SHIP PRODUCTION COMMITTEE
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EDUCATION AND TRAINING

September 1991
NSRP 0340

# THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

## 1991 Ship Production Symposium Proceedings:
## Paper No. IIB-2
## Intelligent Automated Welding for Shipyard Applications

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

| Report Documentation Page | *Form Approved*<br>*OMB No. 0704-0188* |
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| | | |
|---|---|---|
| 1. REPORT DATE<br>**SEP 1991** | 2. REPORT TYPE<br>**N/A** | 3. DATES COVERED<br>**-** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**The National Shipbuilding Research Program, 1991 Ship Production Symposium Proceedings: Paper No. IIB-2: Intelligent Automated Welding for Shipyard Applications** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Naval Surface Warfare Center CD Code 2230-Design Integration Tools Bldg 192, Room 128 9500 MacArthur Blvd, Bethesda, MD 20817-5700** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **SAR** | **16** | |

**Standard Form 298 (Rev. 8-98)**
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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, N.J. 07306

Paper presented at the 1991 Ship Production Symposium,
The Pan Pacific Hotel, San Diego, California, September 3-6.1991.

# Intelligent Automated Welding for Shipyard Applications

IIB-2

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## ABSTRACT

Computer Aided Process Planning (CAPP) integrated with Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) will form the basis of engineering/planning systems of the future. These systems will have the capability to operate in a paperless environment and provide highly optimized process operation plans. The WELDEXCELL System is a prototype of such a system for welding in shipyards. The paper discusses three significant computer technology advances which have been incorporated into the WELDEXCELL prototype. First is a computerized system for allowing multiple knowledge sources (expert systems, humans, data systems, etc.) to work together to solve a common problem (the weld plan). This system is called a “blackboard”. The second is a methodology for the blackboard to communicate to the human user. This interface includes full interactive graphics fully integrated to CAD as well as datasearches and automatic completion of routine engineering tasks. The third is artificial neural networks (ANS’s), which are based on biological neural networks (e.g. the human brain), that can do neural reasoning tasks about difficult problems. ANS’s offer the opportunity to model highly complex multi-variable and non-linear processes (e.g. welding) and provide a means for an engineer to quantitatively assess the process and its operation.

## GLOSSARY OF ACRONYMS

| | |
|---|---|
| ANSI | American National Standards Institute |
| ANS | Artificial Neural Networks |
| ASTM | pan Society for Testing and Materi- |
| AWI | American Welding Institute |
| AWS | American Welding Society |
| CAD | Computer Aided Design |
| CAE | Computer Aided Engineering |
| CAM | Computer Aided Manufacturing |
| CAPP | Computer Aided Process Planning |
| CNC | Computer Numerical Control |
| D-A Net | Delta-Activity™ Network |
| DOS | Disk Operating System |
| DXF | File format used by AutoCad™ |
| FCAW | Flux Cored Arc Welding |
| IGES | Initial Graphics Exchange Specification |
| PSNS | Puget Sound Naval Ship Yard |
| WELDEXCELL | WELDing Expert manufacturing CELL |
| WELDSCHED | Weld Schedule Expert System |
| WJC | Welding Job Controller |
| WJP | Welding Job Planner |
| WPS | Welding Procedure Specification |

## INTRODUCTION

The joining of metals into fabricated components and structures is a difficult task. ‘The most common method of joining metals is welding, but the welding process is complex and requires several important steps to be performed in a carefully integrated manner. The weld joint is first designed and engineered properly, then that design must be correctly communicated to the fabrication facility. The appropriate welding consumables, including filler metal and protective flux or inert gas, are chosen. Then the welding procedure is specified, including preheating schedules; welding parameters such as voltage, current and travel speed; and, postweld heat treating. Finally, the weld must be performed under highly skilled human guidance and control. A minor error in any of these steps, if undetected, can create an unsuitable welded component, which in later use may result in a catastrophic failure and perhaps loss of life.

An extremely complex and interrelated system of codes, specifications, tests, and inspections ensures that the vast majority of welds will never fail in service. A weld, which is a small bit of solidified metal, is expected to have the same (or perhaps better) properties as the base metal that it joins. The base metal may have undergone hours of careful and expensive heat treating and processing, yet the weld must be as corrosion resistant, as strong, as ductile, and as fracture resistant as the base metal. But the weld does not have the advantage of all of that processing.

Fortunately, a large number of engineers, designers, and welders work within the system of codes and specifications to ensure the high quality of welded joints, but this system is very expensive and requires the careful attention of many human experts. As the availability of engineering talent in the United States continues to decrease over the next decade, Computer Aided Engineering (CAE) will take on added importance. Consequently, welding engineering and planning is an ideal application for artificial intelligence technology including expert systems. However, no single expert system could be expected to perform the myriad of tasks required to make a welded joint. For example, there are over 100 welding processes ranging form simple flame heating to exotic laser welding; there are several hundred welding filler metals -- from plane carbon steel to elaborate chemical mixtures of alloying ingredients; and there are over 1000 different grades of steel classified by the American Society for Testing and Materials (ASTM) that may have to be joined. The possible combinations of welding process, filler metal, and steel base metal would number into the millions.

