiency of the downstream process is improved if accurate design and production information is generated during the basic design phase. The research also notes that the proportion of man hour will shift from downstream to the basic design stage.

23.2.3 Collaboration Across Organizations in Detailed Design

Collaboration is important from the CE point of view [10–13]. Depending on the shipyard, hull structure and outfitting design units are working in the same area simultaneously. The structural design team doesn't want another team to make a hole for pipes, while the outfitting team needs that hole for an efficient routing of pipes or cables. This kind of design conflict is illustrated in Fig. 23.2. Some solutions of several major shipbuilding CAD systems follow.

AVEVA MARINE is a CAD system for shipbuilding software derived from Tribon Hull which was originally developed by Kockums Computer Systems, later called TRIBON Solutions. Now, AVEVA MARINE also employs the former AVEVA PDMS CAD system for 3D plant design. The software covers the entire ship design and construction process and also the integration of design and production. As for detailed design, design and process standards can be defined to fit the CAD system to each shipyard. Drawing and bills of materials (BOM) are automatically generated and collaboration across design sections is supported. These features help multiple design tasks such as structural design and pipe outfitting tasks to share design changes in detailed structures and changes of pipes and holes.

CATIA has been developed by Dassault Systèmes, and many automotive companies as well as a huge number of companies in many industrial domains use this software. Though the basic system of CATIA is a general platform, the system can be applied to the ship design process by using the feature for shipbuilding. With regard to shipbuilding, CATIA has a specific feature for pipe design. In the detailed design phase, the software can reserve a space for pipes without creating detailed models of pipes. The information, the desired route for the pipe design section, can be propagated in the data model without detailed design work such as checks for the design standard, or designing flanges, insulators, supports and other details. A route of pipes between the main set of equipment that is reserved in an early stage of detailed design is one of the advantages of the software. Some specific features for

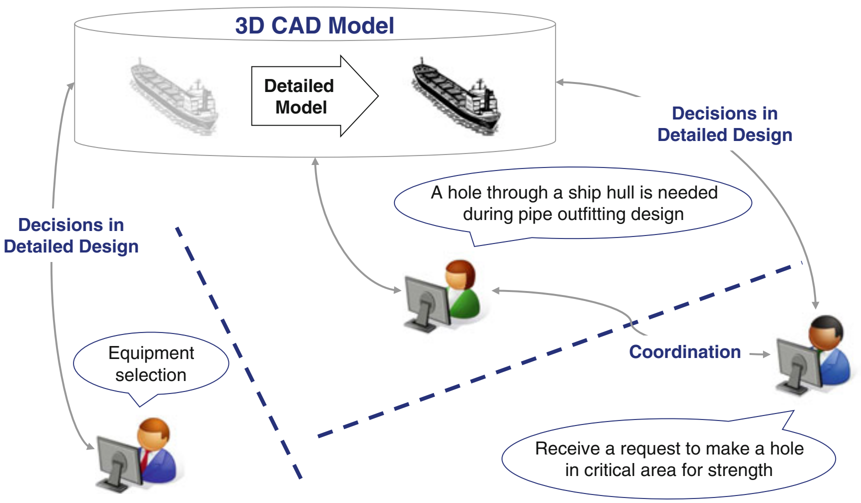

Fig. 23.2 Detailed design process with coordination across the design sections

shipbuilding such as a library for standard parts and parts generation by a macro are also supported in CATIA. In CATIA V4, ship hull design (SHD) is an extension to the product family to create hull structures of vessels. Starting with CATIA V5 and continued with V6 the hull structural design capability is covered by the structure functional design (SFD) module for the basic design phase and structure detailed design (SDD) for the detailed design phase.

FORAN is a 3D CAD system by SENER, Spain, and is meant for design and construction of ships and offshore structures. The software supports interactive piping design by checking and modifying features of the length of the pipes referring to the design standard and design review features for local rules of the shipyards defined in the system. The detailed latest feature is shown in [14]. Not only the interference between design sections, but also restrictions for bending machines or limitation of angles of elbows for material optimization can be considered for solving problems between detailed design and production.

23.2.4 Design Review in a Network

Reviewing the 3D model in a network enables the distributed team to work on the decision-making process along with the design progress. Sharing the updated 3D model is necessary to accelerate the speed of decision making and, thus, solve design and coordination problems. Ideally, all design work should go on concurrently, but the simultaneous update of the design model is difficult even with the deployment of 3D models. The number of design data and parameters is getting larger in 3D models. Moreover, 3D CAD systems usually work together with the traditional in-house software, while the complexity of design practice is getting higher and higher. From the information systems' point of view, just light and sufficient design data should be transferred to designers distributed in the network. However, the question, which data is important and necessary for which point of design process remains difficult. There is no answer still, while most of the software provides features for exporting light-weight models formatted in basic standard 3D format (see Chap. 11).

Collaboration based on sharing 3D models in a network is achieved by sending small sets of data required in design reviews, not by sending the complete data of the design process. For example, the software technology at the client's side is a standard rendering system based on OpenGL. A standard data format such as XGL in XML only delivers shapes and dimensions for an efficient data transfer. The detailed data for other parts can be stored as metadata to leave the handling process of detailed attributes to the generic database system. In general, software features for sharing 3D models are developed based on the open standard.

The JT format proposed by Siemens PLM and published under ISO introduces a method for sharing design data across CAD systems capable of handling this format (see Chap. 11). Especially for sharing rich design models in a CAD system-independent way, 3DPDF developed by the 3DPDF consortium as ISO standard is an alternative for collaboration across companies [15]. The format includes exact as well as light-weight shapes, metadata, dimensions and also product manufacturing information (PMI) such as tolerances (see Chap. 11).

NUPAS CADMATIC is a joint-venture product of Numeriek Centrum Groningen B.V. and Cadmatic Oy. These two companies are specialized in ship hull and steel part constructions and ship outfitting respectively. NUPAS CADMATIC provides a collaboration platform via internet. The platform works as a data server, while the 3D models can be shared. Light-weight data models can be sent by normal e-mails and will be reviewed by eBrowser, their free software for design reviews. Reviewers can give feedback in the software as other CAD systems do as well.

The schematic of the light-weight data shared in most of the CAD systems for shipbuilding is illustrated in Fig. 23.3.

