We Need Better Information Connections for Welding Manufacturing

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This paper was submitted to the Standards Engineering Society's World Standards Day Paper Competition. The contest theme was "Standards Connecting the World". In October 2004 the paper won second prize.

Ships, bridges and buildings connect people, communities, and even countries. Their manufacturing depends heavily on welding technology. A weak area in the manufacturing of these objects, from the conception of the products through their fabrication, is the data that is generated and shared by computer programs. The industries that produce ships, bridges and buildings, have begun defining digital welding information for manufacturing of their products, but the efforts are independent of each other, and the data definitions have little in common.

The current data formats could be improved and harmonized by bringing representatives of these industries together, under support of the American Welding Society. This consolidated effort would:

- reduce cumulative effort by the three industries
- speed the completion of defining a standard format for digital welding information
- attain high quality data definitions that can benefit other industries
- attain definitions that do not vary by industry, that do not present the welding industry with "dialects" of data,
- leverage the expertise of the welding industry and its U.S. standards body, the American Welding Society
- harmonize and connect data definitions from different industries, so that
  - digital data can effortlessly connect design and manufacturing process
  - welding can be used more effectively and more efficiently to connect pieces of metal, to form essential objects, that connect (and support) people.

Here's how it can be done.

BUT FIRST, WHY FOCUS ON WELDING? WHY FOCUS ON DATA FORMATS?

Welding is essential to a high dollar volume of manufacturing processes, including national defense industries. The American Welding Society and Edison Welding Institute commissioned a report, *Economic Impact and Productivity of Welding, Heavy Manufacturing Industries Report , June 2001*. It says that "The contribution of welding to the U.S. economy in 1999 via these industries was no less than $7.85 billion. This figure represented 7% of total expenditures by these firms in 1999." The report includes figures citing *The 1996 Occupational Outlook Handbook* published by the U.S. Bureau of Labor Statistics, which indicates that over 450,000 Americans were employed as welders, cutters, and welding machine operators. Additionally, the *Handbook* lists 25 other trades (e.g., ironworkers, boilermakers, pipefitters) or occupations (e.g., precision assembly, shipfitting) where welding is either a specialized skill or an integral part of the operation. "By including the workers from these professions that are directly involved in welding, the size of the welding community swells to *over 2 million workers*, or *over 10 percent of the manufacturing workforce*."

Another AWS document, *Vision for the Welding Industry*, lists as one of six desirable strategic goals for the next 20 years, "Enhance the use of welding in manufacturing and construction operations by integrating welding with other manufacturing and construction disciplines, at the engineering level and also at the operational level." A trend that AWS anticipates is increased used of automation in welding production. Integration of processes, and increased automation, are made possible by computerized data that is easily conveyed between computer programs. All current efforts to define standard manufacturing data, cite that standard data formats can facilitate increased use of automation, better coupling between product design, process design, and fabrication, all of which result in better, less expensive products.

THE DATA FLOW ISSUE

Many industries generate welding data for product design, manufacturing process plans, programs for automation, and inspection and quality control plans. Currently the data is represented using drawings, paper copies of tables and forms, generic word processing and spreadsheet programs, proprietary databases, and often as digital data encoded in a format specific to the brand of the device or software that will use it as input. Drawings of welded products are encoded in many different computer aided design (CAD) formats. Welding procedure specifications are recipes for making various types of welds, which are often recorded and shared using paper forms, word processing programs, or proprietary database formats. Results of weld testing are often faxed from testing lab to customer, or from sub-contractor to general contractor. Today, when welding data *is* put in digital format, it cannot be interpreted widely due to the variety of formats used.