The solution to this problem is a system being developed for the United States Navy called WELDEXCELL. The test prototype of WELDEXCELL was delivered to Puget Sound Naval Ship Yard (PSNS) for testing during the summer of 1991. The expert systems needed for welding include materials selection, joint design, welding process and procedure selection. There is a standard Computer Aided Design (CAD) system interface to draw the design and communicate that design to the shop floor as well as a CAD interface to the robot path planner. The system also includes intelligent processing to control a complex automated welding system or robot with an array of sensors to guide it and to provide feedback for process control. The system actually being delivered to the Navy will be configured with at least two sensors, but the system is capable of operating in a multiple sensor environment.

The American Welding Institute (AWI), together with its partners, the Colorado School of Mines and MTS Systems, Inc., is developing this intelligent weld process planner and intelligent control system for flexible welded fabrication known as the WELDing Expert manufacturing CELL (WELDEXCELL). This project has entailed development of a series of linked expert systems acting as a computer aided engineering and planning assistant and software to download welding plans and procedures to a welding system and automated manipulator or robot for automatic execution. An intelligent welding control system is being completed which will interface to a robot system, a series of sensors, and to the welding equipment. This paper contains a general description of the system and examples of the operation of the prototype engineering/planning workstation and user interface.

## SYSTEM OVERVIEW

The WELDEXCELL System is logically divided into two major subsystems: the Welding Job Planner (WJP) and the Welding Job Controller (WJC). Figure 1 is a conceptual schematic of the WELDEXCELL System.

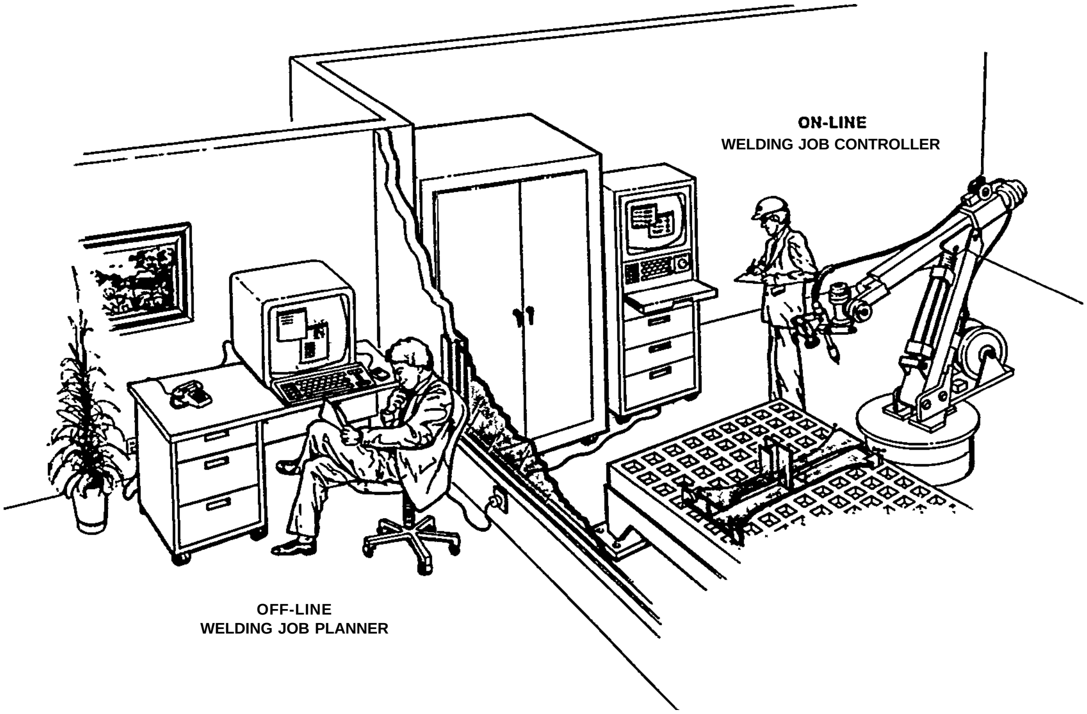


Figure 1

A high-level block diagram is shown in figure 2.

**SYSTEM OVERVIEW**

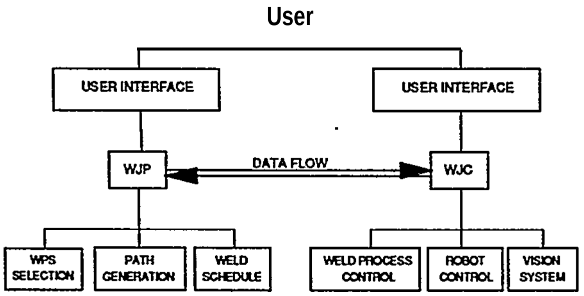


Figure 2

The Welding Job Planner is responsible for helping the welding engineer design and set up a weld path (for the robot or automated system) coupled with a welding schedule (specific procedure for shop floor implementation). The WJP is comprised of several expert systems, each contributing to the design of the particular weld. A software architecture known as a blackboard system is used to manage the interactions of the multiple expert systems. The blackboard architecture is a powerful and flexible software tool for mediating the contributions of several knowledge sources. It is described in detail later in the paper.