23.2.5 Knowledge Management

Automatic check features for designs are useful for keeping the quality of design high. In order to allow automatic checks, know-how and design rules need to be stored in the CAD systems. The know-how, knowledge, and standards stored in the

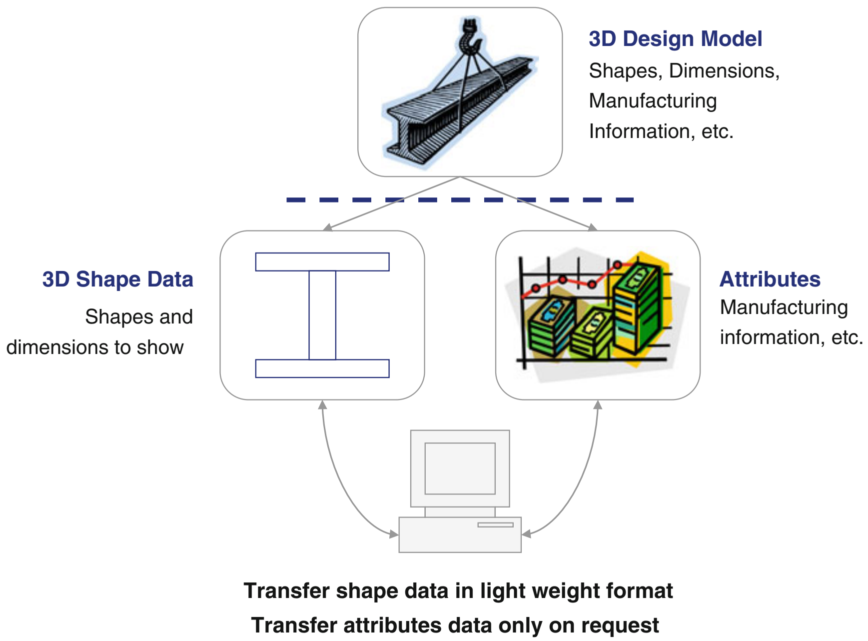

Fig. 23.3 Schematic for design information sharing

systems are, for example, the size of passage space, limitation of gradients for drain pipes, accessibility for maintenance of equipment and so on. These tips can be accumulated by means of the software systems. The difficulty of accumulation of know-how and hints is known as the knowledge acquisition bottleneck in former studies. One solution might be an extraction of the rules from text data generated during daily operations in shipyards [16]. Several other practical solutions have been proposed (see Chap. 10). The rules and knowledge accumulated should be managed well to improve future designs [17].

The software feature to accumulate know-how and rules is mentioned in this section [18]. If knowhow and rules are stored in the systems, those are also helpful for learning design knowledge [19]. Basic and routine checks should be automated by software systems and design engineers should focus on learning from accumulated knowledge and maintaining the knowledge (see Chap. 10) [20].

23.2.6 Integration with External Systems

The deployment of new software systems to shipyards also should be called a kind of integration rather than only development or customization. Similarly to general CAD systems, a shipbuilding CAD system is also required to be working together with many external systems. In shipyards, there are many types of software systems running. In downstream design work, such as detailed design and production design, the information on delivery dates or prices of the parts are helpful in addition to physical shapes and dimensions in BOM systems because the installation of purchased equipment completely depends on the delivery date.

One simple scenario of working with an external ERP system is shown in Fig. 23.4. Design and production data are handled by the CAD system. Broader information is stored in the PDM system, while the ERP system handles inventory, procurement, finance and others.

There are many efforts to implement ERP in shipyards, as well as to apply PLM. Larkins has worked on the development of a neutral data format for shipyards and integrated CAD and ERP [21], based on the ShipConstructor product of SSI. ShipConstructor is a shipbuilding 3D product modeling software running on top of the widely used AutoCAD system. All shapes and attributes are stored in a Microsoft SQL server which makes it more reliable and enables concurrent design. Lin and Gonzalez point out that integration of CAD, PLM and ERP in shipbuilding should be CAD oriented [22, 23], while Rong recommends the utilization of cloud storage for CAD/CAM and ERP integration [24].

Many CAD vendors recommend CAD oriented data integration to fit the current process. Many of the systems focus on linking up the whole process and data, which then means including the purchasing department, the hull structural design and outfitting departments and design work across the design and construction departments. The concept of the integration is the lifecycle of the ship production as supported by PLM systems [25].

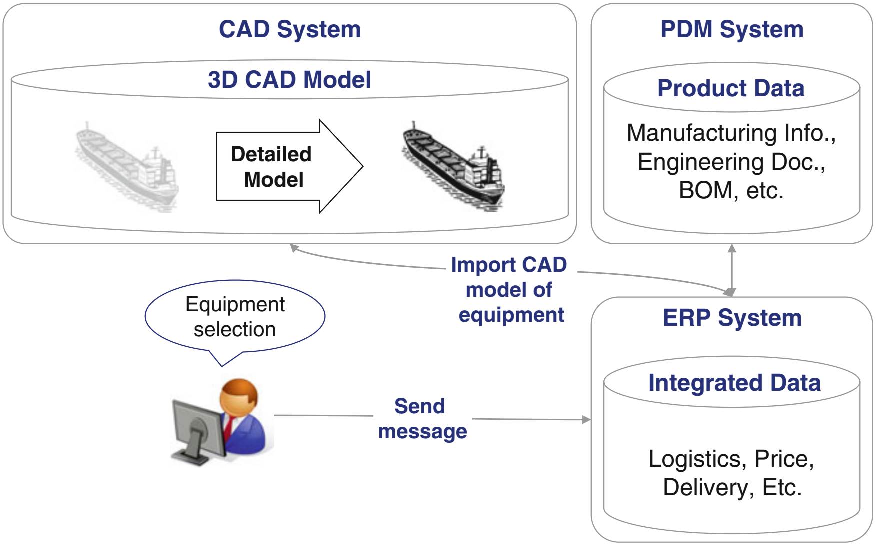

Fig. 23.4 Interaction of design work in CAD, PDM and ERP system

23.2.7 Considerations for Production

One consideration concerning production design is making an efficient plan for welding in the upstream sector. During the fabrication process, a lot of man hours are needed for welding. The environment for the welding processes such as upward has impact on the production costs. Assemblies of ships are huge and cranes are needed to turn the assemblies. The capacities of the cranes, distance of the areas in the shipyard and the weight of sub-assemblies should be considered to optimize production cost.

Even if the design (or the generated 3D model) is not yet completed, an optimized production procedure is required in advance. Park works on the management of deformations by heat to reduce rework [26]. The deformation is predicted by a solver and the results of analysis give feedback regarding the design model. The production will proceed based on the production design. Basically, the procedure as defined in the production design phase will be completed during production. Storch ran simulations of the production process to predict productivity by changing the work environment [27, 28]. Simulation is a powerful tool to improve the production design's quality and efficiency of the production.

23.3 Case Studies

To demonstrate both design and production of ships, we have chosen several "use cases" per domain. Interoperability between design tools as well as seamless supplier integration into the design process facilitates successful engineering collaboration [29] (see Chap. 7). Simulation for predicting the performance of the final product and the efficiency of production is a crucial point of related works. Several case studies illustrate details of the simulation technique.

23.3.1 Design of Equipment and Outfitting

Using the right toolset to design and manufacture outfitting is of paramount importance and should cover all needs from the design of outfitting structures like fundaments for layout and routing task for electrical and hydraulic components up to support for process planning and numerically controlled manufacturing.

The "best-in-class" approach uses the best available tool per design discipline, e.g., one for outfitting structures design, one for piping, etc. The benefit of this approach is perfect support in a discipline with features typically not available in the common denominator. The downside of this approach is the need to integrate the separate tools into a common toolset. Care needs to be taken that the necessary exchange of data from and to the distinct tools does not render the benefits in the various disciplines useless.

