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Proceedings of NIST Workshop: Industry Needs in Welding Research and Standards Development

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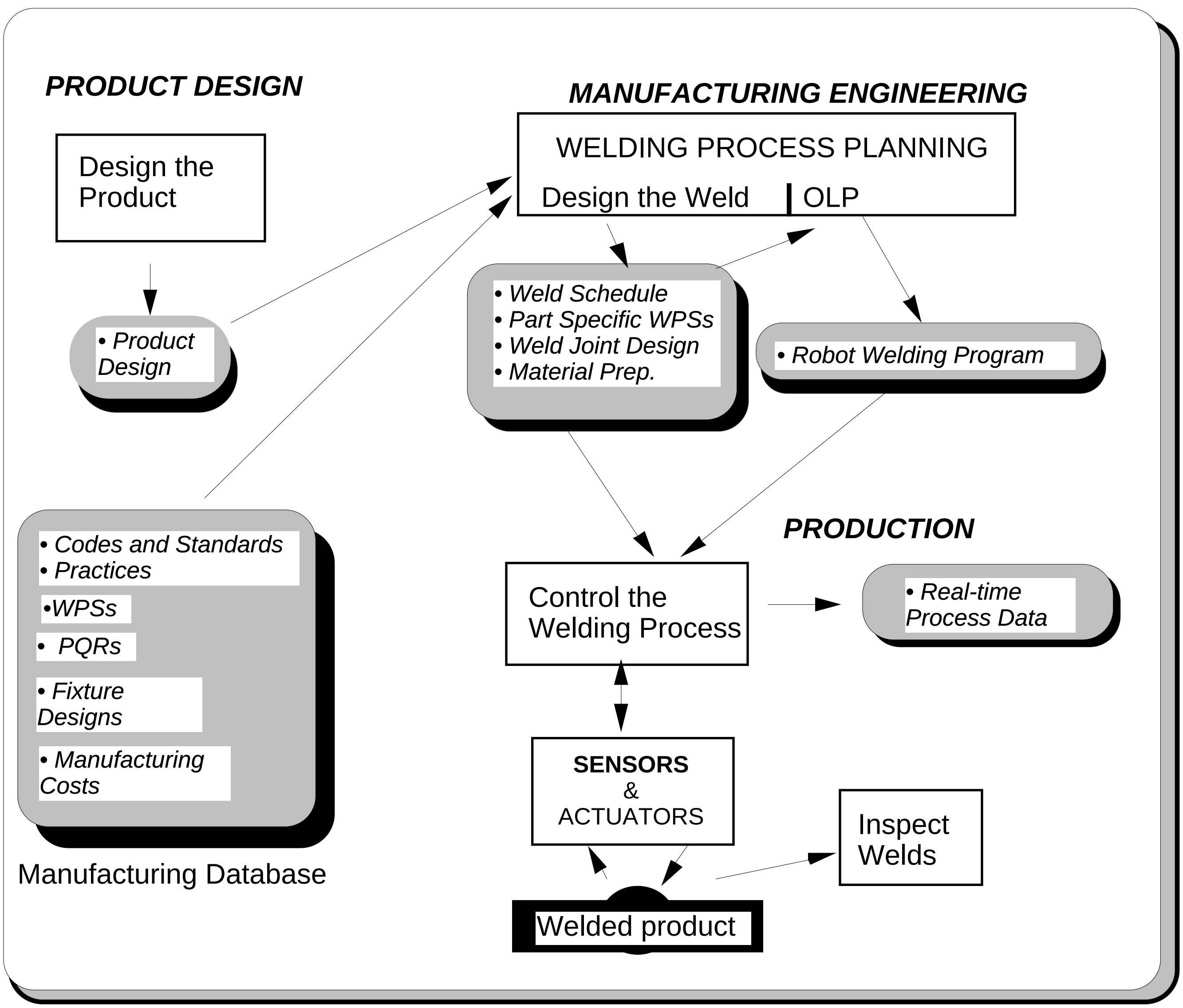

Note: Certain commercial equipment, instruments, or materials are identified in this paper. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment identified are necessarily best for the purpose.

Contents

Proceedings of
NIST Workshop:
Industry Needs in Welding Research and Standards Development

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Thirty-two attendees representing technology users, technology providers, private and university research, and government gathered for this two-day workshop on welding technology. The purpose was to form recommendations to NIST on how to direct its resources to best meet needs of the manufacturing industry. NIST's new research efforts are proposed to be concentrated in the Automated Welding Manufacturing System (AWMS) project.

The meeting produced extensive discussions about welding technology needs. The needs were broadly divided into standards and technology research. Sub-topics were formed to define emphasis. In order to make recommendations to NIST, there was one round of voting to prioritize the sub-topics. More detailed comments were documented by using an on-line group software system to gather inputs from terminals and display them on a projection display.

The attendees defined twelve sub-topics. The top four ranked, indicating where Industry has the strongest needs, were: Interface standards for data exchange, Electrical and mechanical interface standards, Predictive process models and knowledge base, Simulation and off-line programming.

NIST is using the ideas expressed in the workshop to form 3-5 year project plans for AWMS. We are matching the highest priority areas to the capabilities, funding and staffing available. We are planning to form teams with those who can provide skills and equipment that we are missing.

Keywords: technology providers, technology users, welding research, welding standards, welding technology, workshop, manufacturing

1. Introduction

1. 1 Purpose of the Workshop

The workshop was held to address:

- Providing direction to NIST for development of a testbed for investigating technology and integration issues of computerized systems for intelligent, automated, continuous arc welding. NIST proposes an Advanced Welding Manufacturing System (AWMS) as the testbed, available to NIST's industry partners, which will support experiments in welding.
- The need to integrate computer-based welding systems through neutral data formats. Integration means that output of one system is compatible with input of another system. Systems include application-specific computer-aided-design systems (e.g. structures, piping, automotive), weld design, welding process planning, real-time process control, and quality control.

The agenda for the 2-day Workshop is in Appendix B.

1.2 Goals of the Workshop

The goals of the workshop were:

- Introduce the NIST plan for AWMS and invite participation in joint research.
- Generate recommendations from participants about the most important problems and issues for NIST to address, and the approaches to use.
- Identify resources (companies, government agencies, people, funding sources, etc).

1.3 Attendees

There were 32 attendees, including 7 from NIST.

Robert Allen	American Welding Institute
V. Ananthanarayanan	General Motors' Delphi Division.
Lawrence Atterholt	Hobart Brothers Co.
Joseph Baumer	Newport News Shipbuilding
Tom Doyle	Babcock and Wilcox ARC
Joe Falco	NIST, Intelligent Systems Division
Brian Friedrichs	General Dynamics Land Systems
Kyle Harrington	Newport News Shipbuilding
John Hinrichs	A.O. Smith Corp.
Edmund Hobart	Motoman Inc.
Todd Holverson	Miller Electric
Jerald Jones	Colorado School of Mines
Maris Juberts	NIST, Intelligent Systems Division
Mary Jane Kleinosky	Concurrent Technology Corp.
Bryan Lyons	American Welding Society
Bruce Madigan	NIST, Materials Reliability Division
Zane Michael	Motoman Inc.