The blackboard system uses various expert systems, knowledge bases and databases, and a control scheme (usually implemented as another expert system) with the goal of moving the system toward a solution to solve complex problems. In this implementation, the blackboard will also be able to ask for and accept input to the problem solving process from various human users. The user will interface with the knowledge resources and the blackboard to design the joint and then locate or develop an appropriate welding procedure. The WJP configures this information in the form of a Job Description which is in turn passed to the Welding Job Controller (WJC) for the actual execution of the weld.

The Welding Job Controller (WJC) is in charge of coordinating and controlling the various equipment used for the weld, including the welding power supply, the manipulator, the vision system, and other support equipment. This WJC is an intelligent adaptive system. In the WELDEXCELL System being delivered to PSNS the WJC will take data from two sensors, an arc gap controller and a vision system which will be reporting real-time information regarding the three dimensional torch location with respect to the weld seam location and modifying the manipulator path to make corrections from the designed path. At the end of a weld pass, a weld results file will be prepared by the WJC and can, if necessary, be passed back to the WJP for analysis and possible modification to the next pass job description. The WJC is being made as generic as possible in order to permit the WELDEXCELL System to be compatible with multiple torch manipulators including various robots.

## WELDEXCELL Technical Develooments

A number of specific technical developments were necessary to implement the WELDEXCELL System WJP described above. The technical issues involved are described briefly in the following paragraphs. Figure 3 is a schematic representation of the WJP showing the individual constituents of the software.

**WELDING JOB PLANNER**

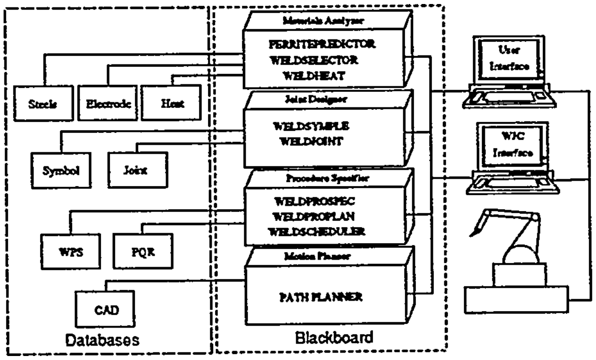


Figure 3

### Weldinp Job Planner Blackboard Svstem

WELDEXCELL consists of a series of expert systems and databases which can engineer and plan a weld, and interact with the user through a blackboard architecture to accomplish each of the required tasks in the weld planning sequence. These tasks include: welding filler metal or electrode choice; joint design and welding procedure selection and development; and robot path plan design and integration with the welding procedure. Finally, the information must be communicated to the fabrication facility in the form of a joint design drawing with a welding symbol and a welding schedule. Each of these tasks is not completely independent and, in the existing manual mode of operation, they are often done in an iterative manner.

The operation of the WELDEXCELL system depends on the interaction and action of several knowledge sources. In this context, we include as knowledge sources, expert systems, data systems (both alpha-numeric as well as graphical and iconic), human users, and artificial neural networks. There are three important features of the WELDEXCELL WJP System which provide this capability. First, the system includes an expert integration environment which allows sharing of information and interaction of all of the knowledge sources. Second, a computer-aided design tool is included to assist in the development of the welding design and drawing.

Finally, a simulation environment, with Computer Aided Design (CAD) interfacing capability, is integrated so that the joint design, welding process and procedure can be tested prior to the welding operation.

Basic blackboard model. The type of distributed problem-solving in multiple knowledge domains (areas of expertise) involved in this multidisciplinary engineering problem cannot be addressed using a single knowledge source (KS). Rather, multiple knowledge sources and humans cooperate to solve a broad problem. The technique which was applied to this data and knowledge-integration problem was the blackboard architecture. A blackboard system was chosen for the expert integration environment because it possesses capabilities to support problem solving by accounting for diverse types of information, combining various types of data and resolving conflicts, and accommodating different program modules without requiring a complex interface.

A good analogy to a blackboard system, illustrated in figure 4, is that of a group of experts seated before a blackboard, with only one expert allowed to approach the blackboard at a time. A monitor is empowered to call on the experts individually to modify the blackboard's contents. Following each contribution, the monitor evaluates the state of the blackboard's contents and, based on its planning algorithms, considers which expert to call on next. Eventually, the monitor and the experts fill the blackboard with a solution to the problem. If the "experts" described in this scenario are replaced by knowledge sources, a computerized blackboard system results. The monitoring and control functions are performed by what is essentially another expert system with planning algorithms designed to move the expert system toward a problem solution.