Blohm and Voss Naval (now Thyssen Krupp Marine Systems), a German shipyard with a long track record, have performed a project for investigating the ≪best in class≫ approach with the mechanical CAD system Siemens PLM NX for outfitting and piping design. This system offers a flexible solution to the design of mechanical structures created from sheet metal and profiles up to the placing of components and routing pipelines. Design of ship hull structures, and work preparation including plate nesting and creation of NC files for profiles and plate parts on the other hand was done using AVEVA's TRIBON M3. This necessitates a powerful interoperability link to transfer the manufacturing data from NX to TRIBON as an alternative to repeating manual rework [30].

The most important findings during the investigation of requirements was that designers could easily create parts in NX that neither obey the yard standards nor were supported by manufacturing. As a result this requires performing the appropriate customization of NX and some kind of validation functionality as part of the link between two CAD systems. The customization of the CAD system serves two purposes: it should support designers with ready-made building blocks like profile cross sections and it should ensure successful data export. As with all kinds of customizations it is important to find the right granularity of building blocks (Fig. 23.5). There should be a balance between patronizing the designer by providing only a few canned solutions and leaving too much freedom.

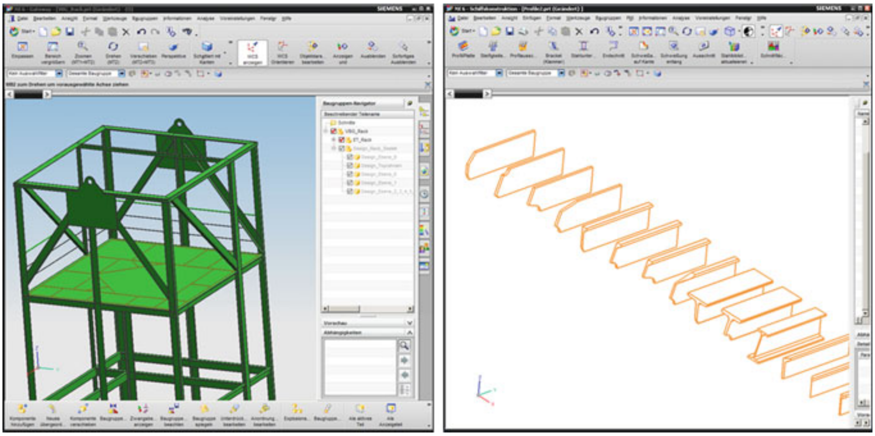

Fig. 23.5 Example structures and profile customization

The second and more involving step in the project was the design and implementation of a solution for the link between the two CAD systems. This link had to transfer the information created in NX containing the manufacturing geometry, validate it against rules defined by the yard and import it into TRIBON for manufacturing purposes. The fundament for all involved activities is the data model of the link solution.

Experience suggests defining a data model not too closely tied to those of the source or target system. It is rather a representation of the complete business data and does not rely on implicit knowledge available only in either of the linked CAD systems. This has the benefit that additional source or target systems are feasible without too much hassle. Furthermore, this "link model" is created in the spirit of the model-driven approach and uses standard technologies like XML schema and JAXB data binding (Fig. 23.6). This is essential as the project software is handed over to the yard. Using standard and openly available technology avoids a vendor lock in and enables further maintenance and development by the customer.

Another aspect important for the daily usage is the validation of the parts designed in the CAD system. While it is common practice to incorporate yard standards to a certain degree into the customization, it is neither useful nor technically feasible to prevent all kind of errors that way. Especially if designers work on multiple projects with different standards it is easier to catch the corner cases by a separate validation step than to switch CAD system customization every here and now. To support this need the link implementation contains a dedicated rule engine used to enforce rules like

- validate the combination of material quality, thickness and dimension for profiles and plate parts
- validate the combination of profile cross section and endcut types
- validate dimensions for endcuts
- validate naming and numbering of items

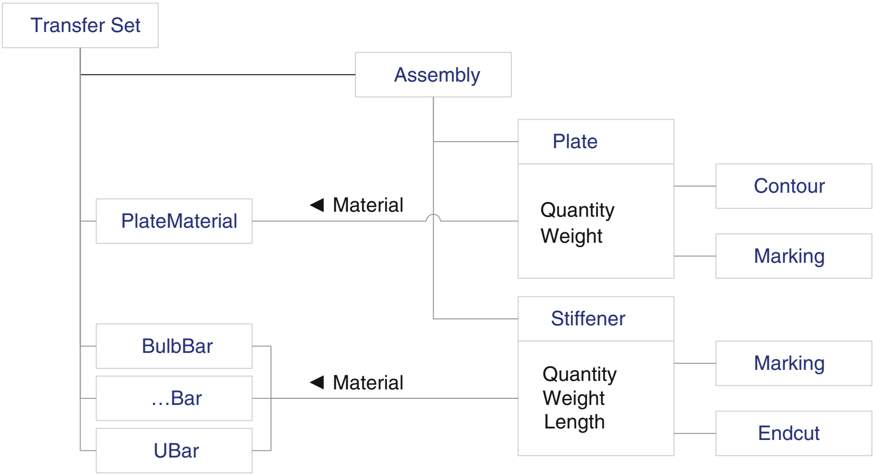

Fig. 23.6 The neutral XML format used as internal format allows easy extension

The rules engine supports checks on all kind of properties using allowed ranges, enumeration or regular expressions as well as conditional checks. The underlying rules are not hardcoded within the software but read from dedicated validation files. These files contain the rules in a domain specific language (DSL) using the vocabulary of assemblies, plates, etc., to allow changes by an administrator at the yard. A rule violation stops further processing and the validation results are shown to the designer. For this very reason the link is implemented as GUI application as the direct feedback enables the designer to change the problematic parts.

Using a "best-in-class" approach is a viable solution to support the design of outfitting parts. However, certain attention is needed to integrate the tools and gain a continuous data flow. In this solution the integration is provided by customization of the source system and tailor made link implementation. It does not only transfer the data into existing systems but also performs project specific quality checks and avoids later processing of non-compliant data. Using such a link enables the yard to use commercial off-the-shelf software without breaking existing business processes harnessing again all the benefits of dedicated "best-in-class" solutions. Furthermore, this approach facilitates continuous process improvements on singular steps in the entire process chain.

23.3.2 Collaboration Enabled by Intelligent PDF Documents

Portable document format (PDF) is a ubiquitous and widely supported document format with Adobe Reader® found on most every personal computer. Over the last several years, functionalities inside PDF have evolved to better support the engineering communication processes including built-in capability for the rendering of 3D CAD in combination with many features found traditionally only in dedicated CAD Viewers [31]. PDF capabilities include such features as digital rights management [32] (see Chap. 18), an ability to include data from throughout the enterprise, 3D CAD visualization, commenting, markup, measurements and PMI (see Sect. 11.3.2). PDF documents can be used for the communication between various stakeholders. In the engineering domain, especially review and approval processes can be supported very efficiently.