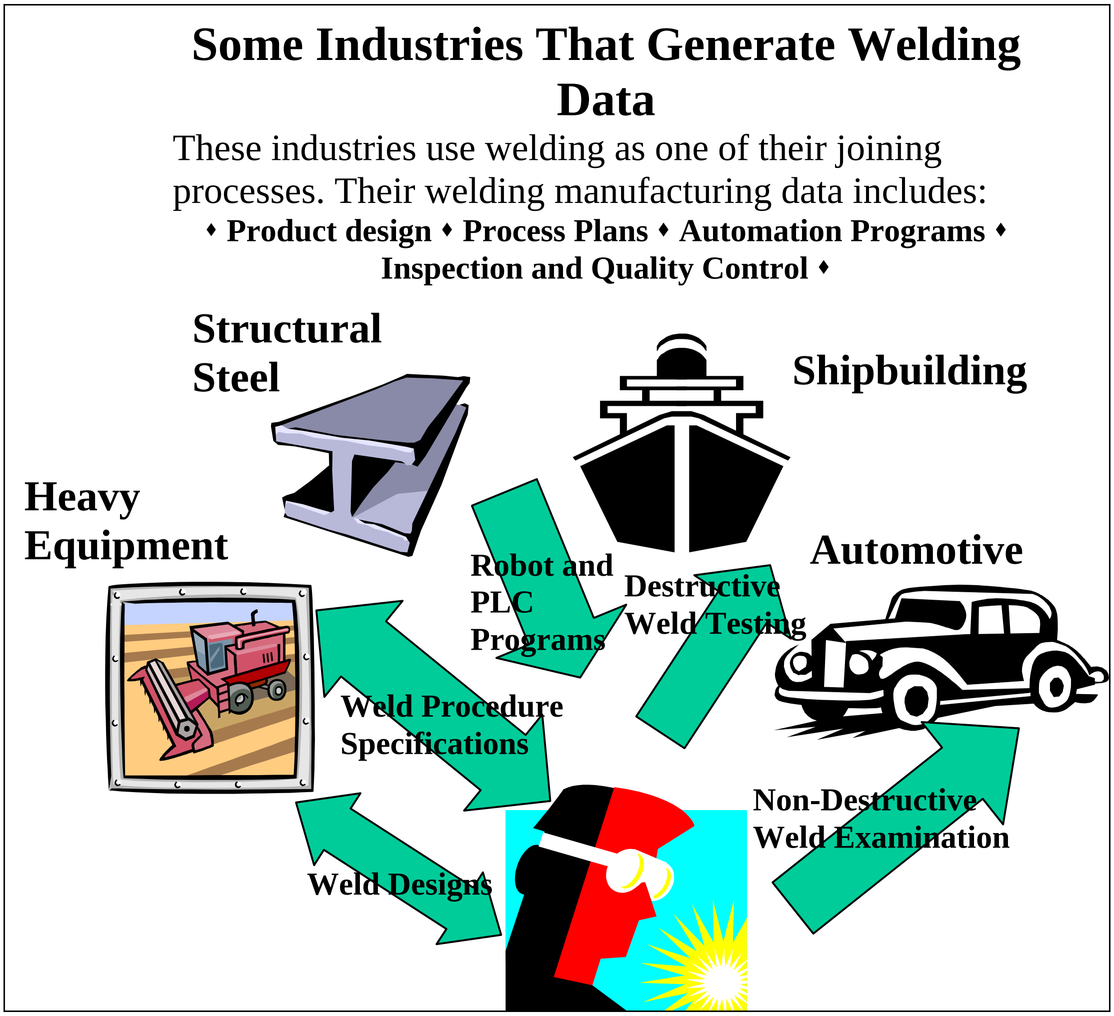

Figure 1 – Some industries that use welding technology

The Data (In)Compatibility Problem

The drawbacks of information stored on paper are fairly obvious: it cannot be used as input to computers or computerized processes such as robots and databases, it cannot be searched by computers, and it must be transformed by a person at a terminal to be useful to computerized processes. When a drawing of a highway bridge is described in a computer file, software can efficiently determine how many welds there are, and their lengths and sizes. From there, the software calculates quantity of consumable materials needed, their costs, estimates of labor hours needed, and identification of welder expertise level needed. Once the welding data is encoded for computers, determining these essential variables is almost as easy as counting the number of words in this document, or finding all instances of the word “connect”.

Computers can process digital manufacturing data efficiently and accurately, but when commercially available programs generate output in incompatible formats, software vendors expend extra development effort, and end-users are limited in choice of tools. Vendors often implement multiple data translators so their products will be compatible with other products. Software users limit themselves to buying components that are compatible with their existing system data formats.