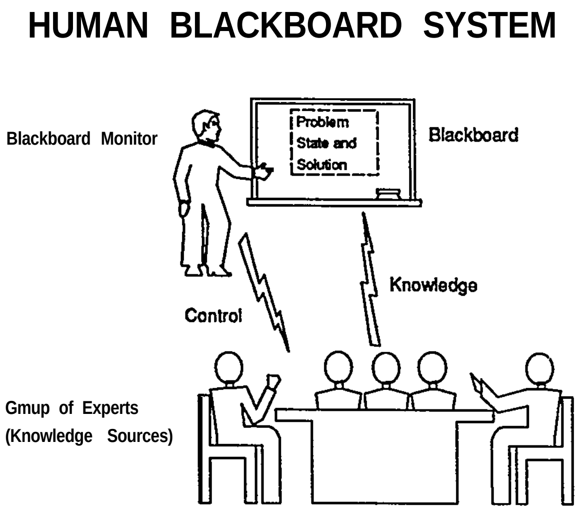


Figure 4

The concept of blackboard architectures was discussed in the literature as early as 1962; however, no applications were built until the late 1970s. The blackboard model was chosen to be used for this expert integration environment because it possesses capabilities to support problem-solving while accounting for diverse types of information, methods for combining various types of data while resolving conflicts, and the ability to accommodate different program modules which allows a completely modular approach to the software (i.e., new knowledge sources can be easily added, or updated, with little integration effort). .

The problem solving technique applied to the blackboard model is: dividing the problem into loosely coupled sub-tasks which are then operated on by the specialized knowledge sources for each of those sub-task areas. The advantage of such a system is that much larger quantities and a greater diversity of types of information can be used in a fully integrated manner to solve the problem and develop a weld plan. The human experts supply the external information about the required welding task and then review the final plan. The system also possesses facilities to query a human expert in the event that conflicts outside of the system's domain expertise occur. The time required by a human expert to resolve conflicts is substantially reduced, thus allowing more design and planning to be accomplished with higher overall quality and reliability by the same number of these human experts (i.e., welding engineers). Figure 5 shows a schematic diagram of the operation of the blackboard. The system divides the problem into two different domains: that of the user and that of the knowledge sources. Thus, through the blackboard architecture, the user solves the problem in his/her reference frame while the system simultaneously solves the problem in the knowledge source reference frame. The blackboard, using the specially designed user interface, allows full communication between the two reference frames while the problem is being solved in the most comfortable way by both the user and the other knowledge sources in the system. This is accomplished by treating each of the knowledge sources as a system that can interface to the blackboard in the same way

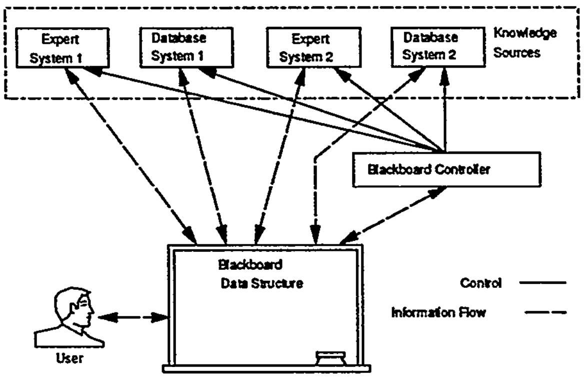


Figure 5

The blackboard's purpose is to provide a framework for the interaction of the multiple independent knowledge sources and to respond opportunistically to the changing contents of the blackboard to achieve a solution. There are seven behavioral goals for the intelligent blackboard control system to accomplish this task. They are as follows.

- Make explicit control decisions that solve the control problem.
- Decide what actions to perform by determining what actions are desirable and what actions are feasible.
- Adopt control heuristics that focus on action attributes which are useful in the current problem-solving situation.
- Adopt, retain, and discard individual control heuristics in response to dynamic problem-solving situations.
- Decide how to integrate multiple control heuristics of varying importance.
- Dynamically plan strategic sequences of actions.
- Reason about the relative priorities of knowledge domain and control actions.

The blackboard controller. The controller controls the blackboard, monitoring the activities of the knowledge sources, attempting to find a solution to the welding problem. At various levels, ranging from abstract to very detailed, decisions are made, such as which problem to solve next, whether forward or backward chain reasoning is to be used, and which knowledge source to activate. While building a second blackboard to control the problem-solving blackboard is a complex solution, it provides the flexibility to solve both broad planning problems and perform detailed scheduling.

The blackboard control system contains support for meta-level facilities; that is, for the capability of the blackboard to modify its own behavior depending on the solution currently posted on the blackboard. The blackboard is divided into multiple partitions which contain classes. The classes contain objects. The objects, which contain the data used by the knowledge sources to solve a problem, are placed in the blackboard by knowledge sources or by external processes such as human interactions or interaction with the databases.

Another concept for organizing problem-solving with multiple, diverse cooperating sources of knowledge has also been applied to the blackboard. A hypothesize-and-test paradigm is a mechanism which can provide a high degree of cooperation among the knowledge sources. Thus, the solution finding is an iterative process, which involves two repeated steps:

1) Create a hypothesis (an educated guess about some aspect of the problem); and
2) Test the plausibility of the hypothesis.