23.3.2.1 Layout and Planning Information in Early Development Phases

In early phases of shipbuilding processes, layout and planning information has to be exchanged between different partners in the shipbuilding supply chain. An example for this is the planning of a ship's machinery room. The main engine supplier has to provide information to the shipyard, which gives an overview of the main dimensions of the engine as well as of requirements for additional space, which is needed for maintenance and service tasks.

Until now, this information is typically communicated by drawings (either on paper or as scanned documents). These drawings are often very complex to be understood by an "external" partner, so the use is time consuming and error prone.

With 3D PDF, this information can be communicated on a level, which is very easy-to-use on the one hand but on the other hand adds additional functionalities into the PDF document by including active 3D geometry combined with PMI (e.g. dimensions or tolerances) into an interactive document.

23.3.2.2 Web Based Assembly of Multi 3D CAD Data

Another use case for 3D PDF is the assembly of CAx data coming either from different CAD systems and/or from different partners. With a web based structure browser ("Interactive Assembler"), different CAD assemblies or parts of them can be selected and afterwards automatically converted into one PDF document. This document then includes all 3D content together with all structure information from the original CAx applications. This PDF document can be used for review, lightweight collaboration or communication processes (Fig. 23.7).

The end user can create a simple and easy-to-use assembly of CAD data from different sources without the need for any CAD seat or an additional viewing tool. Through PDF, CAD independent 3D viewing now can be done on any workstation worldwide. Of course, the functionality is limited and only addresses end users without the need for changing the CAD data themselves. But any user who only has requirements for viewing and checking CAD data, especially outside engineering or along the supply chain, can use these new capabilities without any additional tools or infrastructure on the client side [33].

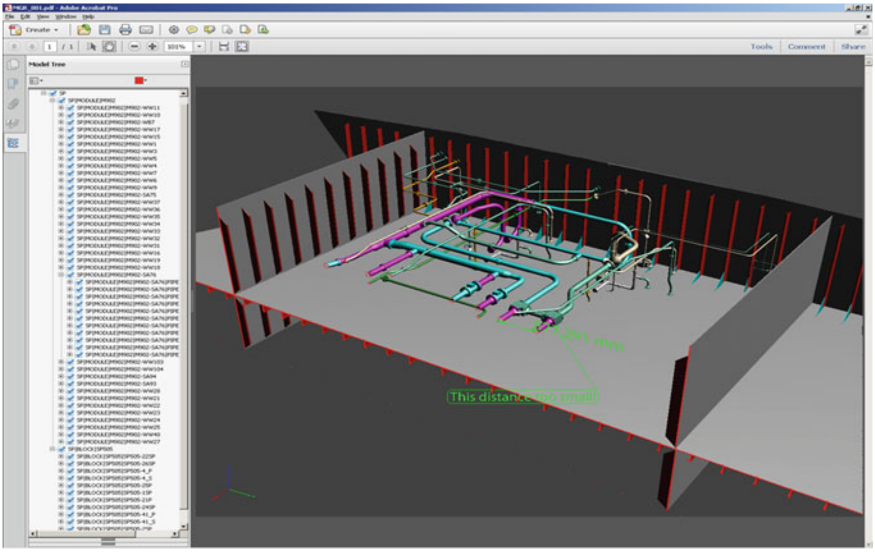

Fig. 23.7 3D PDF document with embedded active 3D CAD geometry (cross sectioned)

23.3.2.3 Cross Enterprise Review and Change Management Processes

The PDF documents can be used for communication between different participants in an approval or change management process which can be long and expensive (Fig. 23.8). Each participant can add comments or redlining into a PDF document (Fig. 23.7). Besides, the document can be approved by adding a digital signature into the document. In combination with rights management a lifecycle can so be built into a PDF document allowing a controlled circulation without having control over the document itself.

Most importantly, the added content of the PDF document (comments, annotations, form fields) later on can be exported again from the PDF document and stored back into virtually any enterprise system. Or, as an alternative, all comments coming back from various participants of a review process could be aggregated into one PDF document. This document then gives an overview of all comments from various review participants in one document.

23.3.2.4 Manufacturing Documentation

Manufacturing documentation means all documentation used for manufacturing processes of a product. This includes work instructions, which are used by workers to assemble products by performing a number of manufacturing steps as described in the instruction. Adding 3D geometry into such documentation avoids long text

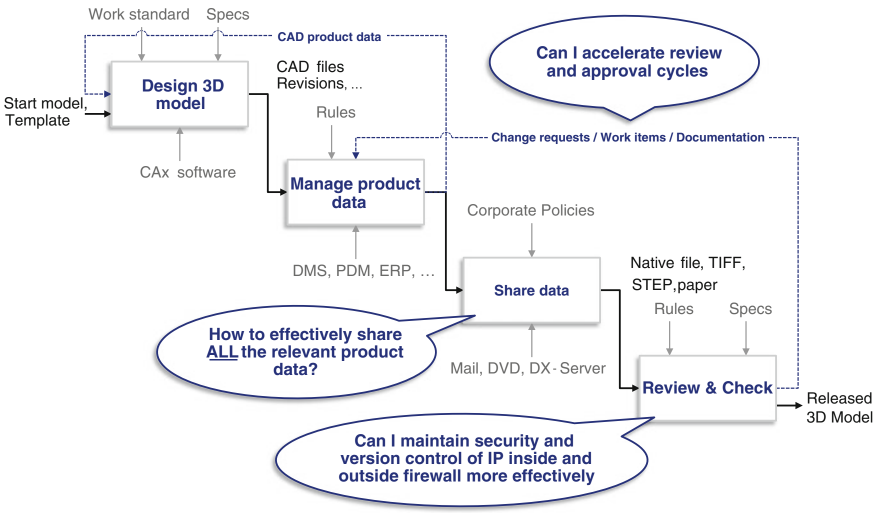

Fig. 23.8 Change management with 3D CAD data

sections and also makes it easier for a worker to understand how a manufacturing process has to be executed.

An example from a recent project is the documentation of holes to route pipes through steel structure. The process is triggered by the piping designer, who selects assemblies and parts to be exported into a 3D PDF document. An automatic process for the generation of a 3D PDF document is started. Together with geometric information (which, of course, also includes the representation of the requested holes), additional metadata information for each hole is exported.

In the PDF document, a 3D representation plus a list with the metadata for each hole is included. The content types in the document are interlinked, so the receiving steel designer can click on the metadata of a specific hole which directly links to the 3D representation of this hole in the context of the steel structure in highlighted mode. By directly showing the active 3D geometry of a ship's section with all of the holes to be included, the steel designer gets appropriate information for his task to approve the requested holes in a very efficient way. He can work on a plain workstation with Adobe Reader and does not need any CAD or PLM access at all.

A similar use case form the manufacturing domain is the "illustrated BOM". In this use case, PDF brings together the BOM coming from an ERP/PDM system and the 3D geometry coming from a CAD system. This information is linked together in the PDF document, meaning that the user in manufacturing can click on an item of the BOM list and automatically gets linked to the 3D view of the selected part(s) on his screen.

