

Completely Rethinking Weld Management: Leveraging 3D Models and Visualization

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Abstract

Managing and tracking welds, as typically practiced in shipbuilding, is notoriously inefficient and error-prone. It is laborious, unintuitive, and disconnected from other processes. This is significant because welding can account for 20-30% of production hours and approximately 10% of total cost. With shipbuilders expanding into the offshore market where weld standards are tougher, addressing this weakness is critical. Therefore, SSI has completely rethought weld management by tightly integrating it with an associative 3D model that provides data-rich intuitive visualizations that can be easily generated and utilized by anyone in an organization using standard tools, thereby improving communication.

1. Introduction

The management of welding continues to grow in importance. Since the financial crisis of 2008, margins have grown tighter and shipyards have been analysing ways to become leaner. An obvious place to search for savings is the welding process due to the amount of money involved. While it can vary depending on the type of project, anecdotal evidence from a cross section of SSI clientele indicates that *Boekholt (2011)* is correct in his estimation that welding can account for 20-30% of production hours and approximately 10% of total cost.

Another driver for re-examining weld management is the diversification of numerous shipyards into the offshore sector which over the last few years has been significantly more buoyant (and lucrative) than most of the rest of the marine construction market. In that sector, weld management comes to the foreground due to heightened environmental and safety considerations. Weld standards are more stringent for both oil rig construction as well as for the fabrication of tankers.

Yet, this new emphasis presents problems. The need for greater rigor in regards to quality, estimation, inspections, and traceability for warranty purposes often is challenging for organizations whose current weld management methods are inefficient at best and rudimentary at worst, with various tools, processes and stakeholders disconnected from each other. Inevitably, there are preventable errors and waste. Clearly, the time has come for a new approach.

2. What is Weld Management?

Before going further, the scope of what we are talking about should be defined and elaborated. When we speak of managing welding from engineering through to production and inspection and beyond, weld management encompasses all of the area shown in Fig.1.

What is Weld Management?

More than just Engineering

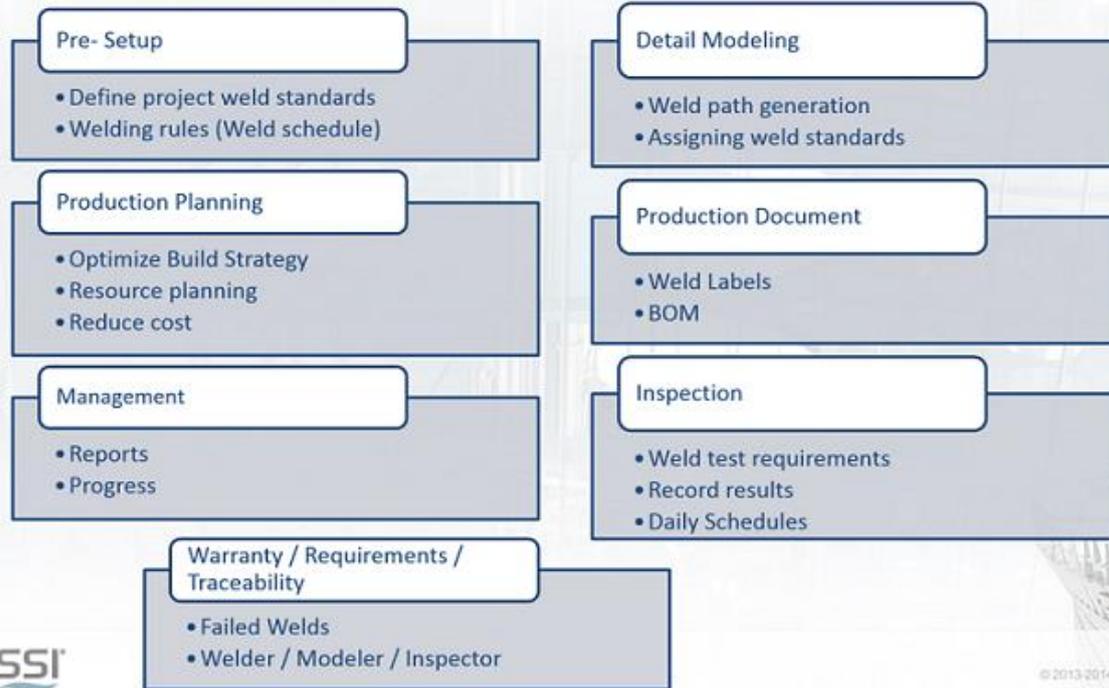


Fig.1: Areas encompassed by Weld Management

The scope of what weld management encompasses is therefore quite extensive. A great deal of information must be efficiently and effectively tracked and utilized. The table below shows the purposes and beneficiaries of this overall process:

Table 1: Beneficiaries of Weld Management

USE CASES	CLIENT TYPE
Estimation	Shipyard
Weld Documentation	Design Agency, Shipyard
Quality	Design Agency, Shipyard
Management	Shipyard
Production floor integration	Shipyard, Offshore Project

3. Current Methods and Their Limitations

Despite the benefits noted above, at the moment, certain organizations shy away from sophisticated weld management because it is a labour intensive undertaking with seemingly little payoff. A traditional approach in engineering is simply to document welds on workshop/assembly drawings using rudimentary CAD functionality and inspection and progress records consist of little more than tables full of text.