Attendees (continued)

Joel Milano	Naval Surface Warfare Center, Carderock Division
Tim Quinn	NIST, Materials Reliability Division
Bill Rippey	NIST, Intelligent Systems Division
Bob Rongo	CYBO Robots
Bob Russell	NIST, Intelligent Systems Division
Don Schwemmer	AMET
Mike Sellers	ABB Robotics
Tom Siewert	NIST, Materials Reliability Division
John Sizemore	Ingalls Shipbuilding
David Trees	John Deere Technical Center
Mark Treichel	Deneb Robotics
Ilhan Varol	Caterpillar
Xiaoshu Xu	American Welding Institute
David Yapp	Navy Joining Center
Glenn Ziegenfuss	American Welding Society

2. Background

2.1 Recent American Welding Society Standards Efforts

Jerry Jones gave an introduction of the activity within AWS Committee A9, Computerization of Welding Data. Jerry is the immediate past chairman of A9. He described the lack of computer based standards for welding information in 1986 and how this drove the committee to develop standards. Joel Milano, the present chairman, presented the future plans for Committee A9 in the areas of interfacing between CAD systems and off-line planning. He also described the neutral file formats that are being developed independently by CYBO Robots and by Babcock and Wilcox.

2.2 NIST Background in Welding Technology and Manufacturing

The Intelligent Systems Division (ISD), of the Manufacturing Engineering Laboratory, began an effort to investigate technology in automated arc welding in 1995. ISD joined with the Materials Reliability Division (MRD), a group already experienced in welding process research, to pursue cooperative efforts in welding technology.

The Intelligent Systems Division has over 15 years of experience in the development and application of real-time control technology. We have developed and applied an engineering methodology called Real-Time Control Systems (RCS) to the analysis of problems and the subsequent development of computerized control hardware and software systems. Applications for RCS have included manufacturing control and integration (e.g. the Automated Manufacturing Research Facility (AMRF)), control of autonomous vehicles, robotic deburring, and robotic crane technology. Scope of the activities has included sensor integration, servo-level control, path planning, off-line task planning, and real-time image processing.

The MRD, located in Boulder, has established itself as a leading research laboratory in developing diagnostics for the arc welding process. MRD has developed and demonstrated methods for control of the process using cost effective computer systems. Welding technology was further advanced during a major 3-year programmable arc welding program with the U.S. Navy.

Other significant NIST progress includes:

* Several corporations are evaluating NIST arc sensing technology in the production of automotive components.
* The Materials Reliability Division was awarded U.S. Patent 5,221,825 in 1993 for the general sensing strategy and several more patent applications have been filed
* The ARPA Technology Reinvestment Program funded a joint program (with Cybo Robots and other automation vendors) to incorporate NIST's present sensing technology in an advanced robotic welding system for shipbuilding.
* ISD has consulted with an experienced commercial partner who would like to participate in the development of an advanced intelligent control system for arc welding equipment. They have been working on a simulation environment product for the arc welding industry and have collaborated with partners in the automotive industry, heavy construction equipment industry and others.

2.3 Current AWMS Concepts

This section describes our concept for the AWMS project at the time of the workshop. The workshop recommendations will be used in establishing AWMS project goals and in planning the project for the next few years.

Need

ISD research aims to improve automation technology to greatly expand the range of applications where machines can perform reliable welds in a cost effective manner. In a 1991 study, the Construction Industry Institute identified welding as one of the top three needs (out of fifty) for automation in construction. This high ranking was based on issues such as safety, productivity, and worker utilization. Further, it is often difficult for users to integrate commercial computerized components of welding design, planning, and automation systems due to incompatibility of their input and output data. The American Welding Society formed a new committee (A9) in 1989 to address this and related issues.

Goals

- Develop improved technology for automated welding using “practical cost” computer systems.
- Develop standard techniques for integration of computerized welding components.
- Transfer advanced welding technology to industry for applications including, but not limited to, ship building, automotive manufacturing, heavy equipment manufacturing, building construction, bridge construction, and off-highway vehicle assembly.

Approach

- Assess industry needs in welding technology.
- Build an Advanced Welding Manufacturing System (AWMS) as a testbed. Integrate autonomous gas metal arc welding technology, including research results from the Materials Reliability Division, with advanced robotics and controls.
- Conduct AWMS activities with industry partners that are based on industry-stated needs. Use the AWMS to demonstrate affordable improved production techniques and quality control procedures for manufacturing industries.
- Work with experienced industry partners to commercialize new technology which increases productivity and improves quality for welded products manufacturing
- Provide industry with state-of-the-art process models and algorithms. Participate in developing versatile control architectures and standard data formats.
- Leverage existing in-house projects such as Enhanced Machine Tool Controller (EMC) (open architecture NC controller), and Advanced Deburring and Chamfering System (ADACS) (CAD directed robotic deburring) projects to get the AWMS up and running more quickly.
- The scope of the AWMS will extend from weld design using commercial CAD systems, off-line programming of robotic welding, and real-time control of arc welding parameters using sensor data and intelligent computer control systems. Advances in autonomous control of the arc welding process will be achieved through the use of advanced sensing, modeling, simulation, and operator monitoring and control stations.

Benefits

- Advanced real-time control technology and robotics technology tested at NIST will be used to help develop new intelligent control systems for the arc welding industry. Users will have better technology for automated welding that can match or exceed manual weld quality at lower cost, with higher productivity.
- Components that satisfy interface standards can be more easily integrated by users. If multi-vendor components become interoperable, supplier competition will increase, which will mean a continuous stream of improved modules which will easily interface with existing installations.

3. SCOPE OF THE WORKSHOP

3.1 Questionnaire

A questionnaire was sent to all people invited to the Workshop. The following topics were cited as broad starting points for discussions at the Workshop. The responses received before the workshop are included in section 5. The workshop discussions expanded the list to the 12 items presented in Section 6.

Standardization, and Welding Technology Research

- General issues
- Sensors
- Models and knowledge bases
- Computer requirements
- Welding power supplies
- Robots and actuators
- Architecture
- Control systems
- Simulation and off-line planning
- Other

3.2 Welding Activity Model

Figure 1 is a model that shows the processes and information flow involved in manufacturing activities using welding. The model was presented to stimulate and focus discussions--it will be revised and expanded to be used as a tool in defining project scope, defining system requirements, and developing detailed architectural specifications.