Preweld engineering/planning. The blackboard is presented to the user as an onscreen Welding Procedure Specification (WPS) that is filled in by the knowledge sources as they determine appropriate answers for the necessary WPS data entries. Since information can be changed as more facts are deduced, some data spaces on the interface screen do change in the process. The user interacts with the blackboard by selecting window based menu items using the mouse as described later in the section on the user interface. The display shows initial information (such as material type and joint geometry) and the evolution of the WPS as it is developed, including the joint design, robot path planning, and simulation information. The blackboard controller, which controls the blackboard and monitors the activities of the knowledge sources, attempts to find a solution to the weld design problem. The blackboard controller is written in object oriented C language interfaces directly with the expert systems and controls interactions with the user. The main problems the controller must solve determine a set of goals which are the drivers of the system actions. These goals are:

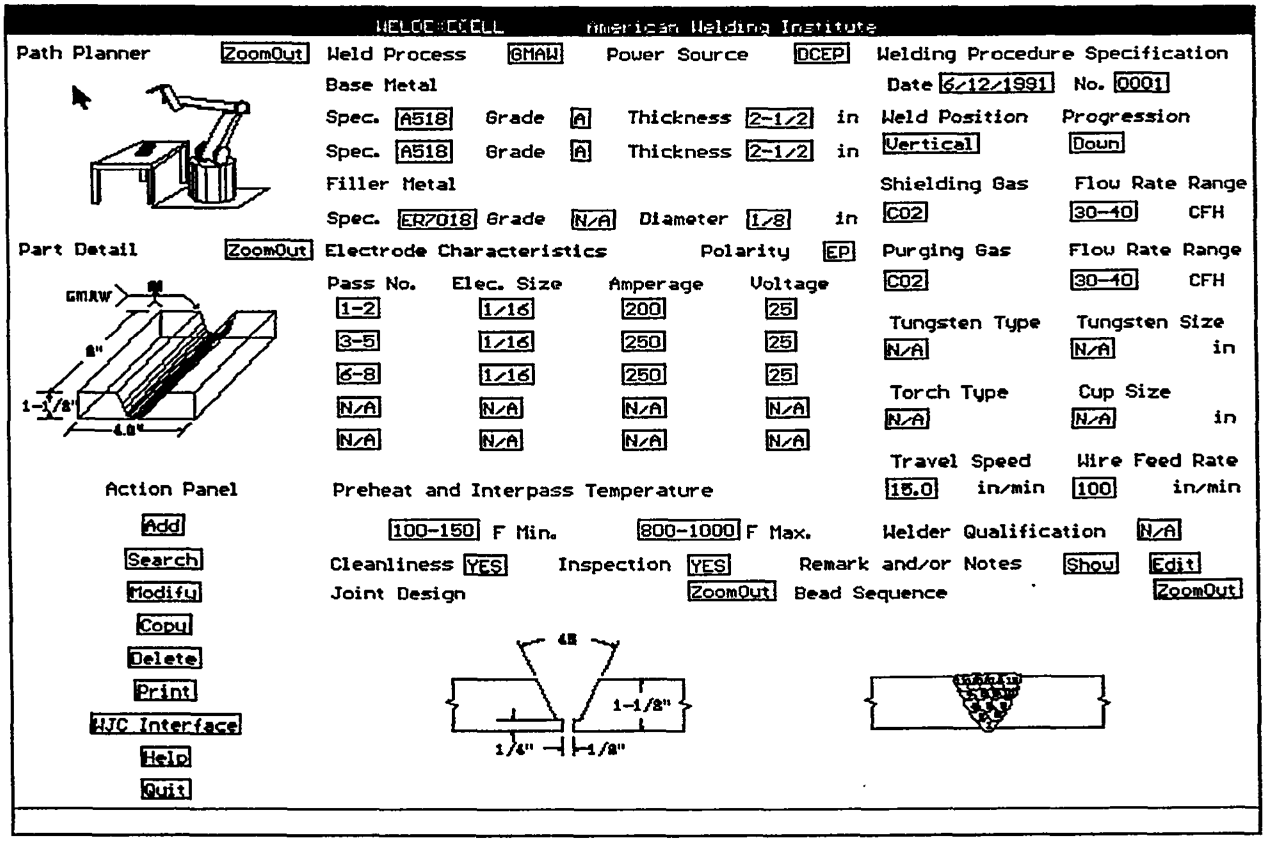
1. Select Joint design
2. Determine Weld process
3. Select Filler metal
4. Write the Procedure including:
    (a) Number of passes
    (b) Voltage,current, travel speed, electrode (filler) feed rate
    (c) Preheat and postheat requirements
    (d) Inspection and other requirements
5. Develop welding symbol and other joint details in CAD
6. Download control information to the robot

The specific details of this pre-weld planning and engineering activity are described in the discussion about the User Interface which follows.