At a greater degree of sophistication, there are 3D CAD marine solutions that offer some tools for generating welds and documenting them on drawings. However, the overall process of management is unchanged. Thus, the benefit of these supposedly sophisticated solutions is marginal at best.

The reports are also unintuitive. For instance, consider a typical report on the daily weld progress.

(See Fig.2 for an example.) A typical report would contain columns of text showing Weld Name, Tag, Status and Location, etc. This report might be generated via the information contained in the product data model but it does not harness the model's complete capabilities. It requires time consuming, careful consideration and interpretation by the reader. That is because a text-only report is not really fully taking advantage of today's advanced 3D technology.

Weld Tag	Weld Standard	Location	First Member	Second Member	Length (mm)	Status
P74-018	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	284	Modeled
Assembly: P75					Weld Length (m)	21.90
Weld Tag	Weld Standard	Location	First Member	Second Member	Length (mm)	Status
P75-001	DC-5.0	Int Deck & Below	Bracket	All Boundaries	658	Modeled
P75-002	DC-5.0	Int Deck & Below	Bracket	All Boundaries	658	Modeled
P75-003	DC-5.0	Int Deck & Below	Bracket	All Boundaries	658	Modeled
P75-004	DC-5.0	Int Deck & Below	Bracket	All Boundaries	534	Modeled
P75-005	DC-5.0	Int Deck & Below	Bracket	All Boundaries	534	Modeled
P75-006	DC-5.0	Int Deck & Below	Bracket	All Boundaries	534	Modeled
P75-007	DC-5.0	Int Deck & Below	Bracket	All Boundaries	658	Modeled
P75-008	DC-5.0	Int Deck & Below	Bracket	All Boundaries	534	Modeled
P75-009	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	1086	Modeled
P75-010	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	3598	Modeled
P75-011	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	3598	Modeled
P75-012	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	3598	Modeled
P75-013	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	1086	Modeled
P75-014	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	3598	Modeled
P75-015	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	284	Modeled
P75-016	I-5 0-65-225	Int Deck & Below	Bhd WT	Stiffeners	284	Modeled
Assembly: P76					Weld Length (m)	26.37
Weld Tag	Weld Standard	Location	First Member	Second Member	Length (mm)	Status
P76-001	DC-5.0	Int Deck & Below	Bracket	All Boundaries	902	Modeled
P76-002	DC-5.0	Int Deck & Below	Bracket	All Boundaries	496	Modeled
P76-003	DC-5.0	Int Deck & Below	Bracket	All Boundaries	496	Modeled
P76-004	DC-5.0	Int Deck & Below	Bracket	All Boundaries	496	Modeled
P76-005	DC-5.0	Int Deck & Below	Bracket	All Boundaries	496	Modeled
P76-006	DC-5.0	Int Deck & Below	Bracket	All Boundaries	536	Modeled

Fig.2: Traditional weld management report is text heavy.

4. The Ideal Solution

3D is the key to understanding the problem and 3D is also the solution. Below are the key features required for any modern weld management software.

4.1. Integrated weld standards and weld schedules

Catalogs, libraries and rules should be incorporated into a weld management program for the same reason that they are incorporated into modern marine software products in other disciplines. You want your experienced and knowledgeable team members to populate the catalogs and set up the rules from which other members of the team can select. Catalogs make work easier and also increase quality.

A catalog of weld standards used for the project should be able to be defined which should contain all relevant information (weld processes, symbolic representation, attributes, etc.). Then, if a standard was changed, it should be able to be propagated throughout the entire project with little or no effort required by a user. Automatic propagation would enhance quality and efficiency as long as appropriate permissions were required to ensure that only the users who understood the effects of the changes had the power to make them. Thus, the ability to set permissions is also a key part of an ideal weld management solution.

On a related note, an ideal weld management software application would additionally include support for weld schedules. These are rules to specify the valid weld standard for a specific weld.

Organizations may have schedules such as this but they are typically created in spreadsheets that are disconnected from the product model which of course is problematic. It's not the tool that is at fault per se, just the disconnection. In fact, familiar Excel style features and views are a must for an ideal weld management solution because there would be less of a learning curve and errors would be reduced if the workflow was similar to current processes.

Another required feature is that weld schedules should be able to be easily exportable to a standard format to allow approval by class societies and / or other stakeholders. During this process, it is extremely important that the weld schedule be correct and exporting the information entered in the weld management program is the best way to achieve that goal. This is because you are taking

information directly from a single source of truth.

Finally, it is always important to be able to identify welds throughout the lifecycle. This means that an ideal weld management program would give a weld a unique name or tag which would never change. To help manage this important requirement, the weld management program should support a weld naming convention.