Processes are shown in square boxes, information conveyed between processes is shown by shaded round-cornered boxes. The model does not assume computerization or automation of all processes or data. There are three major types of processes: product design, manufacturing engineering, and production.

3.3 AWMS Model

Figure 2 is a more detailed view of the activities that are within the scope of the initial AWMS project proposal. Initial scope includes: weld design using commercial CAD systems, off-line programming of robotic welding, and real-time autonomous control of arc welding parameters using sensor data and intelligent computer control systems. Processes will be developed by NIST, or will be supplied by research partners.

While developing and testing a detailed architecture we will identify interfaces that may be candidates for standardization. Initial project scope includes neutral language formats for product design and process control information, interfaces for performance measures and post-process evaluation, and interfaces for distributed operator monitoring and control.

4. PRESENTATIONS

4.1 User Presentations

Three industry attendees gave invited presentations on their companies' experience and needs in welding technology. Below are very brief descriptions of the presentations.

John Hinrichs, A.O. Smith - A.O. Smith products include light and heavy truck products, including frames and engine cradles. Issues John cited included:

- their customers supply product design CAD files that are formatted according to CAD system-dependant specifications. These files are often not compatible with software packages that simulate manufacturing processes, and with packages that are used to perform finite element analysis for mechanical testing.
- wire delivery systems with condition monitoring are needed, especially to predict failure for maintenance scheduling
- production data from workcells needs to be uploaded and used to validate and improve process models.
- raw weld data is massive and uniformative--it should be reduced to conclusions about the weld quality as soon as possible, especially to be used to meet customers requests for ISO 9000 conformance.

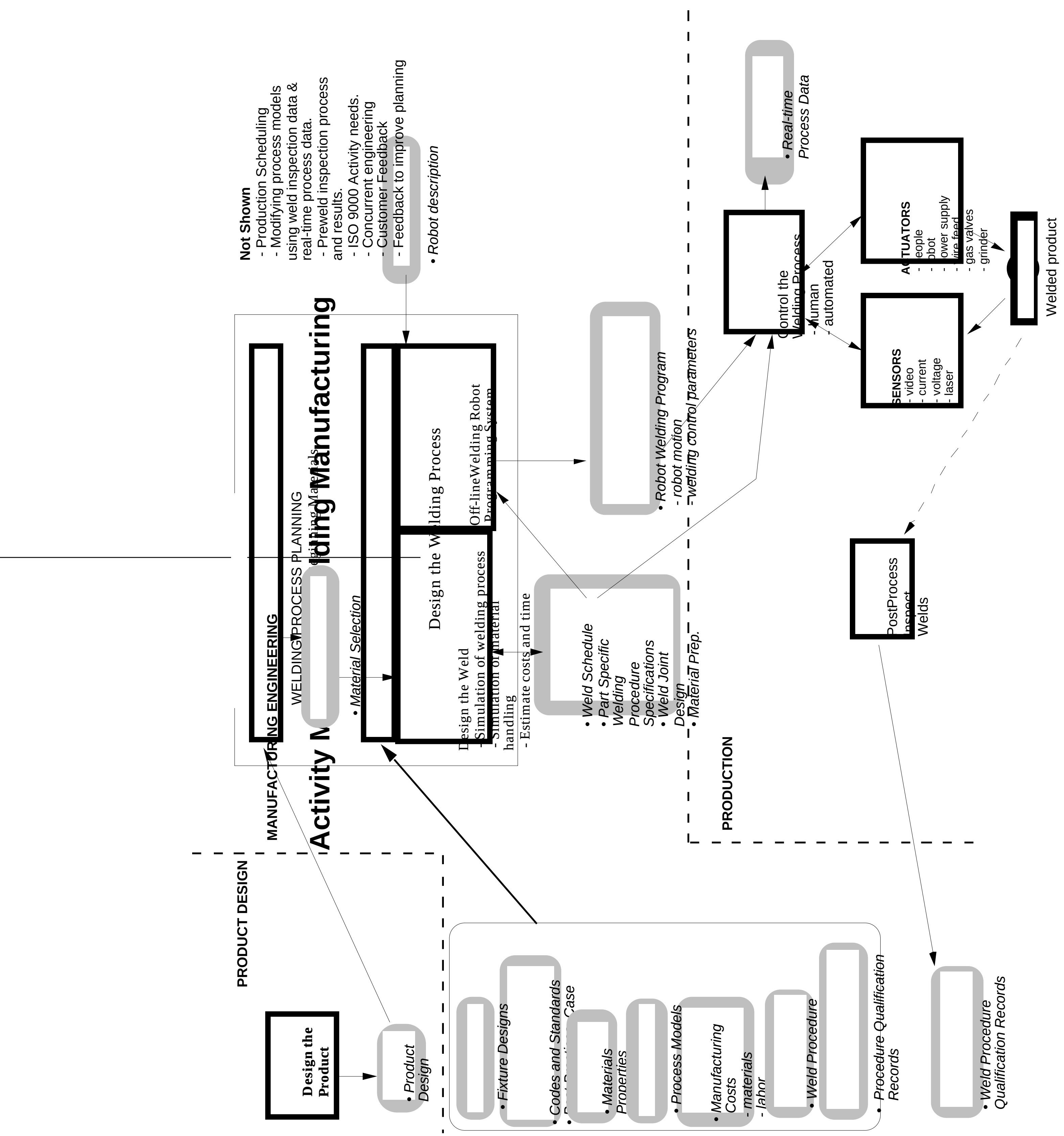
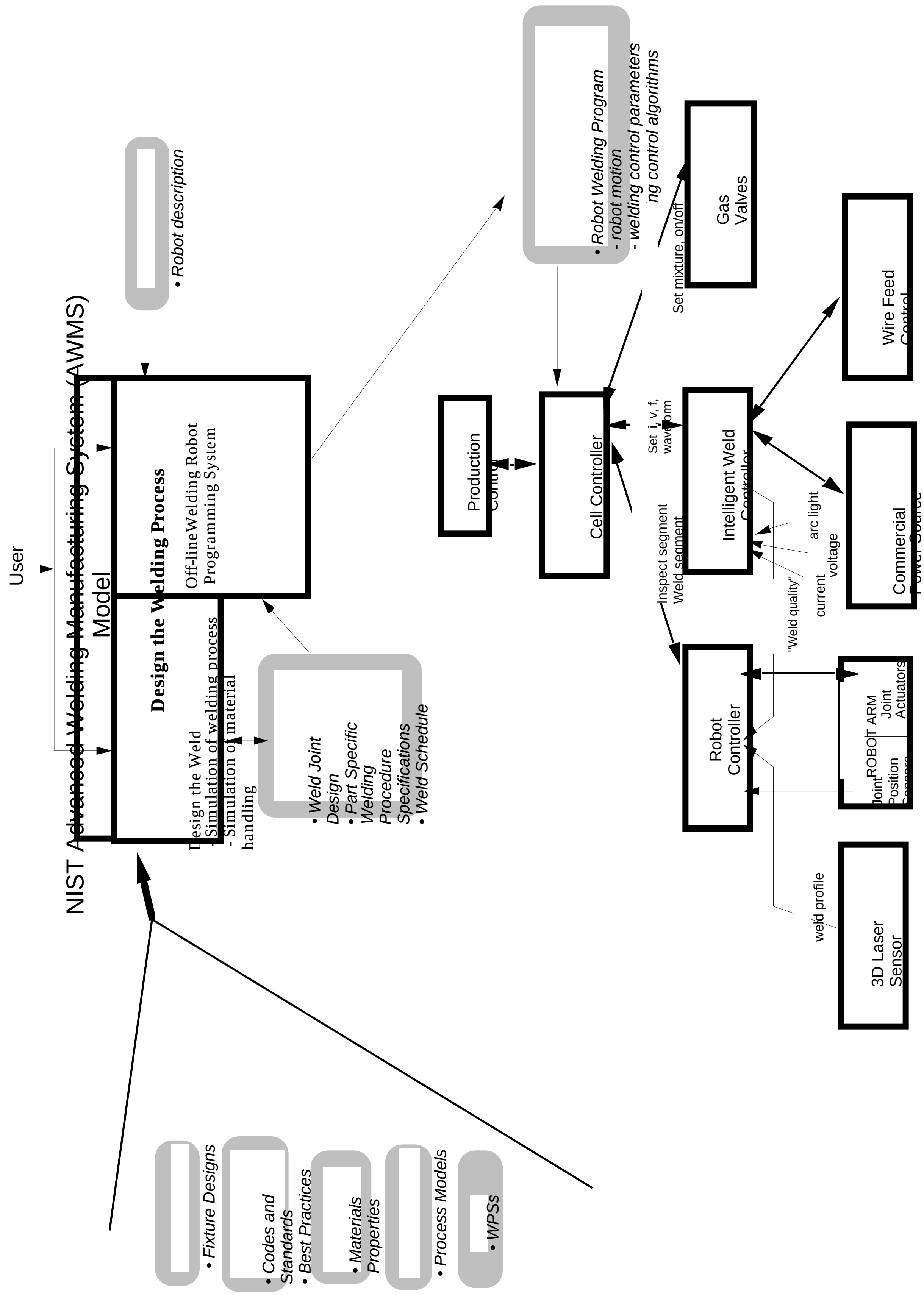