The Benefit of Standard Data Formats

The benefit of standard digital data can be effortless, error-free transfer of information from one process to another. When digital formats are standardized, the brand of component you buy for your design department or manufacturing factory depends not at all on whether it can read or write a particular format, but only on how good a device it is or how much you like it. If your robotic welding cell were like a modern stereo sound system, your welding recipe for a ship hull section (music CD) would be effortlessly compatible with robot cell programming software (CD player). The automation program produced (audio signal) would flow effortlessly and error-free to your robotic cell (amplifier and speakers) regardless of who built the cell for you or whose components they used. The robot motions, coordinated with control of an arc welding power source, would produce the part you originally designed on a CAD system (a song, “Anchors Aweigh”). Hear the connection?

To summarize the benefits of standard formats: vendors don’t spend effort adapting their products for multiple data formats (and perhaps they then spend more time improving the product), and users get more choices of components – they can choose on the basis of familiarity, functional quality, company policy, anything but what flavor of data it can read or write. In the big picture, quality of welding manufacturing systems may improve, just because the choice of compatible components is wider, and it is easier to try different combinations.

A FEW DATA SPECIFICS

For the industries of shipbuilding, structural steel, and highway steel bridges, let's look at their efforts to define standard formats for digital data. We'll focus on the welding information in their current product definitions. As we go along, we could ask the people who perform welding some questions. Do they "see" different formats for identical or similar information, that will make their job of producing welded products more difficult or more expensive? Are the definitions rich enough to adequately describe the features of the desired products and details of the welding methods? Though there are probably few welding firms that weld for multiple industries, there are hardware and software vendors, and system integrators, that produce tools for all industries that use welding.

The goal expressed in this paper is to compare the information needs of the industries, and consolidate as much of it as possible. The following is an analogy using data models that might be used for a database of recipes for cooked meals. We would first define the terms for food preparation, e.g. cut, peel, measure and mix, then categories of ingredients: vegetables, spices, poultry, fish, grain, then categories of applying heat: bake, fry, deep fat fry, boil, poach. These terms would be a foundation for all food preparers. Then we could let experts in each area of food preparation hone their specific terms for pastries, pasta, poultry, seafood, and ethnic recipes.

The three efforts we review are ISO 10303 (STEP) *AP 218 – Shipbuilding Structures* (published May 2002), *CIMSteel Integration Standard* (2003), and National Cooperative Highway Research Program (NCHRP) Project 20-64, *XML Schemas for Exchange of Transportation Data.* This is the newest effort, begun in March 2004, with milestones in late 2004 and in 2005. All three are recent efforts, and AP 218 and CIMSteel are existing documents that are being revised as an ongoing effort.

ISO 10303 AP 218 is a part of STEP, the Standard for the Exchange of Product Data. Application Protocol 218 describes the product definition data for ship structural systems. Its scope is the design and manufacturing phases of shipbuilding. Its formal designation is ISO/DIS 10303-218:2002, dated May 28, 2002. This very large document describes data flow in the shipbuilding industry and the details of the data, using formal data modeling techniques. We will look only at the welding definitions. AP 218 has the richest set of welding data of the three, with 18 entities and 25 data types.

The **CIMSteel Integration Standard version 2.0** (CIS/2) is the product model and electronic data exchange format for structural steel project information. Its scope is design and manufacturing of buildings, using structural steel. CIS/2 was produced by ten years of effort by Leeds University (UK) and Steel Construction Institute and has now been adopted by the American Institute of Steel Construction as well. Version 1 was implemented in 1995, followed by Version 2 in 1999. Its goal is to allow seamless flow of information among design, analysis, and fabrication software programs. AP 218 and CIS/2 share the use of the Express language for modeling data. The latest version of CIS/2 is 2.1, published July 2003.