4.2. Identifying Welds

After all the above setup is done, the next area to look at is how welds would be identified in an ideal weld management solution. With all the geometry contained in the product data model, automatic weld geometry/path generation is a necessity. In fact, it is always surprising to see that companies manually trace all the weld paths to determine the weld lengths. This is an inefficient way to calculate weld paths and the problem becomes compounded when people are forced to wait until the 3D detail design is complete just to do weld path calculation.

A second critical requirement for identifying welds is that automatic identification should include all geometry, even if the product data model lacks a defined relationship between parts. It's true that if a relationship is defined by the connecting geometry, other enhancements can be implemented (e.g. automatically setting weld standard by determining parts relationship and part properties). However, having a relationship between parts should not be a requirement for creating a weld.

Finally, an ideal program should be able to handle cases where the automatic weld generation includes welds between parts which are not needed. As is done with clash detection, these should be set to be ignored.

4.3. Interacting with welds in a 3D environment

At this point, some notes about the value of an interactive 3D environment should be expanded upon to show how it significantly increases usability, reduces man hours and improves final results. Besides being simply more intuitive, it also is ideally suited for handling the differing needs of different individuals who require unique sets of tools, features and user experiences (UX) in software. Consider the needs of different personae involved:

Persona 1 is a Designer/Engineer with the task of assigning the appropriate weld standard to each weld. After all the weld geometry/paths are generated by the automatic method mentioned above, it is up to the engineer to select the appropriate weld standard for each weld. Doing this one by one with no visual reference would be a daunting task. However, using the 3D representation of the weld and the 3D representation of the adjoining parts with sophisticated selection criteria would speed up this process. Therefore, once welds are assigned to a weld standard they should be represented differently visually in order to easily communicate important information to the user without the need to perform any other action.

Persona 2 is a Checker/Shop floor worker/Inspector/Manager who needs the ability to view the welds and their properties in a fast and light manner. He would only need to review the welds and their properties but would not need all the features required for Persona 1. He would require the ability to see a more complete section of the project (i.e. entire block or unit) and would need to navigate the model which contains the welds (with attribute information) and parts very quickly. Since he would be viewing a larger portion of the model and only need a subset of features, a specific workflow and Graphical User Interface (GUI) would be recommended to enhance user experience.

The ability to generate different representations is one key advantage of an *interactive* 3D environment. More benefits will be shared later on.

4.4. Integrated change management

But all the benefits would be irrelevant if a program couldn't handle change which is a constant in the real world. To meet the demanding schedules of marine and offshore projects, an ideal weld management solution would need to work in a concurrent engineering workflow. This means that the solution would have to allow users to start generating and assigning weld standards before the detail model is complete. When the model changes, welds should automatically be updated with new paths while retaining their previous properties. Also, when welds are updated, there needs to be a basic level of revision control to notify the user of the changes. Then, the user should be able to decide on the appropriate action which may simply be to accept the new geometry path with no other changes.

Another critical change management feature is the ability to handle weld property changes arising from external sources such as from the production floor. These changes should update the properties (i.e. weld status: Created/Applied/Approved) of the weld without effecting other weld characteristics.

4.5. Documentation: Exchange of info between engineering and planning & production

Change Management is important but there is another requirement that is perhaps even more critical and that is how a weld management software solution deals with documentation. It does not matter how efficient the previous steps are, if you cannot produce accurate and comprehensive documentation in formats required by planning and production, all previous efforts are for nothing. There are several types of documentation required:

4.5.1. Production drawings

First of all, there are production drawings. On the production floor, the typical way to communicate weld information is via weld symbols on assembly or workshop drawings. Creation of the weld symbolic representation should be done by the weld management program itself and should use the weld standard information stored in the catalog. This is because using information directly from the model would significantly reduce the time users need to detail a production drawing and also improve its accuracy. Changes to the model should also easily be propagated to the production drawings while allowing users the ability to view changes in case extra modification is required.

4.5.2. Reports

Reports are a second required type of documentation that should be generated directly from the 3D model. One use case that should be supported is reports for determining the amount of weld length per weld standard in a user selected assembly. Another use case could be a report which illustrates the progress of welds completed on the shop floor. These, and other reports generated should be able to be easily customized for different departments and use cases by selecting any weld property contained in the product data model.

4.5.3 Production inspection

A subset of reports is an inspection report. With the increased requirement to have a significant amount of welds inspected using non-destructive testing, there is a need to have information available for inspectors in a format that they can utilize when managing their inspections. This information, if provided in a representation that is disconnected from the product model (e.g. Excel spreadsheet), must support the ability to be imported back into the product data model. This is not ideal. What you would really want is for the weld inspectors to access and modify the live information contained in the product data model but the reality is that most yards currently do not support the means to do so. Therefore, seamlessly importing the information back into the model is a minimum requirement for an ideal weld management solution.