23.3.2.5 Supply Chain Collaboration

All aforementioned scenarios imply a point-to-point connection between two partners (e.g., shipyard and supplier) who are familiar with each other. In case of a shipyard which has to keep relationships with many suppliers simultaneously, manual management of data exchange becomes too complex and has to be maintained through specific tools. Furthermore, data exchange with partners in the product development process requires some additional topics to be addressed:

- **Security**: Public networks are open to everybody—sensitive information needs to be exchanged in a secure way.
- **Reliability**: Public networks are often not as stable as required, especially for transmission of large amounts of information (e.g. large CAD model file packages).
- **Traceability**: For the exchange in a globalized economic environment often—even legally binding—prove of data transmission and reception is required.
- **Efficiency**: Process security (such as repeatable exchanges and defined content) without loss of competitiveness becomes more and more crucial.

The speed of bulk data exchange not only depends on the available network bandwidth, but also on network latency over lengthy transmission distances. As soon as distances are long and data volume is high, latency can result in considerable delays and low throughput. This calls for a parallelization of the transmission stream as known from so called peer-to-peer networks. Such networks move single files in multiple threads in parallel, thus distributing data transmission on several channels thereby achieving a twice to three times better throughput. In cases where the connection is lost despite all efforts to minimize latency, a mechanism to resume data transmission where it left off is required. Records of who has uploaded or downloaded what data and when are kept via appropriate logging functions, so that they can be traced at any time.

Document management and provision features are needed, so a capability to organize exchanged files in a structured way (e.g., a by project and/or by exchange partner) will be required. In addition a publish/subscribe mechanism will be helpful in order to keep recipients informed about new or updated information. Updated files need to be managed by the exchange platform in a way that they are only available for download in their latest version and outdated versions are optionally archived.

Given the vast quantities of data and the numerous exchange processes handled by many companies on a daily basis, users should not be expected either to upload their data to the exchange portal or to download incoming data manually. A capability would be needed to automate these activities thus synchronizing the incoming files at the exchange platform with the local file system of the recipient. Even more, this should not only be available on a user basis but needs to be part of the companies IT infrastructure to avoid administration effort grows linear with the number of users.

Where appropriate a capability is needed to integrate the exchange process into back-end systems such as PDM on the sending and/or receiving side of the exchange. This allows locating or dropping all the relevant information in the internal data management environment thereby bypassing an intermediate storage in a file system and even enables automated further processing to take place such as creating a revision or locking.

All these requirements can be implemented by a secure data exchange platform which represents the hierarchy of the entire supply chain network (Fig. 23.9). The basic communication runs via web, the tool is installed in the demilitarized zone (DMZ) and can thus be accessed by all involved parties.

Prior to its implementation in shipbuilding, this solution was already widely used in other industries [34] which employ more than 10,000 users per installation. Usually it is included into supplier portals as an additional feature. For each partner, of which the number can be almost infinite, a specific exclusive web-space can be allocated which allows encrypted data exchange via the web. For processing of data workflows several functions can be defined, e.g., encryption/decryption, translation, filtering, quality check, packaging, check in/out to databases. On the shipyard site user-specific pre-processing dialog and methods can be defined, e.g., connecting the Adobe Life-Cycle product suite for derivation of 3D PDF models with corresponding PDF sheets and presetting the access rights to singular documents. In the solution a role and access concept is stored as well which can seamlessly interoperate with the Adobe suite.

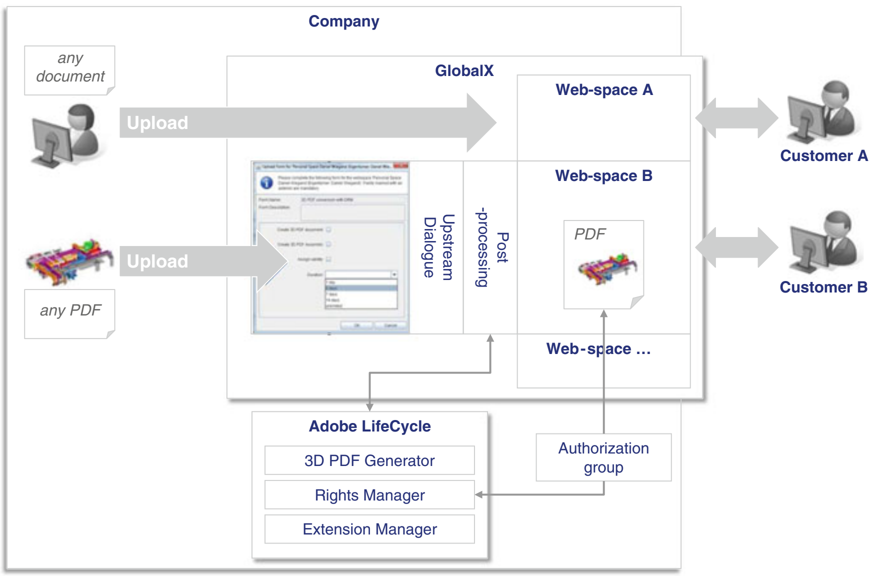

Fig. 23.9 Supply chain collaboration enabled by managed file transfer

The solution allows the distribution of data packages to multiple receivers (e.g., in case of request for quotation). Subscription of specific content (e.g. project relevant CAD models) is also possible. After the receiver has downloaded the data package, the sender gets the corresponding message and, thus, is aware that the data exchange has been executed properly. The user has to select the data for the exchange, his exchange partner (receiver) and the processing method (e.g. native CAD data, exchange as PDF package). After starting the action the entire processing runs fully automatically.

23.3.3 Data Management in Production Process

Recently, some accuracy evaluation systems using measured data of assemblies obtained from laser scanners are proposed. Laser scanners measure the whole surface of the parts as point cloud data. Measured data can be used for evaluation, checking the accuracy of shipbuilding blocks [35] or surfaces of shell plates [36]. The measured data and evaluation results have much information content, so these data are expected to help to discover knowledge about the manufacturing process. However, in most shipyards, the search and reuse of evaluation results is difficult because large amounts of accuracy information are stored without an adequate data management. To utilize the accumulated data, a data management system for measurement data and accuracy evaluation results of shipbuilding assemblies gauged in the manufacturing process is needed.

The proposed system has three functions: (1) accuracy evaluation, (2) accuracy data accumulation, and (3) search and reuse of accuracy data. The objective of the study shown in this section is to build a method for identifying knowledge, know-how and techniques in the field based on the data managed by the developed system and evaluated by the three dimensional measured data in the ship construction process. The overview of the whole system is shown in Fig. 23.10. All types of data are stored in the database and, as well, the metadata is assigned to the data. Any data stored in the system can be reachable efficiently thanks to the metadata.

In an accuracy evaluation system, the accuracy of assemblies is calculated by comparing measurement data obtained by a laser scanner to design data. The methodologies for an accuracy evaluation are different according to assembles, and some existing method can be applied for the evaluation.

In the accuracy data accumulation system, measured data, design data and evaluation results are accumulated according to name, feature, or evaluation result of assembles. The metadata is attached in resource description framework (RDF) format [37] and has URI for identifying the accumulated data. Relationships of each assemble are structured in RDF format, and the user can edit the relationships.