## USER INTERFACE

The concept of this CAE and planning system which motivated the user interface was to design a system that is primarily driven by the user, not the underlying software. To provide a system that is "transparent" to the user and thereby allows the user to proceed at their own pace and approach with the software operating in the background. Yet, the interface had to be able to allow extremely powerful engineering software to operate and to accomplish all of the routine engineering tasks without the user having to remember which systems to call at any given time in the engineering process or how to use them.

Since the interface is primarily represented as a Welding Procedure Specification (WPS) with associated graphics entirely on the screen, there is insufficient space available to provide all of the data to the user at any given time. Instead, each specific section (e.g. joint design, robot simulator, etc.) is "opened up" by clicking with a mouse. The user can then access all of the information in that section while remaining dynamically "connected" to the remainder of the system. A screen print of the highest level interface is shown in figure 6.



Weld Process GMAW  Power Source DCEP

Base Metal
Spec. A518 Grade A Thickness 2-1/2 in
Spec. A518 Grade A Thickness 2-1/2 in

Filler Metal
Spec. ER7018 Grade N/A Diameter 1/8 in

Electrode Characteristics  Polarity EP

| Pass No. | Elec. Size | Amperage | Voltage |
|---|---|---|---|
| 1-2 | 1/16 | 200 | 25 |
| 3-5 | 1/16 | 250 | 25 |
| 6-8 | 1/16 | 250 | 25 |
| N/A | N/A | N/A | N/A |
| N/A | N/A | N/A | N/A |

Preheat and Interpass Temperature
100-150 F Min.  800-1000 F Max.

Cleanliness YES  Inspection YES  Remark and/or Notes

Joint Design  Bead Sequence

Welding Procedure Specification
Date 6/12/1991 No. 0001
Weld Position Vertical  Progression Down
Shielding Gas CO2  Flow Rate Range 30-40 CFH
Purging Gas CO2  Flow Rate Range 30-40 CFH
Tungsten Type N/A  Tungsten Size N/A in
Torch Type N/A  Cup Size N/A in
Travel Speed 15.0 in/min  Wire Feed Rate 100 in/min
Welder Qualification N/A

Figure 6

As information is determined by the expert systems and knowledge and data sources, the onscreen WPS is constantly updated. The display shows initial information (such as material type and joint geometry) and the evolution of the WPS as it is developed, through data searches or "writing from scratch." The user can interact with the blackboard by using the mouse and the keyboard when the system needs the user to provide, or when the user wants to provide, information to the system. Messages are communicated to the user via "pop-up" windows and menus. During path planning and simulation, graphical displays of the simulated robot are provided.

## Computer Aided Design and Graphics

A major part of any engineering task is necessarily graphic or picture oriented. Therefore it was important for the system to be able to provide the user with a very rich environment for graphics and other analogic knowledge. A CAD system was developed for use with this interface that is completely welding specific. It easily communicates with the blackboard by providing drawings of the pieces to be assembled into a fabricated part in 3 full dimensions. Details of the joining of these pieces is included in the CAD representation. A special welding CAD system was developed which is compatible with the ANSI/AWS A9.4-9x standard currently under development. In some cases the rendering of a shaded drawing may be necessary to visualize the welding environment; this is possible using the system. Three separate areas of the interface are provided for CAD based weld engineering: Part Design, Joint Design, and Joint Detail. Features include an expert system to draw the welding symbol and welding specific graphics like standard joint designs, welding bead placement, etc. This CAD system is fully interfaceable to any other

CADKAE system that uses standard data exchange formats (i.e. IGES and DXF). Thus the user can do all or part of the CAD work in another CAD system and download automatically to the WELDEXCELL system, and can modify existing mechanical drawings from another CAD system with welding specific details as necessary.

Part Design The CAD Part Design sub-system is used to produce a CAD representation of the part to be produced. This sub-system can contain a welding "layer" or overlay segment which describes the weld bead and weld path to be produced. If the weld overlay segment is used, then this system provides the facility to automatically provide the robot simulator with a CAD representation that can be used by the simulator to automatically complete the path plan for the robot and do collision detection. Figure7 shows this Part Design sub-system window opened. Opening the window is accomplished by clicking a mouse on the Part Design subsystem section of the main interface.

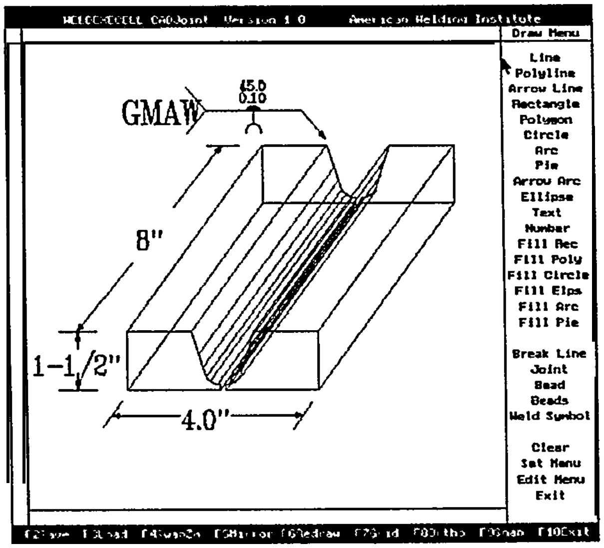


Figure 7

Joint Desire. The CAD Joint Design sub-system is used to produce a CAD representation of the joint to be welded. All of the machining details are represented in this sub-system. This CAD drawing can be sent electronically to the machining facility for production of the parts and, if the CAD system being used by the machining facility has the capability, the machining of the part can be done automatically. A Computer Numerical Control (CNC) code can be developed by the appropriate CAD system and then downloaded to a CNC machining center for automated metal removal. Figure 8 shows the Joint Design sub-system window opened-up and the joint design prepared with this sub-system.