4.5.4. Traceability and “Trackability”

All throughout the design, engineering and production process, traceability and “trackability” are important. Even when the job is supposedly finished, you still should be able to trace and track welds for repair and warranty purposes. To satisfy these conditions it is essential that the weld management solution support a unique name for each weld that never changes. It should also record all the changes to these welds. This includes the generation of the weld path to the final approver of the weld. These revisions should be easily accessed via an easily generated report.

5. Workflow: ShipConstructor WeldManagement for Weld Management

Incorporating the principles above, SSI has now developed a product called ShipConstructor WeldManagement as part of its ShipConstructor portfolio of CAD tools. The work flow for implementing ShipConstructor’s solution is as follows:

6. Setup

You begin with the setup.

6.1. Project specific weld standards and symbols

First the user needs to create a project specific weld schedule consisting of project specific weld standards and weld types. A few notes about these catalogs are shared below.

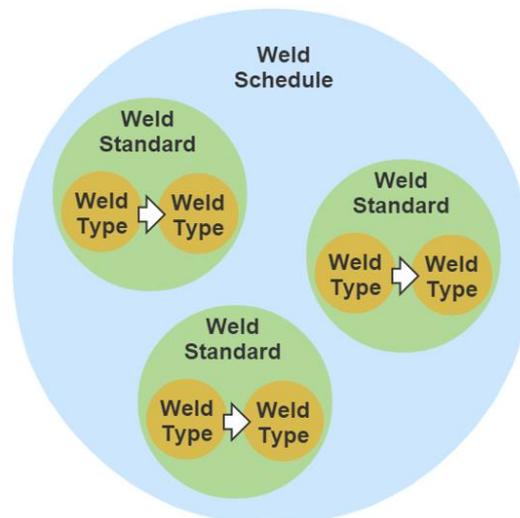


Fig.3: Relationship between weld schedule setup of weld standards and weld types

6.1.1. Weld Types

The Weld Types catalog is prefilled with eighteen definitions of basic weld procedure symbols such as fillet, bevel, v-groove and other types that may be modified by users to adjust the appearance or size of a default symbol in paper space. Each weld type represents the type of weld done on a single pass of the welder.

6.1.2. Weld Standards

After weld types have been defined, weld standards are defined. The Weld Standards catalog presents a library of all weld procedures used by a shipyard. Each weld in a project has a weld standard assigned to it so that the welder knows what types of welds to apply to a given joint, how many passes

are required, and any other details. A weld standard is made up of one or more weld processes where each process is one of the types defined in the previous stage. Once all desired processes have been added, the symbol can be further customized.

6.1.3. Weld Schedule

The Weld Schedules catalog contains a table that lists general sizes, locations and member types as well as assignments of weld standards to various combinations of the first three parameters. It is used to organize weld standards into particular scenarios where they will be used. These scenarios consist of a physical location on the ship, as well as two types of parts to be welded together. Each of these scenarios is further subdivided by the minimum thickness columns which represent the thickness of the smaller part to be welded.

6.1.4. Weld Statuses

Another catalog, Weld Statuses, presents a user-configurable list of different states that may apply to individual welds as part of the quality control process. By default, every project has the Created, Approved, and Rejected statuses. This list can be expanded by the user.

A key point to note is that different statuses have *different colors*. Color differentiation is extremely important to provide instant, intuitive, visual understanding throughout the entire weld management process. This point will be highlighted later on.

6.2. Import/Export

As per the requirement of the ideal weld management solution noted before, ShipConstructor allows the ability to export weld schedules and other data to Excel via TSV files. Exports are done for a variety of purposes. For instance, Excel files of weld schedules are often included with work packages for production. They also could be used for quality inspection. Of additional benefit is the fact that the information flow goes both ways since the Excel files can be changed and the information can be imported back to ShipConstructor.

6.3 Naming Conventions

As per the requirements noted earlier, for traceability purposes, every weld needs a unique Weld Tag that is generated on weld creation. Therefore, defining a naming conventions is an important part of the setup. The naming convention may consist of information pertinent to the weld such as the unit and assembly that the welded parts exist in. It could also have any other user defined text.

7. Detail Modelling

Once the project is set up, the user may proceed to generating and managing welds. This is done in weld management drawings in conjunction with what is called the Weld Manager which is the primary interface for defining and modifying welds.

ShipConstructor WeldManagement *automatically* finds and generates weld paths. The welds are generated for assemblies that exist in what in ShipConstructor terminology is called the “primary product hierarchy” tree. For practical purposes, the primary product hierarchy can be explained as all the parts in an assembly sequence for a particular build strategy.

The weld generation operation searches the ShipConstructor product data model for physical connections between individual parts and larger assemblies and creates one or more weld objects for each connection. A key point is that, as per the requirements specified earlier, it finds and tracks undefined welds, even if the product data model lacks a defined relationship between parts.