Activity Model: Welding Manufacturing
PRODUCT DESIGN
Design the Product
• Product Design
MANUFACTURING ENGINEERING
WELDING PROCESS PLANNING
• Material Selection
Design the Welding Process
Design the Weld
- Simulation of welding process
- Simulation of material handling
- Estimate costs and time
Off-line Welding Robot Programming System
• Weld Schedule
• Part Specific Welding Procedure Specifications
• Weld Joint Design
• Material Prep.
• Robot Welding Program
- robot motion
- welding control parameters
Not Shown
- Production Scheduling
- Modifying process models using weld inspection data & real-time process data.
- Preweld inspection process and results.
- ISO 9000 Activity needs.
- Concurrent engineering
- Customer Feedback
- Feedback to improve planning
• Robot description
PRODUCTION
Control the Welding Process
- human
- automated
• Real-time Process Data
ACTUATORS
- gas valves
- grinder
SENSORS
- video
- current
- voltage
- laser
Welded product
PostProcess Inspect Welds
• Fixture Designs
• Codes and Standards
• Materials Properties
• Process Models
• Manufacturing Costs
- materials
- labor
• Weld Procedure
• Procedure Qualification Records
• Weld Procedure Qualification Records

Figure 1.



NIST Advanced Welding Manufacturing System (AWMS) Model
User
Design the Welding Process
Design the Weld
- Simulation of welding process
- Simulation of material handling
Off-line Welding Robot Programming System
• Robot description
• Weld Joint Design
• Part Specific Welding Procedure Specifications
• Weld Schedule
• Robot Welding Program
- robot motion
- welding control parameters
Production Control
Cell Controller
Intelligent Weld Controller
Robot Controller
Gas Valves
Wire Feed Control
Commercial Power Source
ROBOT ARM
Joint Actuators
Joint Position Sensors
3D Laser Sensor
Set mixture, on/off
Set i, v, f, waveform
Inspect segment
Weld segment
arc light
voltage
current
"Weld quality"
weld profile
• Fixture Designs
• Codes and Standards
• Best Practices
• Materials Properties
• Process Models
• WPSs

Figure 2.

David Trees, John Deere Technical Center - John Deere builds heavy equipment and agriculture machinery. Some of the subjects David discussed were:

- Deere is working to adapt the welding technology, currently used for high-value welds, to mid-value weld production.
- controls for production components should be integrated seamlessly to reduce the number of interfaces and modules that engineering and maintenance staff have to deal with.
- operator interfaces to systems must be improved. They must allow easy programming of automated systems and provide easy to understand feedback.

Joe Baumer, Newport News Shipbuilding - Joe cited the characteristics of shipbuilding, including small batch quantities, long product cycles, large product size, complexity of parts and assemblies, and difficult accessibility to weld joints. Needs for welding systems include:

- need to handle complex geometries with limited physical access
- automated programming from CAD data.
- improved product designs for producibility/weldability, including the reduction or elimination of tack welding.
- improved welding process, including increased speed, improved though the arc sensing, and adaptive fill capability.

4.2 Developing STEP Standards

Mary Mitchell of the Integrated Systems Division of MEL gave a presentation on STEP, the Standard for the Exchange of Product Model Data. The objective of STEP is to develop a general format for the sharing of engineering data, a concept that is finding broad application in industry. There are 84 active projects in STEP: most are in digital product data representation. Our welding applications could be best served by development and use of STEP application protocols (APs). The primary purpose of these protocols is to define the scope, context, and requirements of an application. They also specify the information needs of the applications, and state conformance requirements for evaluating the compliance of products to the standards. The protocols can be further divided into ARMs (application reference models that define the requirements), and AIMs (application interpreted models, that map the requirements to the STEP standardized structures).

4.3 The NAMT Program

Dave Stieren of NIST gave a presentation on NAMT, the National Advanced Manufacturing Testbed. It is a successor to the Automated Manufacturing Research Facility, which had the participation for over 50 companies and 40 universities, and participated in development of 25 commercial products, 25 international standards, and 20 patents. One of the motivations for the NAMT was the National Science and Technology Council's recommendations for a stronger manufacturing infrastructure. The challenges included large-scale demonstrations and testbeds. The mission is to conduct cross-disciplinary research. Goals are to enable standards development for interoperability, encourage collaboration, and serve as a testbed for distributed (geographically dispersed) and virtual manufacturing research and evaluation. The AWMS may be developed as a NAMT project.