The newest effort is **National Cooperative Highway Research Program (NCHRP) Project 20-64, *XML Schemas for Exchange of Transportation Data***. Its goal is to develop a set of Extensible Markup Language (XML) schemas for transportation applications. It has not produced a standard yet. The scope of NCHRP 20-64 includes highway bridge structures. A previous effort, NCHRP 20-07 Task 149, has developed a draft data model, and thus the group has the farthest to go in establishing data models and formats, and also potentially the most to gain by leveraging a high quality effort in modeling welding data. This project began on March 1, 2004, and has milestones in the years 2004 and 2005. The time may be ripe for sharing some knowledge.

This brief survey considers two aspects of the welding information models: their things and actions, or *entities*, and the names used as labels for the entities. If the three committees who are designing data formats generate entities in common, it means their information needs are similar. Elements that occur in one specification and not the others means either that the need for the element is unique to that specification, or the other groups have not considered the element. An example of comparing information models is comparison of address databases among countries. Databases for the United States and France share identical entities of street address, city, country, county or province, and they both store alpha-numeric strings in addresses that help their mail delivery systems route mail. The U.S. label for this string is *zip code*, the French label is *code postal*.

The CIS/2 specification has 27 entities and 22 data types related to welding. The AP 218 specification has 18 entities and 25 data types related to welding. NCHRP 20-07 Task 149 has 5 entities and 31 data types which it calls *attributes*.

One High Level Entity Example

The first example compares the ***WELD_MECHANISM*** element of CIS/2 to the ***WELD_JOINT_DESIGN_DEFINITION*** element of AP 218. The two are quite alike. By the way, the figures below were produced using a single software data display tool. This is possible because CIS/2 and AP 218 are both described using the same modeling language, called Express.

As you scan the data definitions in Figures 2 and 3, you will see some words that appear in both: *fillet, spot*, *groove* and *butt*. You can connect the meaning of the definition in one specification to the meaning of the other. The two specifications, for structural steel and shipbuilding, share several similar entities.

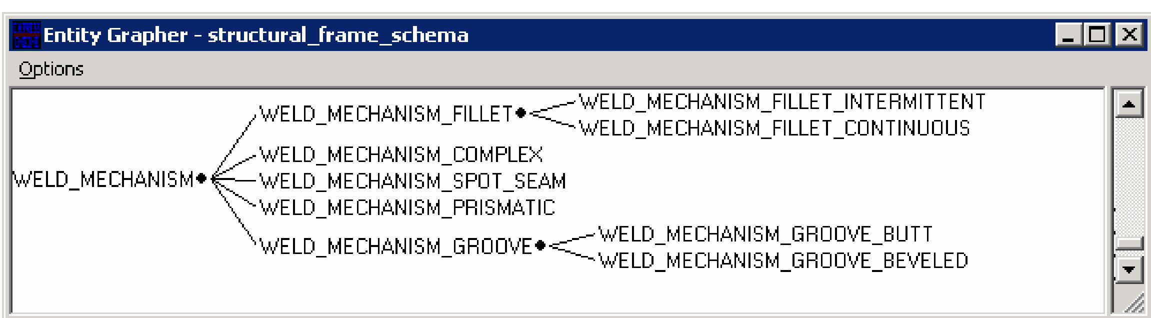

Figure 2 - The WELD_MECHANISM entity from CIS/2, the structural steel data format.

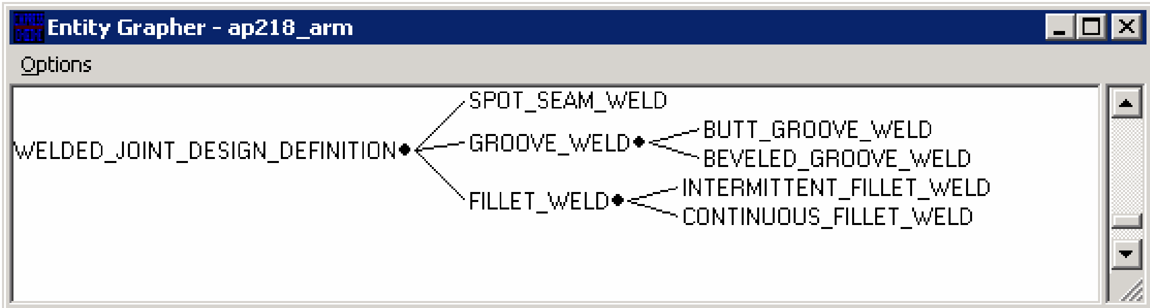

Figure 3 – The WELDED_JOINT_DESIGN_DEFINITION entity from AP 218 Shipbuilding.