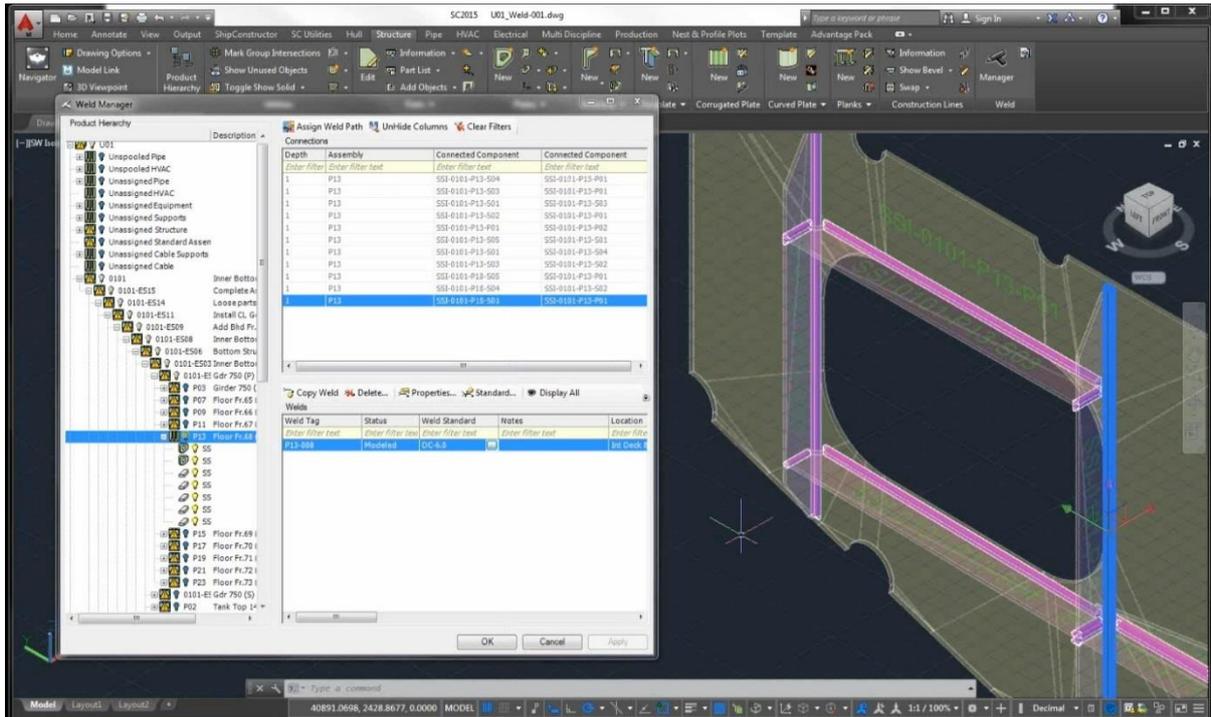


Fig.4: Weld Manager Dialog over top of a Weld Management Drawing inside ShipConstructor. Weld types and statuses are displayed in different colors on the drawing.