In the accuracy data search system, data are searched by querying RDF metadata attached to accuracy data. The value of the attached metadata and the name of assemblies defined in the RDF relationships visualized as a tree structure are used for metadata search with SPARQL. Search results are displayed as a summary of

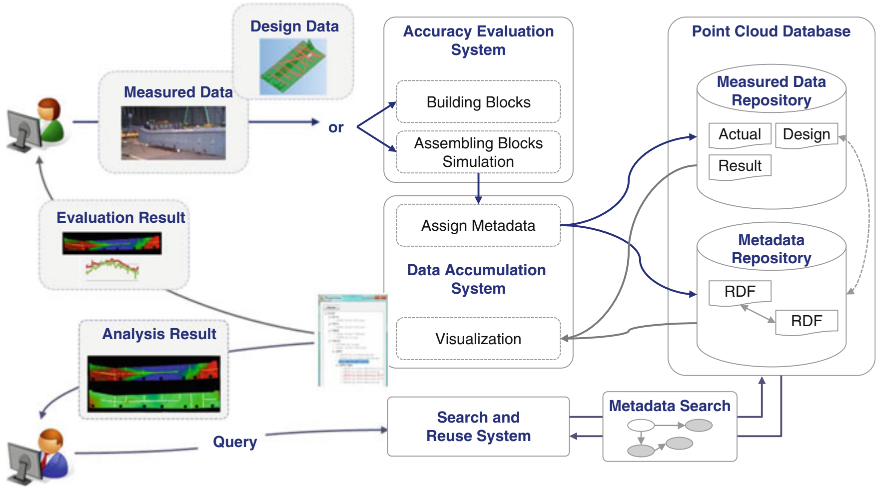

Fig. 23.10 Overview of the data management system

metadata, while accuracy data identified by the searched metadata are loaded and compared.

The accuracy of sub-assembly parts manufactured in a shipyard is evaluated and measured by data accumulated in the proposed system. In these experiments, a decrease of distortion of the panel surface is confirmed by comparing the accuracy of the panel before and after the heating process. This system is also helpful to identify areas featuring high distortion by searching data extracted from measured data and comparing it to the evaluation result. The findings obtained by these comparisons can be utilized for redesign of the manufacturing process.

One result of case studies with the system is shown in Fig. 23.11. This figure gives an overview of the shipbuilding blocks and the deformation of internal structural members calculated from accumulated measured data by laser scanners. The vertical axis of the graph is offset along with the depth of blocks and the horizontal axis corresponds to the width. Two measured data are retrieved in a 3 months interval, however the same tendency of the deformation can be found.

The accumulation of the data will enable shipyards to do this kind of analysis easier and avoid uncertainties in the production process. The accuracy of shipbuilding blocks can be evaluated by the proposed system. The deformation of the shipbuilding block in the production process will be recorded by the raw measured data and the analyzed results. The evaluation of the feasibility of the system is going on.

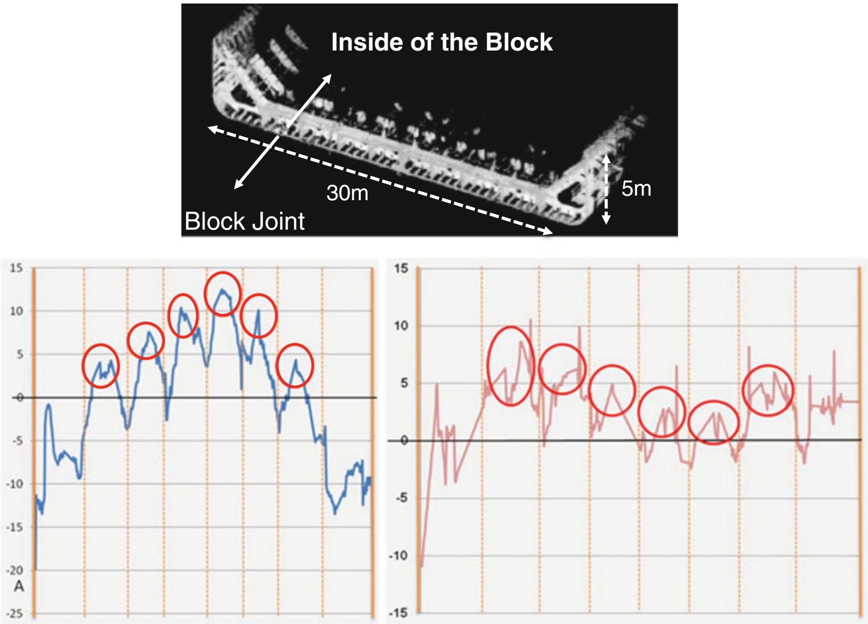

Fig. 23.11 Deformation in fabrication process

23.3.4 Simulation of the Production Process

As described in this chapter, simulation techniques are crucial to predict the subsequent process. Especially the process which requires huge volume of man hour such as production process should be correctly estimated. This case study proposes a methodology to evaluate organizational performance based on the research described in [38].

The developed system defines workers, facilities, activity models and a production strategy. The evaluation of organizational performance is done through the following processes: (1) create the enterprise model and strategy, (2) calculate a work plan by optimizing the weights of each strategy, (3) compare the basic scenario to the scenario of a changing situation. The system proposes an initial work plan. The plan minimizes the total cost in doing the work activities considering the weight of each production strategy by introducing genetic algorithm.

The proposed methodology is applied to some sample scenarios in a fabrication shop. Results show that the methodology can evaluate organizational performance successfully by analyzing the work plan. In addition, the methodology also evaluates the effect of improving organization and sudden trouble quantitatively. Figure 23.12 shows the overview of the proposed method.

Initially, an enterprise model is developed based on the workers and facilities in an organization including the different work activities and skills set, while the

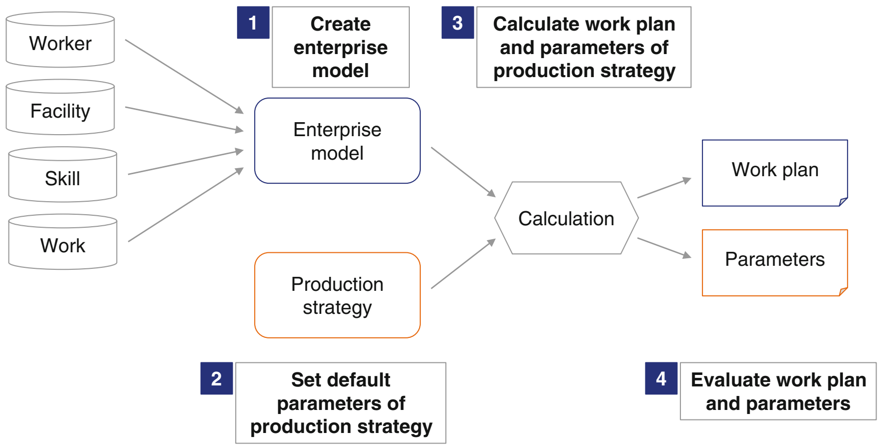

Fig. 23.12 Overview of simulation system for fabrication workshop

production strategy is made by setting each parameter. Next, the optimal work plan for the enterprise model is calculated by designing the parameters of the production strategy. Finally, the organizational performance is examined by evaluating the optimal work plan and parameters of the production strategy.