NCHRP 20-07 describes two weld types, *fillet_weld* and *groove_weld*, though it did not call them out as formal definitions. It lists a data attribute of *weld_classification*, which may be intended to encompass these two weld types.

These two entities in CIS/2 and AP 218 are very similar, indicating similar information needs in the shipbuilding and structural steel industries regarding weld types. In general only a few entities and types in CIS/2, AP 218, and NCHRP 20-07 are similar. This indicates that some of their data needs are similar. However, all of the efforts fall far short of the richness described in AWS documents.

A Data Name Example – If You Say *Welding* and I Say *Soudage*, Did We Connect?

Even if we agree on the entities of our data, do the exact names matter? There are at least two reasons that exact names matter. First, the names may be used to generate the encodings of the computer data formats. Even slight differences between the names will be recognized by computers as totally different entities. Second, names are used for recognition by people reading and for understanding the data model. We should harmonize the names as well as the types and entities.

Data format names matter – we can harmonize them!		
CIS/2 Structural Steel	**AP 218 Shipbuilding**	**NCHRP 20-07**
TYPE weld_penetration = ENUMERATION OF (full_penetration, deep_penetration, partial_penetration, undefined); END_TYPE;	TYPE weld_joint_penetration = ENUMERATION OF (FULL, PARTIAL); END_TYPE;	Comment on weld_classification attribute: - complete penetration - partial penetration

Figure 4 – type definitions for penetration, the distance the melted metal extends into a joint.

Figure 4 shows the data entities that describe weld penetration, a common design parameter that states how much of the original material of the weld joint is melted. A welding expert understands the names "full_penetration", "FULL", and "complete" as essentially the same. Though these three data entities express the same welding concept, they use different names to do it. A computer program needs consistent tags to recognize data elements and would need a translation table to determine the equivalence. Regarding CIS/2's "deep_penetration", welding experts will have to get together to decide if they all need it.

Someone Has Already Thought About Welding Data Terminology

The welding world has several reviewed and tested documents that suggest names for welding data objects. You can buy these documents online. An essential document is *AWS A3.0 Standard Welding Terms and Definitions*. It is formatted primarily for people that speak and write about welding, but is not directly suited for computerized formats. However, it can be a stepping-stone to the design of formal data models. The document comes with a cast of experts that continue to maintain it and improve it every two years. If you join the A9 committee of AWS you can meet some of them, and they will help you build data models to help your industry.

AN APPROACH TO CONNECTING WELDING DATA DEFINITIONS

The American Welding Society is well suited to host the consensus welding data definition effort. It routinely brings together people from different industries, people with intellectual and economic stakes in the results. AWS is sanctioned by ANSI, which means it has credentials, as well as procedures, for gathering experts and achieving balanced standards that have had industry review. Members of the shipbuilding, highway bridge, and structural steel industries would join a committee of AWS, likely A9: Computerization of Welding Information. Members of other AWS committees may join A9 as advisors or members, to contribute expertise in welding technology and in standards development – they have a stake in the standards effort too. The best approach for a useful document across many industries is to develop a data dictionary that leverages existing AWS and/or ISO documents. The data dictionary is the result of welding experts pooling their knowledge and recording it in a way that it is one step away from being massaged by a software expert into formal computerized language. The advantage is that welding experts, not computer experts, build the data dictionary, and a data dictionary can be encoded by the software experts into various formats, e.g. XML or STEP. The foundation information remains the same, which makes future translations between formats, if needed, very easy.