7.1. Interactively assign weld standards to welds

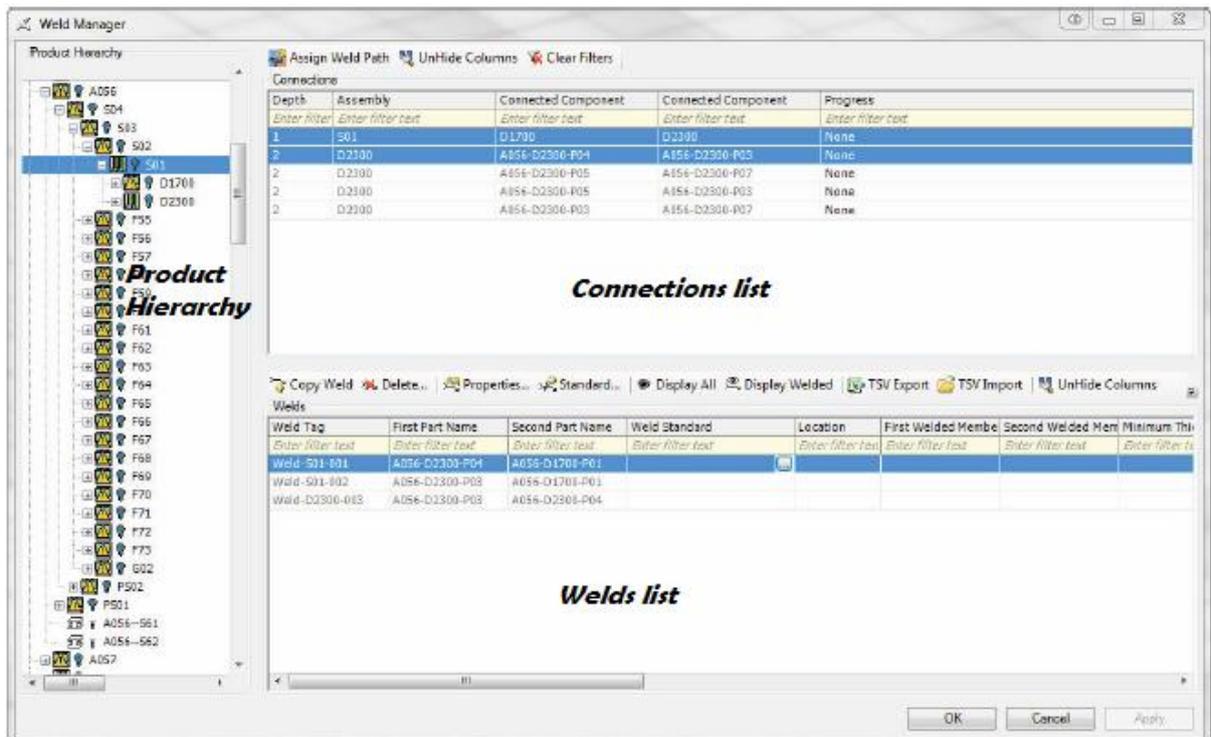


Fig.5: Weld Manager

Next, the user needs to decide which weld standards to assign to individual welds depending on the parts, thicknesses, locations, and material grades used in places where different welds apply. It is a very interactive process. The Weld Manager dialog offers a convenient interface that presents multiple columns populated with data that can help the user to make the correct choice of weld standard based on weld schedule. When choosing weld standards, some users may find it is sufficient just to look at data present in the Weld Manager dialog. Others may want some visualization of this process because seeing the actual weld in the drawing can be helpful. For that you would look at the weld management drawing. The weld management drawing is a special type of production drawing that acts as a viewport into the database. (See Fig.4 to see the interrelationship between the Weld Manager and weld management drawing.)

7.2 Visual verification for quality control.

A key feature for quality control purposes is visual verification. Specifically, colors in weld management drawings play a critical role in promoting quality because an “at a glance” inspection can show if a certain weld has the incorrect type; you see that the color is wrong. A check can be performed and the status can be changed to indicate that the check has been completed. A status view could then be selected and, as explained earlier, once again, the different statuses would be delineated by color. This provides another way to ensure quality in the workflow.

7.3 Updatable when 3D Model Changes

But visual inspections with colors are not enough to ensure quality if one is inspecting the wrong thing. That is why, as per the requirement explained previously, the ShipConstructor WeldManagement product updates information when the underlying 3D product data model changes. When the model is modified, welds automatically are updated with new paths while retaining their previous properties. The reason this is possible is because everything is tied back to the ShipConstructor Product Data Model, the Marine Information Model, the MIM.

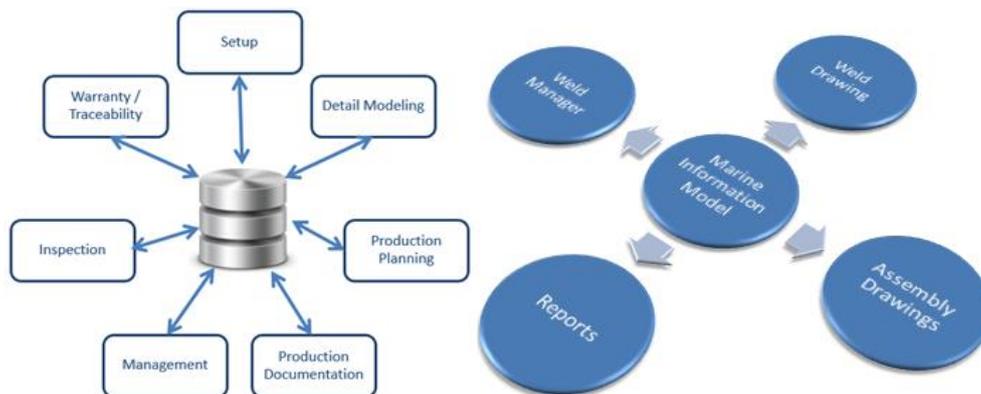


Fig.6: Data from the Marine Information Model Database

8. Production Planning

Back to the workflow, next comes production planning. Here, a key advantage of this weld management solution is its usefulness for estimation. You can estimate without weld properties with little effort and this will still give you improved planning related to welding labour which, as noted earlier, is a major cost. If you go further and actually do estimates with weld properties, still with very little effort compared to value, you can get a really accurate estimate of material usage which will reduce overstock and thus costs. Furthermore, you can do estimates on weld orientation which is critical information related to the strength of joints. Based on your analysis of the above factors you can make changes and then, due to the connection to the Marine Information Model, have those changes instantly reflected in the build strategy.

9. Production Documentation

The next item to be mentioned in the workflow is the creation of production documentation such as reports and production drawings.

9.1. Reports (Status and Estimation)

From WeldManagement, customizable reports can be created to show status of welds for various assemblies. And, as highlighted above, because the lengths are all known, reports can be created for estimating the amount of weld material required.