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

This method is evaluated in the fabrication process of simple panel structures in the case study. The process model is shown in Fig. 23.13. The simulation scenario is that 11 workers using 6 facilities are working on making 10 panels. The result is also shown in Fig. 23.14 in Gantt chart format. The weight vector for the strategy for assigning activities to workers is also obtained. This simulator shows that the job allocation strategy will change from cost saving to first-in first-out to keep the delivery date in case of resource shortage. The simulation results are suggestive however the effort for making process and organization models is barrier to actual deployment to practical situation.

23.3.5 Summary

The first case study demonstrates advantages of using “best-in-class” design tools combined with powerful interfaces. These advantages comprise gaining benefits of high productivity and high user confidence.

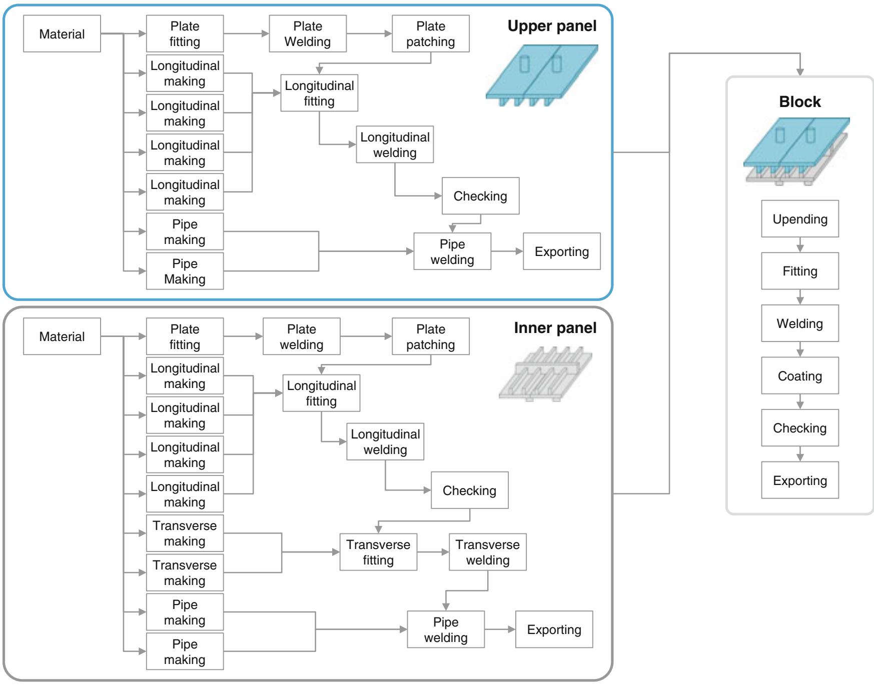

Fig. 23.13 Process model for fabrication of simple panel structure

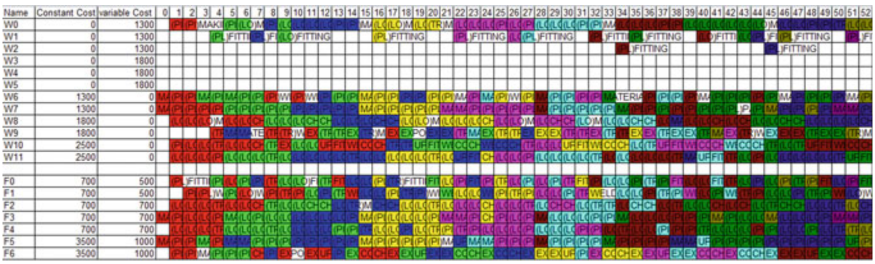

Fig. 23.14 Calculated schedule by proposed system

The second case study with multiple scenarios in engineering collaboration shows the benefits of using intelligent documents with embedded 3D data implemented in 3D PDF.

The third case study shows the power of accumulated data to improve the current practice. There is a plenty of data in manufacturing practice, however, the utilization for improvement is still emerging. The data can be called big data and its utilization in future is expected.

In the fourth case study, tips for scheduling can be found even in a simple process model. Simulation results depict the details of operations, making the simulation very helpful for engineers to make decisions for planning. The detailed behaviour of complex and concurrent downstream process can be simulated to reduce the uncertainties in the plan.

23.4 Future Directions for CE in Shipbuilding

Direction for the future in shipbuilding is discussed in this section. Challenges to improve the design process and the state of the art of the software feature are discussed.

23.4.1 Early Design for Concurrent Engineering

Shipbuilding industries spend a lot of time and cost on fabrication and assembling work. In addition, the volume of man hour in production is subject to the design phase. In other words, upstream design has a strong influence on the time and costs of production. The costs for production can be reduced by defining more accurate and detailed design parameters in the upstream design process. In practice, uncertainties in production can be avoided by employing detailed 3D models into the design work to fix more design parameters during the basic design phase. Concurrency and flexibility of the design process are required to improve the plan. Upstream design should resolve design uncertainties as far as possible to facilitate the CE design process in downstream.

Without 3D CAD technology, fewer design parameters can be considered explicitly in the basic design phase, and conflicts caused by the limitation of the design parameters are solved only in a downstream design process such as the detailed design and production design phase. Design experts require skills of many implicit design parameters and considerations. Designers can learn these skills in on-the-job training and from their experiences. The deployment of a 3D CAD system and the improvement of its computational power will enable description of a complete ship model containing more than half a million product parts and simulation of the process to assemble all the parts. Model and process can be simulated in detail by computers, and taken into consideration.

Design systems supporting the management of the CE approach are expected to significantly improve design quality in shipbuilding. This can be an innovation for the design process. The decisions in each design phase are taken to the subsequent process as design information. The next process assumes the decisions of the preceding process as design constraints and defines more detailed design parameters. The time history of design information generated in the design process is illustrated in Fig. 23.15. Considerable time and costs are spent on the creation of

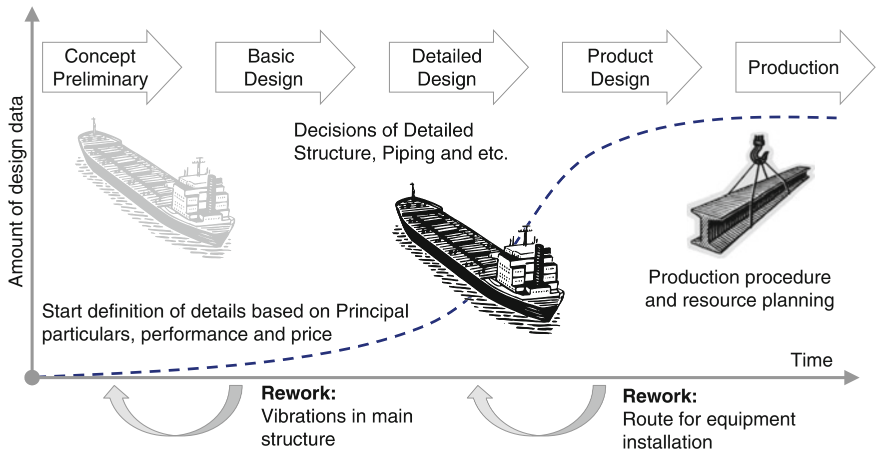

Fig. 23.15 Design information generated along with the design process

detailed models and drawings by defining many dimensions and attributes of parts. Although the number of design parameters and man hours in design work are not that big within the basic design phase, significant time and costs are spent for the design work based on the results of the basic design process. If design problems or conflicts caused in basic design cannot be solved within the downstream process, the rework of the problem will have a very serious impact on the whole process. Predicting detailed operation of the following process and efficiency of working on the downstream process can have a positive impact on the shipbuilding industry.