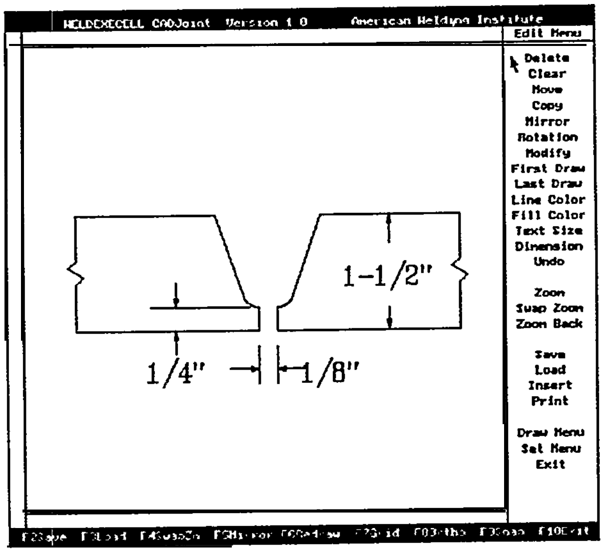


Figure 8

Joint Detail. The CAD Joint Detail sub-system provides the engineer using WELDEXCELL to prepare a joint detail in the CAD system that includes the weld bead design, placement, and sequencing. This sub-system includes a facility to draw the weld bead according to the ANSI/AWS A9.4-9x standard for CAD Layers. The user can place all of the weld beads for a multi-pass weld and automatically sequence the beads for multi-pass welding. Figures 9a and 9b show the Joint Design window open and the detailing of the weld beads being made using this sub-system,

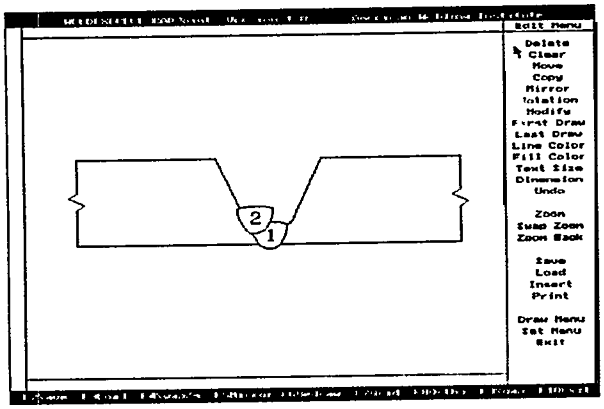


Figure 9a

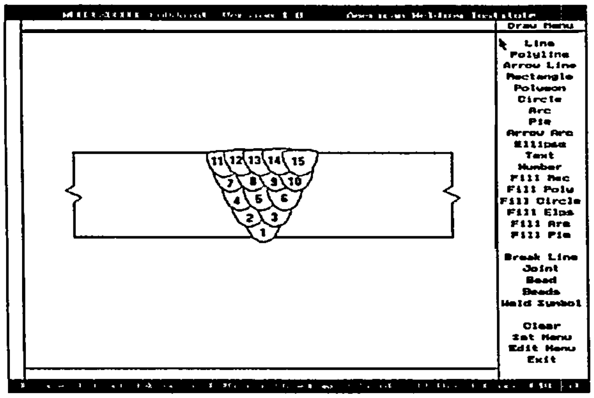


Figure 9b

## Robot Simulator System and Path Planner

The Robot Simulator System allows the user to simulate the robot movement relative to the workcell and the parts to be welded by downloading the parts from the WELDEXCELL CAD system (or other CAD system) into the simulator. The Path Planner automatically plans the robot movements thereby eliminating the necessity to do the path planning with the actual robot. The WELDEXCELL system produces robot path and motion control information in a format which is fully compatible with the supported robot systems. The simulation graphics assist in planned path verification and collision avoidance. The system is capable of providing an environment which allows the user to prepare for a robotic welding application without ever using the robot system. WELDEXCELL has overcome the most significant problem with regard to the use of robot systems for the "ordinary" (few of a kind) welding applications, thought to only be capable of being done economically with semi-automated or manual welding.