9.2. Production Drawings

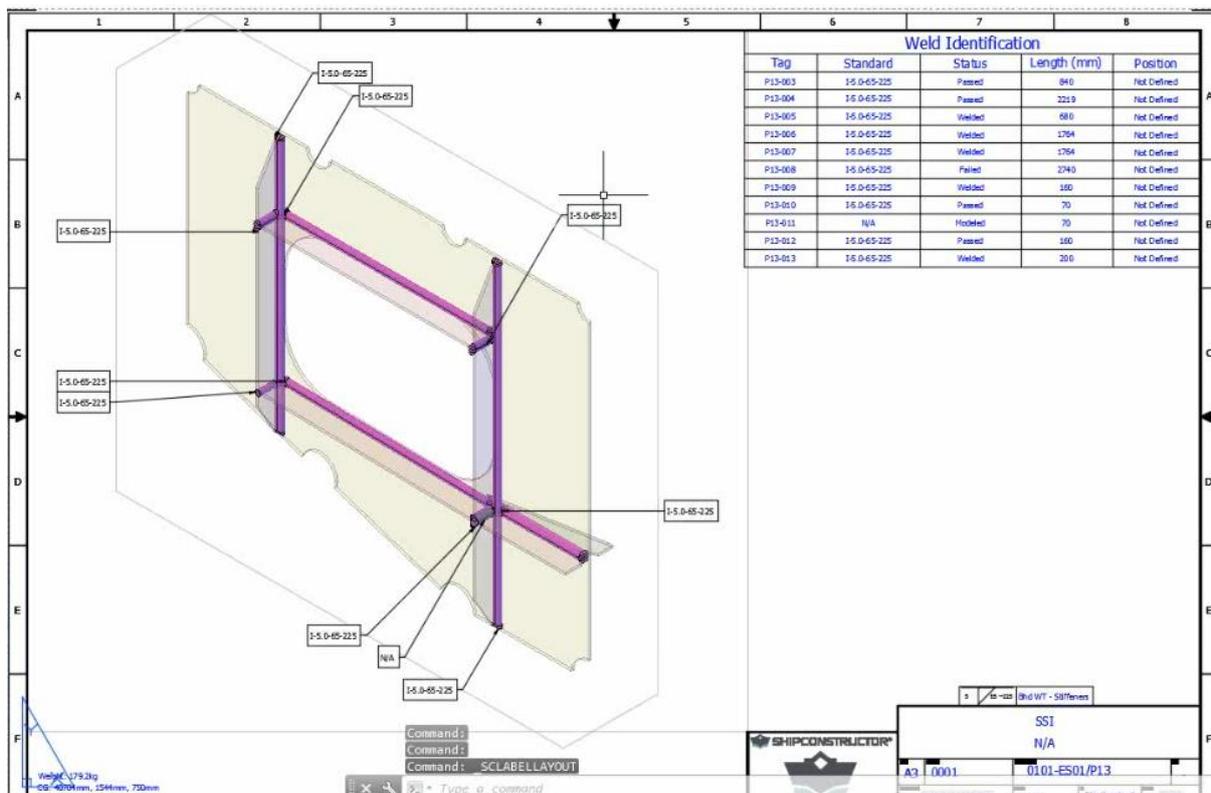


Fig.7: Assembly Drawing with welds labelled and identified in Bill of Materials table

Once the welds have been generated and assigned with standards in the WeldManagement product, the user may proceed to production output. Assembly Drawings are automatically generated and weld objects can be included in ShipConstructor assembly drawings by checking a single box in a dialog. From there, the user can label welds as annotations from an assembly drawing Bill of Materials (BOM) table that contains data retrieved by a “weld collector”. Labelling then is done via ShipConstructor / AutoCAD’s regular methods and tools for this process. As of the release of ShipConstructor 2015 R2, the labels displayed Weld Tags only but future versions will display weld standard symbols.

10. Management

As mentioned earlier, on an ongoing basis, WeldManagement will be used for exactly what its name implies: management. You can use the tool to find out the progress of detail modelling, whether or not all welds are accounted for, estimation, and progress of implementation. And, you can have confidence in the information knowing that it is up to date since it is coming from one source of truth.

You can get information and interact with information via textual reports or, even better, via visual representation. This visual representation requires no CAD experience to generate. The visual representation is so different and such a vast improvement over current methods, that it bears highlighting which will be done in the next section regarding inspection.

11. Inspection: visualization and Production Inspection using Navisworks

The next step in the overall weld management process is down on the waterfront. An example from here really shows the advantage of the visual approach using the 3D Marine Information Model. The example would be when an inspector or project manager wishes to determine the progress of welds of the ship or offshore structure under construction.

Inspectors need to generate and document daily work in order to make plans. They then need to import the results back to the product data model so that everyone and everything is updated.

And inspector would want to be able to identify:

- Welds that have been welded
- Welds that have not yet been welded
- Welds that have been inspected
- Welds that have passed inspection
- Welds that have failed inspection

Typically, to determine the weld progress, one would have to look at numerous pages of weld reports from the inspectors and consolidate all the information mentally. This method of determining the weld progress is very time consuming and requires a lot of effort to collect, merge and process the information that is provided.