4.4 Forming Cooperative Research and Development Agreements (CRADAs)

Ernie Graf of NIST's Industrial Partnerships Program explained CRADAs and their advantages to both NIST and any industrial partners we may work with. The CRADA is a legal agreement that provides the federal laboratories and their research partners greater flexibility in accommodating the needs of each organization and research situation. Some issues covered are protection of a firm's proprietary information, treatment of research results so a partner can retain any competitive advantage from its investments in research with NIST, and patent rights.

5. DISCUSSION

5.1 Workshop Methodology

The methodology for forming the recommendations to NIST was based on using the "Group Software System" to gather comments from attendees, form a small number of technical areas, and then to prioritize the areas by voting. The System comprised five user terminals networked to a server which an operator used to prompt people, and to gather and process typed inputs. Inputs and processed results generated on the server terminal were displayed to the attendees using a projection device. The goal in using the System was to allow the attendees to generate comments and form the recommendations, without intervention or interpretation by an editor. Don Freedman of the Defense Systems Management College (DSMC), Ft. Belvoir, Va. was moderator of the discussions.

5.2 Categorized Input from Workshop Participants

Open discussions were conducted for several hours of the workshop. There were no separate break-out groups: all attendees were present for all discussions. The information in this section is "raw" data that came from questionnaire responses received before the Workshop, and data typed in by attendees, during moderated workshop discussions, using terminals of the Group Software system. Section 6 contains the recommendations that came from the Workshop, namely the prioritization of the 12 technical areas formed by the group.

The recommendation information is grouped under twelve categories that were formed during the discussions. When a comment was made by more than one person, the number of entries is shown in parentheses. The comments are answers to the questions "What welding technology or standards areas are important to your company?", or "What is your recommendation to NIST in conducting technology research?". The comments made by workshop participants are in italics.

Editing of entries has been limited to correcting typos, eliminating duplicate comments, and placing some of the comments into categories. No comments that were entered have been omitted.

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1. **INTERFACE STANDARDS FOR DATA EXCHANGE**

- *CAD/OLP interface, OLP/Robot controller interface, and Simulation/Robot interface. (6 responses)*
- *In general, please make sure that you clearly understand what other funded projects have accomplished and what roadblocks they have run into. Examples: SMART/WELD (Sandia), WELD/EXCELL (AWI), CYBO Robotics. Otherwise, you cannot benefit from their learning curve.*
- *It is important to include the factors which will be important at the shop floor. Data exchange will start from design to post weld inspection. We would want to also include data coming from real time process control and use this data in an intelligent way.*

  CYBO Robots is currently designing and building an interface which enables data transfer of ship panel assemblies into solid format (with weld specifications) suitable for path planning by off-line programming systems. This work is being performed under a TRP project. We would be willing to share the data exchange format for possible use as a AWS A9 standard for ship data exchange between ship assemblies and OLP systems. Our goal is to automate the off-line path planning (weld path and sensor requirements) of robotic ship assemblies to a point where a user is only required to handle exceptions.

  - *There are a number of interfaces which should be reviewed before tackling this project.*
- *Language concepts from Postscript have great similarity with some of the automation issues; there is shape description, external controls, and error reporting.*
- *A few years back, the electronic musical instruments were having the same issues as automatic welding is facing today. The result was the creation of the MIDI (Musical Instrument Digital Interface). With MIDI, each component has its own controller and all of the instruments in a group are tied together through a sequencer. We need each component in our cell; the power supply, positioner, robot, and even the CAD input systems, to speak the same language through a standard interface connector. MIDI was able to look ahead and, as more advanced instruments have been introduced, MIDI has been able to control them. This is a very practical approach. There also needs to be a facility provided through the Standard to allow the programs, or sections of programs, to be up-loaded to higher machines for storage, retrieval, and transfer to other sites/companies.*
- *Consolidate the various efforts by different organizations for weld standardization, procedure development, and weld requirement definition. Standards are desperately needed throughout the welding environment. Other parts of the world are moving ahead of the U.S. because their governments provide significant support to the standards development efforts. NIST can help this problem by using their facilities to develop standard prototypes that can then be evaluated and modified by the "volunteer" standards committees in industry*
- *Need to assert U.S. influence in world standards.*
- *Common interfacing languages.*
- *Develop system so that different robot users can use the same protocol.*
- *Standard Electronic data movement*
  - *Process data into information move information to high computer level.*
- *Need standards for data between simulation and OLP (3 responses).*
- *Standards for identifying weld paths and weld requirements in CAD.*
- *Develop an neutral file interface standard for data exchange between ship assembly and off-line planning stations.*
- *Standards for OLP i.e., CAD data feedback.*

- *Architecture protocol for definition of "Open" and other styles.*
- *Robots/Accessories.*
- *Develop standards in regard to sensor interfaces. Currently sensors exist for pre and post inspection, preview and real time adaptive process control, etc.*
- *Standards for interface of robot control systems with sensors.*
- *Data acquisition protocol.*
- *Open architecture and PC based. Get manufacturers to listen*
- *Weld cell equipment communication standard.*
- *Common robot protocol*

2. **PREDICTIVE PROCESS MODELS AND KNOWLEDGE BASE**

- *It is believed that an awareness of Key Process Variables and sensor outputs will help drive improvements in equipment, fixturing and parts welded.*
- *Development of empirical weld model.*
- *Fundamental Property Data - most important, since we are currently limited as to the specific types and details of control, because we cannot easily or adequately understand the process.*
- *Models are constrained by the lack of mechanical and thermophysical data that is critically needed. Some development of this data is on-going, but not in an organized way, and it is only a drop in the bucket compared to the total amount of standard data that is needed. NIST can significantly contribute to the overall capability of welding by utilizing the system that they develop here to contribute to the overall body of knowledge in this area.*
- *There needs to be a US model/knowledge base on weld conditions and specifications for "typical welds" including torch angle, volts, amps, stickout, WFS, travel speed, etc..*
- *Should this data base be on Internet or be accessible from a computer service? Who should build and maintain the knowledge base?*
- *A simulation of projection weld heat flow/deformation to permit better nut/bolt welding to sheet material.*
- *NIST could significantly contribute to welding industry by organizing and maintaining a knowledge base relating weld procedures to weld quality/properties.*
- *US model/knowledge base on weld conditions, volts, amps, WPS on Internet.*
- *Need for US model knowledge base on weld conditions and specifications*
- *Integrated product, process, material models.*
- *Need to have models to predict process output to use in controls.*
- *Weld Process Knowledge.*
- *Accurate Process Models.*
- *Research on models for adaptive control.*
- *Neural net to work from accurate process models for adaptive control.*
- *Materials characterization (Fundamental material properties).*
- *Materials physical properties--tables.*
- *Features model relating macro to micro features and fundamental properties.*
- *Models/knowledge bases:*
- *Accurate, high temperature thermophysical properties are required for any process modeling.*
- *Fundamental properties data.*

- Standards Thermophysical data at high temperatures.