AWS has recently adopted internet meeting technology to minimize travel but not reduce the effectiveness of groups. This reduces the overhead of participating in a standards effort. The scope of the effort will be modularized so efforts could be incremental, leading to the first stage that would be modest but quick to fruition. This effort would include identifying diverging or mutually exclusive needs of the industries and isolating them for later study. A top-down effort that considered the most important common data needs in product CAD design files would be a good start. The details of weld joint design, and weld process specification could be tackled after the scope definition has matured and the committee has become a well-oiled information manufacturing factory. Subsequent technical areas are: specification of weld testing methods, both destructive and non-destructive, recording weld test results, pipe welding, aluminum welding, railroad applications, aluminum ship hulls, and even terms for describing the skills qualifications of welders.

Among the many mature AWS document resources are: *AWS 3.0 -- Standard Welding Terms and Definitions, AWS D1.1: Bridge Welding Code -- Steel*, *AASHTO/AWS D1.5M – Bridge Welding Code*, *D1.4-98 Structural Welding Code --Reinforcing Steel* and *B4.0-98 Standard Methods for Mechanical Testing of Welds*. It seems as if some AWS members have already been thinking about these areas.

Specific Goals

- Draft a scope document two months after the initial meeting. This will define the major areas of welding information that the three industries care most about, and possibly in what order they will be addressed. This will reveal, before the work begins, how much consensus there already is. This stage will also identify the most applicable AWS standards documents.
- Produce a draft document of the high level data definitions six months later

- Expect that an AWS standards could be approved in about a year after final draft if the committee meets frequently enough, and if industry comments are not counter to the document's content.
- Begin a phase two round of additions to the scope eighteen months after first meeting. At this point if there are different data needs, separate sub-groups may be formed to refine specialized needs.

Some Possible Challenges

- The obvious, potentially rewarding goal is to define some level of definitions that these industries have in common. Welding engineers from each industry will get together to try to gain consensus.
- The committee will decide emphasis on international versus U.S. audience. There are U.S. and ISO versions of welding standards that are often not identical.
- The automotive industry is a huge user of welding, but applications tend more to thin metal stock, and spot welding, features not used in the original three industries. Will they be interested in an effort begun for heavy manufacturing welding? Could they join the effort and still produce some consensus definitions?
- Each industry loses a little leverage over its current definitions. Do they lose their favorite terms of usage, or specialized techniques? If the original scope is modularized, they can establish a derived data set for their industry that includes synonyms for AWS terms, and adds specialized information that may be specific to only their industry.
- AP 218 is fairly mature. Would its committee members be willing to compromise to adopt to a common set of definitions? Several software vendors have implemented CIS/2, and they may be reluctant to consider changes to the specification.
- AWS and ISO welding standards don't specify information about the geometry of the weld path, as both AP 218 and LPM-6 do. The shipbuilding and structural steel industries may choose to agree on welding terms, and then treat geometry as a separate issue.

THE PAYOFF

One result of a well run standards effort will be consensus -- connections between people that verify that we agree on information concepts and that our goal is mutually beneficial. A committee effort is a challenge, but the project would be supported by organizations whose purpose is to bring people together. The technical result will be better connections between digital design and manufacturing processes. Data that can be digested by more software products facilitates better designs and manufacturing processes, that result in higher quality products.

A concentrated effort by these three industries may allow other industries to leverage the initial specifications, and establish standards that satisfy their specialized needs much faster. A single core of data definitions that apply to multiple industries will present the welding industry with fewer dialects of electronic data to use.

SUMMARY

The next time you drive your car over or under a bridge see if you can find some welds in its steel. Or, the next time you take a ferryboat ride or an ocean cruise, know that the hull of the ship is held *entirely* together by welds. The quality of those welds is critical to your safety. The quality of the information used to make the welds affects their cost, strength and longevity. Manufacturing industries can make a choice about how the design and manufacturing data of those welds is recorded and shared. It can be expressed on paper. It can be put in computer data formats that can be read by some software programs, but not by others. Or, it can be computerized in a format that all design and manufacturing programs can read, so the design can be optimized for strength, the fabrication will produce high quality welds at lowest cost, and your ocean liner will have its best chance to float through rough seas. Given the choice, which way would you like the design and fabrication of *your* ship's welds to be described? Bon voyage!