With ShipConstructor's WeldManagement product, the process of determining the progress of welds is much more efficient and requires significantly less mental effort from the user. The main reason is that it communicates this information visually rather than by using pages of text via reports or Excel.

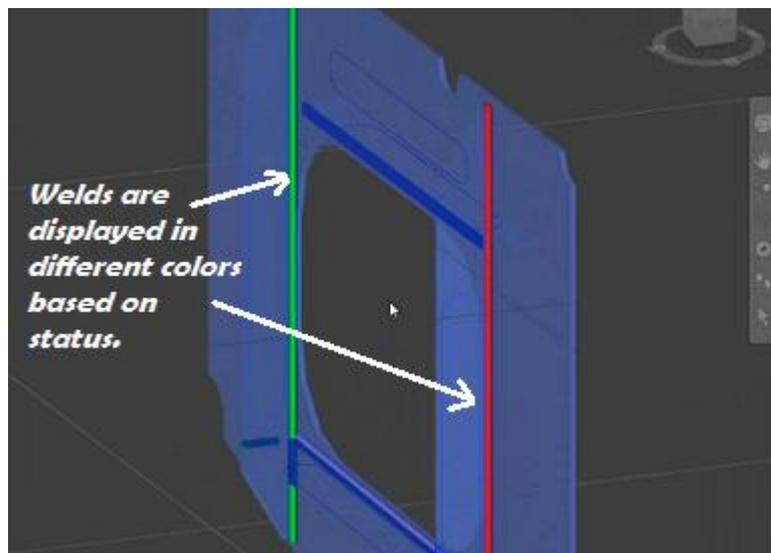


Fig.8: 3D Visualization of welds with status shown in different colors

Fig.8 instantly shows where welds are located in relationship to structure and weld statuses are immediately apparent. You can configure the settings so that the screen shows whether or not things

have been welded or not. Alternatively, you could display different colors showing what has passed and failed inspection.

This is a dramatic contrast with a text report, as shown in Fig.2 at the beginning of this paper. A text report would typically require about 10 pages to illustrate the same information displayed visually in a full color 3D diagram. Therefore, the visual method communicates the data in a much more intuitive way. It's the same information, but it's far more user-friendly. Furthermore, the 3D method is not just a static drawing. It is actually an immersive virtual world that can be "flown through" using the Autodesk Virtual Reality viewer application, Autodesk Navisworks.

Navisworks is a cost effective program that is part of SSI's complete solution because it enables 3D design review, customer review, supply chain collaboration, project scheduling and shop floor 3D applications. It works seamlessly with ShipConstructor due to the shared Autodesk Platform along with several tools that ShipConstructor incorporates for quickly gathering and sharing information. This information is comprehensive in that it includes all the object properties from ShipConstructor which are available in Navisworks at the click of a mouse.

Even better, the integration works both ways because Navisworks users are able to navigate back to the original ShipConstructor drawing to make any required changes. This allows external non-CAD users to comment in the light weight Navisworks model and then have a CAD user take the appropriate actions on the model by directly opening the affected ShipConstructor drawing. The reason for emphasizing the normality of this in the context of a discussion of weld management is that some people think that creating and interacting with a visual representation of the weld progress requires some sort of special skills and tools. That is not true. With ShipConstructor extending the AutoCAD foundation, it really makes the process very easy for anyone, even someone with no CAD experience, to create a visual representation model of welds. A workflow description shows how this can be done in just a few steps.

The process is seamless. And, it should be noted that viewing these fly-throughs does not have to be done in an engineering office. A key advantage of utilizing Navisworks is that it allows viewing the model on tablet computers down in production. In Navisworks, ShipConstructor models can be viewed on commonly available tablet devices with the same fidelity as they can be displayed on desktop computers. In addition to navigating the model, this includes the availability of all properties from the ShipConstructor model and the ability to measure and control visibility of various portions of the model. Using tablet devices really makes the 3D solution accessible and available to everyone.

12. Warranty / Faults

Records for warranty and fault tracking are a requirement for some types of projects. Every aspect of the weld lifecycle is captured for future analysis. This includes who defined the weld schedule, the user/checker who approved the weld, the inspector, and even the welder.

13. Conclusion

In conclusion, there are many stakeholders involved in weld management, each with their own skills and knowledge. A modern weld management solution provides the right tool and context for each stakeholder to produce and consume information efficiently and effectively. That starts from Setup and carries on throughout the entire process. To make this possible, SSI has developed a weld management software application that works from one source of truth, is visual and interactive, and promotes quality at all stages by reducing the chance of errors. It is a complete solution for the entire lifecycle of managing welds in any project.

References

Boekholt, R. (2011), *Welding mechanization and automation in shipbuilding worldwide*, Philadelphia, Abington, p.5