3. **ELECTRICAL/MECHANICAL INTERFACE STANDARDS**

- New technology must accommodate legacy technology of relays and PLCs.

- We have a hodgepodge of controllers, power supplies, ancillary systems, etc. none of which can easily (if at all) transfer information to each other - difficult to "mix-and match" components (e.g. you must buy all of your equipment from one vendor, or it will not communicate correctly).

- Standard interface between sensor subsystems and automated manufacturing systems.

- In the world of digital communication, the welding industry is small. The standardization of the welding cell communications must copy/follow other industries. Let's learn from their mistakes and make use of the economics of their higher volumes. Ideally, a plant manager should be able to monitor/control a welding cell with the same communication system that he monitors/controls the machine tools, air conditioning...... A number of protocols exist such as: Device Net, Lonworks, RS232, RS485.... At this point Lonworks looks very attractive.

- The AWS has set up the A19 committee to standardize the power source electrical connections. Are there any attempts to set up future serial, or optical fiber communications standards?

- Communication network protocols, network architectures, distributed architectures, interprocess communications.

- Mechanical and electrical interface for electrical power and signal.

- Standardization of equip. vibration and interfacing.

- Understand root causes of contact tube failures. Tribology of copper contact tube materials at weld tip temperatures.

- Develop methods and techniques of how and what to measure in regard to weld process variables i.e. voltage, current, pulse parameters, etc.

4. **SIMULATION AND OFF-LINE PROGRAMMING (OLP)**

- Under our TRP project CYBO robots is developing an application layer on top of commercial CAD and simulation systems to automate path planning of robotic welding on ship assemblies.

- OLP is a center for processing data.- It will integrate all geometric, weld process and robot information. At the same time it will interact with robot controller to download the information and will be able to react to information coming from real-time process control which will lead to intelligent control.

- Simulation needs to include cell integration.

- Handle complex geometry including curved surfaces. Turn key setup certification standards.

- Collision detection/avoidance.

- No standards exist for these systems to communicate with other hardware and control systems, and no unified strategy exists (integrate robot and weld process control).

- Integrate OLP with weld process. Ability to import geometrical and other external information (e.g. welding procedure databases). User interface allowing non-expert to rapidly generate programs.

- OLP is very desirable. Desire capacity for cascading a series of off-line system components together and form a plant simulation/evaluation capability at various levels of input.

- Ability to have a common OLP work with one or more robots independent of application.

- *Ability to be upward compatible with new robots or controllers .*
- *Automatic ability for simulation without manual operation or special data formats (solid representation).*
- *CYBO is currently working on the development of a standard data exchange to transfer shipyard CAD data to a simulation system. This data exchange is in the form of a script file which uses structural element descriptors and weld specifications. We are hosting a meeting in September to solicit requirements from shipyard CAD and design personnel.*
- *A standard to transfer information from one specific robot to generic simulation software. This standard should address the issues such as the inverse and forward kinetics, dimensions, limits of the work spaces.*
- *Generic "user" common languages for all off line programming operations.*
- *Development of common protocols for OLP.*
- *Desire capability to perform "what if" scenarios.*
- *Desire minimal training required.*
- *Resources: Deneb, ROBCAD, Witness, Symon, Safety.*
- *Automated robot programming including representation of welds in databases.*
- *Help with a projection weld simulation (heat flow and deformation) will help design better projections in nut and bolt welds with sheet steel.*
- *Good and fast algorithm to generate collision-free robot path.*
- *Parametric CAD for welding.*
- *Develop shop floor usable GMAW spray transfer without pulsing in thin sheets.*
- *More advanced "Design" tools including automated learning.*
- *More intelligent weld process planning.*
- *Develop automatic OLP that can be implemented in design tools.*
- *Automatic OLP.*
- *Common user standards for all off line programming.*
- *Simulation and off line planning--generic "user" common language.*
- *Investigate optimization in OLP.*
- *Need to develop intelligent weld system to test standards.*
- *Simulation and OLP.*
- *Simulation cable management*

5. **STANDARDS FOR DATA METRICS**

- *Different vendors are developing proprietary wave forms for power supplies. A problem is how to assess their performance and compare different ones, to match process specifications.*
- *Maybe simplify sensor requirements.*
- *Introduce and install standardized and calibrated NIST (appropriate) sensors into GMAW equipment.*
- *This topic is imperative to the completion and success of topic 2. This is a sub set of that topic.*
    - *Consistent output performance ratings for power supplies.*
- *Development of Welding Process Metrics*
    - *Standardize terms to measure and describe current and voltage measurements.*
- *Standard methods for mesurement of process variables.*

- Need standards for data acquisition.

6. **ADVANCE INTELLIGENT CONTROL SYSTEMS RESEARCH**

- Control systems need to allow parameter changes during the weld. This is especially needed while welding thin galvanized sheet metal.
- Control Systems
-To permit changing weld parameter during the weld.
- Controls that allow the establishment of an electrical contact between the weld wire and the part will help program robots with constant CTWD paths.
- This topic is actually a sub topic of topic 2.
- Real time arc monitors for welding quality assurance and/or automated path adjustment.
- Affordable compact sensors that can verify weld quality and store information .
- Need to promote new advances, high risk technologies, in electronics for power supplies.
- Need development and commercialization of high risk sensor systems specifically for welding, not just adaptations of other types of sensors.
- Assess non-traditional techniques, e.g. fuzzy, neural net, heuristic based design.
- Control of coordinated multiple manipulators, separate motors, amps from computer platform.
- Adaptive fill capability.
- Control of highly redundant manipulators.
- Fuzzy logic
- neural networks
- Research needed: Can time series diagnostics and prediction based on nonlinear dynamics (chaos theory) be used for monitoring and control?

7. **INTERPRETATION OF SENSOR DATA**

- For data acquisition of arc parameters (Volts, Amps, WFS, Gas) what is the accuracy requirement for measuring the parameters? Is 1% accurate enough or 3-5%?
- Need to minimize development of add-on sensors and ensure that existing (or sensors that can be built-in) are survivable in rigorous welding environments.
- Sensors developed by NIST are very useful to the large volume manufacturing industry in making relevant process measurements; There can be no intelligence without sensing.
- Evaluation of the sensors in a high volume manufacturing environment needs to be done to assess factors that can cause variability in their measurements.
- A decision based on calibrated NIST sensors and vision sensors is needed on whether a weld was made inside a validated weld window or not. This kind of approach is used in the auto industry successfully in resistance spot welding.
- Sensors
-Standardize interface of sensor equipment.
-Requirements/calibration
- Arc and completed weld monitoring to measure weld quality in real time.