During the detailed design process, quality and quantity of design information within an early design stage can reduce time and costs for design more than the effort of resolving design conflicts downstream.

The quality of the concurrent process can be improved by prediction; using 3D models and simulation techniques will play a key role [39]. For example, if there might be plans to build block divisions for production, the trade-off of each plan can be shown with quantitative data and the best plan can be chosen based on costs, schedule and other limitations. Time history of design information will change as shown in Fig. 23.16. Much more design information will be created within an early stage of the design process. As for designing simple bulk carriers, more than 20,000 h are spent on the design work and the efficiency varies according to the quality of work in the design process. The concept of CE was introduced to shipbuilding industry years ago and has delivered improvement; however, barriers for implementing fully concurrent and front-loaded design, such as local optimization and data conversion, still exist [18, 20, 39].

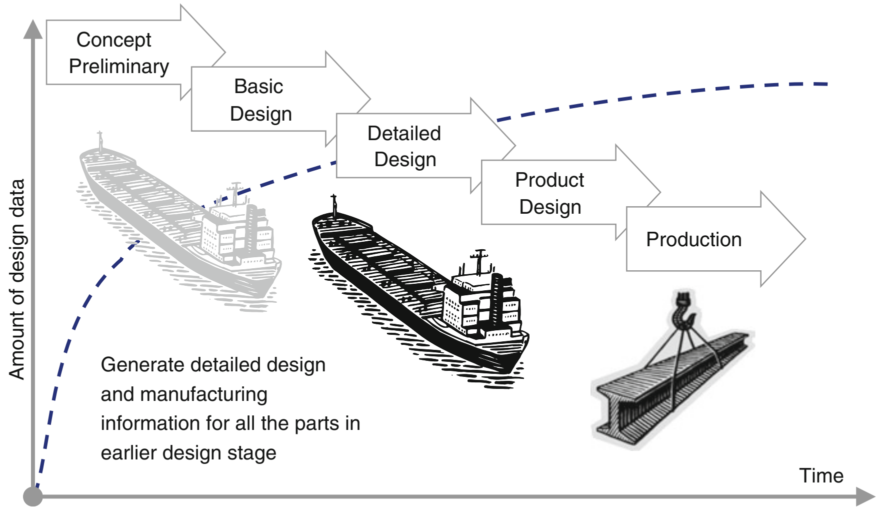

Fig. 23.16 Design information generated along with the concurrent design process

23.4.2 Reflections on the Organization Structure

The information infrastructure of CE is still not elaborated enough for shipbuilding. The design process is going on concurrently but the data is not shared in real-time because of the limitations of the information system. Consequently, a design conflict will emerge after combining design data. The route of pipes and cables is often blocked by structural parts, while usually the hull structural design section has priority over outfitting design sections. This problem is solved by some work-arounds with extra man hours in production design or during the production phase. Early integration of data can reveal this problem.

The concept to improve the design process is very simple, but time and costs of defining detailed 3D models in basic design will cause a large increase in man hours within the basic design phase. To make good use of the CE concept, in addition to the support by a sophisticated software platform, shipbuilders are required to change the organization of the design department to have a larger number of engineers in basic design process.

23.4.3 Concurrent Engineering for Production

Ship design and construction process are going on in a concurrent manner even in a very early stage of the process. Some problems exist, however. For example, shipyards need to purchase steel for the structure in an early stage of design, while the detailed structure has not been defined yet and the exact amount of steel is unclear. For a bidding process, the costs of production should be known, though the weld length cannot be known without a detailed structure. The accuracy of estimation depends on the experiences of designers. Human skills are thus needed to make the process concurrent.

To start the production process without the final design, 2D drawings are sometimes generated before the completion of the design work by 3D CAD system. The work for creating 3D CAD models is redundant. This redundancy should be eliminated with incomplete design information for the production.

The other problems in production process are delays in the production schedule owing to weather conditions, late delivery of purchases and unexpected problems in resource or facility. These unavoidable troubles which experienced experts manage with their skills in current practice should be handled by software platform to keep the production schedule.

23.4.4 Considerations for Software

As for the deployment of CE, a sophisticated CAD system may allow removal of barriers related to information technology. As shown in this chapter, data sharing across design phases is a key feature for an efficient concurrent design process. In the meantime, shipyards with a long history have a lot of in-house software to facilitate each design process and the data flow from upstream to downstream. This kind of software is useful and shows good performance in local process optimization. The quality of the design may be currently satisfactory for the local process with the use of in-house software. The installation of a single database for all design stages appears to be very difficult and is not yet feasible to handle huge number of parts of a vessel. Single databases and sophisticated design information sharing systems will be a good solution for new emerging shipyards and will be introducing a new concept along with the legacy systems for the shipyards with history. The concept of CE is common and will be deployed with human skills in both types of shipyards by adopting appropriate software systems.

An integrated software system supporting all design phases might be a good solution, but design departments often have their own historical data for in-house legacy software. This kind of in-house software is very useful in case of accessing past design information but may have a risk for maintenance.

23.5 Conclusion

For the deployment of CE in shipbuilding, the following items can be stated in this chapter.

In the early design phase, the trade-offs for many design consideration are to be addressed. Early adoption of 3D models and its utilization for engineering calculation are keys for a design process improvement.

As for basic design, detailed design and production, detailed and well matured design and manufacturing information is required. History data management and simulation techniques for prediction are the key for solving this problem. Organizational changes will also be required to generate design information earlier.

23.6 Future Trend

Accumulation of design cases is huge, while the computational power for detailed simulation is available now. Making decisions for the design and construction process in an early phase might be realistic in the shipbuilding industry.

The shipbuilding process and software for ship design and construction have been described in this chapter. The concept of CE has already been deployed in shipbuilding companies. However, information infrastructures are not enough to support efficient concurrent design and construction processes. The work load in upstream design such as basic design will increase by deploying the CE concept into practice, but is expected to decrease time and costs downstream, by improving the quality of the products and reducing rework. Prediction by simulation and detailed design and construction plans made possible in an early design phase may pave the way to innovation in matured shipbuilding industries.

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