8. **DESIGN FOR MANUFACTURING**

- *The first area of importance should be directed towards design. Once this technology is well understood and implemented, then issues such as OLP and robotics can effectively be addressed.*
- *Designers do not have tools to evaluate the manufacturability of designs.*

9. **FUNCTIONAL COMPOSITION**

- *Consider UTAP.*
- *Distributed architectures.*
- *Identify the "best" architectures and help support the development of standards for computer systems to communicate welding specific information.*
- *Open architecture for "plug-and-play" for production.*
- *Cross-platform code portability.*
- *Open architecture that can handle different tools for weldability or producibility.*
- *Definition of tools for building various architecture.*
- *Standard control protocol*
- *Standards - Architecture*
- *open architecture*
- *cross platform portability*
- *Standard data protocols*
- *Interface definitions supporting plug and play of distributed applications across hardware/software architectures.*
- *Standard operator interface*
- *Design of architecture for open interconnection of systems (controllers, robots, sensors.*

10. **USER INTERFACE**

- *This is critical and can for the most part be handled via software development.*
- *Low cost , easy to use, packaged well ---I mean really easy.*
- *Icon driven man machine interface.*

11. **EQUIPMENT IMPROVEMENT NEEDS**

- *Welding Power Supply - A continuity check based method to enable programming of a constant CTWD path for a robot.*
- *Require easy realignment techniques for robotics.*
- *Desire reprogrammable fixtures.*
- *Robots with more DOF's to reach areas of limited access.*
- *Use of high precision multi-axis CMM is being used for quick small batch.*
  - *Improve robot ability to handle assemblies as is, without tack welding.*
- *Seam trackers that do not slow down the robot are needed. Also, the cables connecting them need to be flexible enough to permit considerable bending in assembly.*
- *Both forward and backward tracking (pre and post-tracking) may be helpful. This can help in providing a good/no good weld decision and in particular help in converting data to information.*

- *Need improvements in materials contributing to process variability such as contact tips, and gas cups.*
- *Need a resistance weld tip material for welding aluminum that will last a few thousand welds on the shop floor.*
- *Also need distortion/softening/joint efficiency improvements in aluminum alloy welding needed to reduce car weights.*
- *Minimization of the size of sensors, such as the laser tracking sensor to increase the accessibility.*
- *Through the torch sensor technique will be very helpful in both increase accessibility and flexibility in path plan.*
- *Ability to use bottom line computer systems.*
- *Develop more capable robots that can handle complex geometry with limiting accessibility*
- *Increase weld speed with new wire feed/consumable or other new technology.*
- *Industrial based micro packages of sensors.*
- *Develop a cost effective sensor to measure/monitor weld perfection.*

12. **PROCESS STABILITY**

This category was generated very late in the discussions with no opportunity for attendees to type in comments.

5.3 General Comments

These are comments, made by attendees, that did not pertain to any one of the 12 categories. Comments typed in by attendees are in italics. The other comments were made verbally and recorded in the editor's meeting notes.

- Shipyards of the world that have been successful in computerization have concentrated on a top down approach, with primary emphasis on design. Has NIST sought input from other programs (e.g. CYBO and PAWS).
- An automaker strongly prefers resistance welding and would like to eliminate all other types of welding. They have had poor success with welding sensors.
- Shipbuilding requires bringing the welding robot to the part
- NIST will have difficulty in determining an appropriate program scope.
- Involve end users and equipment managers in your program.
- *I agree and concur, the design and standardization of design are key to creating an environment which improve production time, which is of course the objective. The problems of course is the diversity of the scope NIST has outlined, specifically related to design, that appears to have been ignored.*
- *To gauge industry needs, go beyond the typically large companies gathered here and survey smaller companies.*
- *Don't forget manual welding, and the needs for getting information to people.*
- *Organizational coordination between Navy, shipyards, robotic welding system developers and AWS.*
- *Need cost effective sensors to track seams with significant joint deviations.*
- *Desire simple solutions. Use them to avoid extensive setup routines.*

- Keep computer outputs simple. Complex things do not work on the floor.
- Choose right computer platform. Easy for engineers to use. Keep in mind that most of the users are not computer folks! Sophisticated systems, such as UNIX workstation will increase the complexity and training required a lot.
- Standard recipes for welding different metal stack-ups with different coatings is needed. These recipes may need to vary along the length of the weld. Power Supply/Control systems that permit these running changes are needed.
- NIST serve as consolidation agency for different organizations.
- General Issues - Consolidation of specifications for welding (i.e.,WPS, PQR).
- Ability to handle life cycle concerns for a product.
- Don't proceed without a full needs/products market study.
- Realize that business needs are not all high tech.
- Robot arc welding cell safety
- Down loading programs and running robot in cell safely for people and equipment.
- Standardization
- Standard Control Systems
- Control systems must allow parameter changes (i.e. follow distortion during welding).
- Technology
-Computer Requirements
-Centralized interface language
- Develop welding rules engine
- Protocol system for arc transfer modes
- Develop capable systems curved surfaces without exact fit-up
- Improvements in aluminum alloy welding with respect to distortion/softening/cracks electrode material RSW .
- How to use PLC's (programmable logic controller's) and PC's personal computer in same robot cell environment.
- OTHER...Measurements
- A decision based on sensor outputs ,whether a weld is good or bad.

6. RECOMMENDATIONS

6.1 Ranking of Issues

The group formed twelve categories during several hours of moderated discussions. Near the end of the Workshop all non-NIST attendees voted once to prioritize the categories according to needs of their companies.

VOTING RESULTS

Group size: 24
10-Point Scale
Number of items = 12

DSMC Participant Instructions:
9 = HIGH
3 = MEDIUM
1 = LOW

---------- Items Sorted By Total (Highest priority first) ---------------------------
1. INTERFACE STANDARDS FOR DATA EXCHANGE
2. ELECTRICAL/MECHANICAL INTERFACE STANDARDS
3. PREDICTIVE PROCESS MODELS and KNOWLEDGE BASE
4. SIMULATION AND OLP
5. STANDARDS FOR DATA METRICS
6. ADVANCE INTELLIGENT CONTROL SYSTEMS RESEARCH
7. INTERPRETATION OF SENSOR DATA
8. DESIGN FOR MANUFACTURING
9. FUNCTIONAL COMPOSITION
10. USER INTERFACE
11. EQUIPMENT IMPROVEMENT NEEDS
12. PROCESS STABILITY

-------------------- Graph of total scores --------------------------------------

```
 1. INTERFACE     ************************************************** 202
 2. ELECTRICAL    ************************************** 155
 3. PREDICTIVE    ************************************ 146
 4. SIMULATION    ********************************* 136
 5. STANDARDS     *************************** 110
 6. ADVANCE IN    ************************** 106
 7. INTERPRETA    ************************ 99
 8. DESIGN FOR    ************************ 98
 9. FUNCTIONAL    *********************** 94
10. USER INTER    ********************* 88
11. EQUIPMENT     ********************* 86
12. PROCESS ST    **************** 68
```

-------------------- Number of Votes in Each Rating ----------------------

	1	2	3	4	5	6	7	8	9	10	Mean	Std	n
1. INTERFACE	1	-	1	-	-	-	-	-	22	-	8.42	2.00	24
2. ELECTRICAL	5	-	5	-	-	-	-	-	15	-	6.20	3.56	25
3. PREDICTIVE	2	-	9	-	-	-	-	-	13	-	6.08	3.28	24
4. SIMULATION	4	-	8	-	-	-	-	-	12	-	5.67	3.47	24
5. STANDARDS	2	-	15	-	-	-	-	-	7	-	4.58	2.95	24
6. ADVANCE IN	7	-	9	-	-	-	-	-	8	-	4.42	3.41	24
7. INTERPRETA	6	-	13	-	-	-	-	-	6	-	3.96	3.01	25
8. DESIGN FOR	8	-	9	-	-	-	-	-	7	-	4.08	3.34	24
9. FUNCTIONAL	10	-	7	-	-	-	-	-	7	-	3.92	3.44	24
10. USER INTER	7	-	12	-	-	-	-	-	5	-	3.67	2.93	24
11. EQUIPMENT	11	-	7	-	-	-	-	-	6	-	3.58	3.31	24
12. PROCESS ST	14	-	6	-	-	-	-	-	4	-	2.83	2.94	24

6.2 Next Steps

NIST will use the ideas expressed in the workshop in planning and carrying out the AWMS project. We will match the highest priority areas to the capabilities, funding and staffing available. We will also look to form teams with those common interests who can provide skills and equipment that we are missing.

We welcome partnerships with commercial technology providers and users. Their collaboration on important issues and approaches, and the benefit of expert experience is invaluable to our programs meeting real needs, and to leveraging available technology for faster results. Our partners often benefit from new research results, new device or algorithm development, and visibility of the company name and/or product.

ISD and MRD will work together to leverage MRD experience in welding process technology and ISD experience in control systems and integration.

AWMS controller development will be based on ongoing NIST efforts in open architecture and the RCS methodology. An example of this effort is the NIST EMC controller that is in place on a machining center at General Motors. Initial sensors used will likely come from the experience of MRD. FY 96 goals include completing renovation of a laboratory in the Shops building, procuring a robot arm, welding equipment, and controller and sensor system development platform and software. We will leverage past experience in real-time control and sensor systems, and robotics, as well as current activities in CAD based off-line planning, and user interfaces.

Regarding standards development, though ISD does not work primarily in STEP, we will consult with standards activities (e.g. AWS, STEP) on our experience in welding technology. This report will be shared with others.

If you have comments or questions about the workshop or this report, contact:

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ACKNOWLEDGEMENTS

Our scheduled speakers, Joe Baumer, John Hinrichs, and David Trees gave very good, enthusiastic presentations.

Tom Siewert played an essential role in planning the workshop and making contacts with the welding industry. He also gave the editor of this document use of his meeting notes.

Joe Falco and Bob Russell, and Robocrane project staff of Roger Bostelman and Nick Dagalakis developed the welding demonstration.   Ann Virts exercised good judgment and energy in making many arrangements for the workshop.

Appendices

Appendix A. Description of NIST Demonstrations

People to contact for more information are named in parentheses: their phone numbers and email addresses are in Appendix C.

Enhanced Machine Tool Controller (EMC) project - NIST has developed an open-architecture numerical control (NC) controller. The ISA bus based controller uses commercially available hardware and software. The goal is to demonstrate open-architecture, cost effective NC control. A NIST EMC controller has been retrofit to a 4-axis machining center at General Motors for their evaluation. (Fred Proctor)

Hexapod - the Hexapod is a machining center based on the Stewart platform mechanical principle.   A platform that supports the spindle motor is connected to six linear actuators. The mechanical design of the Hexapod offers unique stiffness properties and offers interesting challenges in real-time control and in machine tool metrology. (Al Wavering)

Virtual Manufacturing - NIST is developing a distributed and virtual manufacturing environment where design data can be transferred interactively between a design site, Sandia National Labs in Albuquerque, and a production site, NIST. Machining operations at NIST can be viewed in real-time by

Sandia to monitor the manufacturing process. NIST is using this technology to develop environments which will allow remotely distributed collaborators such as industry, universities, and other national laboratories to access NIST's advanced manufacturing testbeds via network. (Joe Falco)

Robocrane Welding - NIST has developed the Robocrane, a Stewart platform based manipulator that can perform a wide variety of tasks. The system manipulates a platform suspended on six cables that are supported on a frame that is six meters high. We have fit an arc welder to the platform and demonstrated basic Robocrane off-line programming, arc welding and bead grinding. We have also fit sensors developed by the MRD, to the power supply and gathered voltage and current data on the weld. (Roger Bostelman)

Appendix B. Agenda

NIST Welding Workshop Agenda

------------------- Tuesday, August 15 ---------------

0830-0850	* Welcome and Individual Introductions
0850-0900	* Present the Agenda and Meeting Style
0900-0915	* Description of Group Software Facility - Don Freedman, DSMC
0915-0930	* Welding Workshop Background - Tom Siewert
0930-0955	* Goals of the Workshop - Maris Juberts
0955-1010	* Issues Overview - Bill Rippey
1010-1025	* Recent AWS Standards Efforts - Jerry Jones, Joel Milano
1025-1035	* Break
1035-1115	* Automotive Component Manufacturing - John Hinrichs, A.O. Smith
1115-1155	* Heavy Equipment Manufacturing - David Trees, John Deere
1200-1300	* Lunch
1300-1340	* Shipbuilding - Joe Baumer, Newport News Shipbuilding
1340-1650	* Discussion - 5 minute presentations - Questionnaire results - Open discussion, recording of issues and comments
1650-1700	* Agenda for Tomorrow

------ Wednesday, August 16 ---------

0830 - 0840	* Review Today's Agenda and Goals
0900-0925	* Cooperative Research and Development Agreements (CRADAs) Ernie Graf, NIST
0925-1005	* Developing a STEP AP - Mary Mitchell, NIST
1005-1020	* NAMT - Dave Stieren, NIST
1020-1030	* Break
1030-1200	* Make Recommendations (moderated session) - Prioritize research and standards areas - Recommendations for NIST AWMS Plan, Industry Participation - Next Steps

1200-1300	* Lunch
1300-1500	* Recommendations Continued.
1500-1700	* NIST Laboratory Demonstrations

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Appendix C. Attendee Contact Information

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