Once the weld is designed and the weld path is placed into the weld layer in the CAD system (using either the WELDEXCELL interface or another CAD system), then robot path planning is automatic. The path planner includes a full kinematic model of the robot system as well as an interpreter/writer of program code in the language of the robot controller. If the fixturing and other "collision objects" are included (e.g. downloaded from the CAD based fixture design) in the part design, then the path planner will also do a collision detection for the workcell. This provides the user with a nearly complete automatic system for robotic weld planning, programming, and development. The only additional algorithm needed in follow-on work is to develop a collision avoidance system that can re-plan the robot path whenever a collision is detected. Such a system may be included in later releases of WELDEXCELL. A typical robotic weld path plan and weld simulation, including collision detection, is performed by the Robot Simulator System, as shown in figure 10.

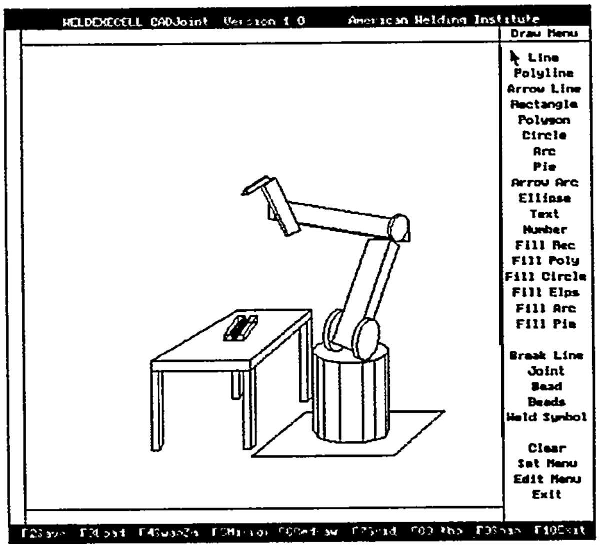


Figure 10

## Welding Schedule Development

Finally, the WELDSCHED expert system ties the robot path plan together with the welding procedure into a full weld schedule that can be automatically downloaded by electronic network to the welding workcell. In addition, with the appropriate software in the workcell, robot path modifications or procedure/process changes can be incorporated into the weld schedule and uploaded back to the database of the Welding Job Planner.

## NEURAL NETWORK BASED WELD

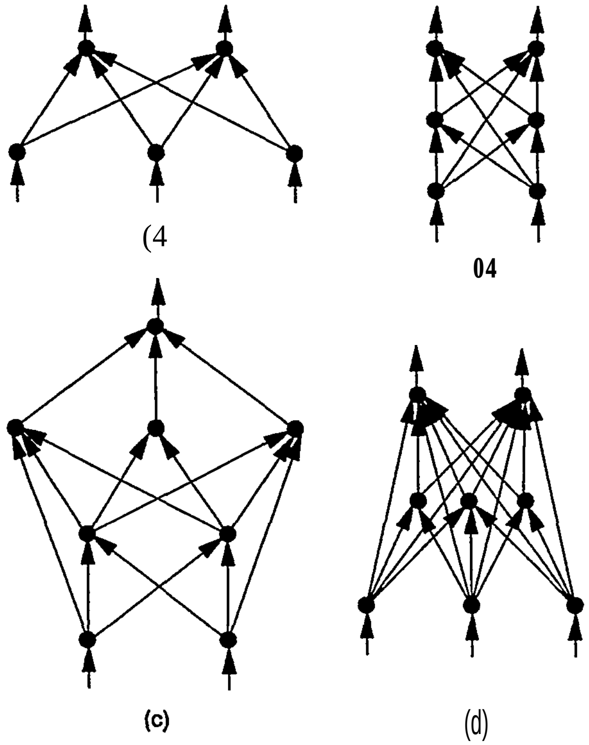
The planning and engineering of a weld requires that the welding engineer have available the necessary information to select appropriate welding parameter values such as voltage, current, travel speed, and wire feed rate. However, arc welding processes today are far more complex than can be modelled using mathematical relationships. Thus, the selection of optimum parameter values is a "seat-of-the-pants" type operation which includes much testing and "educated guessing" to develop a new welding procedure.

WELDEXCELL includes an Artificial Neural System (ANS) based weld modelling package that allows the welding engineer to "try" various combinations of welding parameter values working at his or her desk before generating a welding schedule. Thus the welding schedule that is electronically transmitted to the workcell is nearly optimum and need little, if any, changes on the shop floor. This eliminates a large amount of engineering time and effort in comparison the "typical" methods used to develop welding schedules.

## Artificial Neural systems

Artificial Neural Systems are an attempt to develop computer systems that emulate the neural reasoning behavior of biological neural systems (e.g. the human brain). As such they are loosely based on biological neural networks. The ANS consists of a series of nodes (neurons) and weighted connections (axons) that, when presented with a specific input pattern, can associate specific output patterns. It is essentially a highly complex, non-linear, matbematical relationship or transform. However, it is not necessary for the developer of such a system to understand the basic underlying principles of a process in order to develop a highly accurate ANS based model of the process. Thus, in this way it is quite different from other mathematical modelling approaches.

The problem of ANS's is to decide how may nodes and connections to have to model a specific problem, to decide how to configure them, and to decide the specific values of the connection weights and the transfer functions that exist within the network. Figure 11 shows a schematic diagram of a neural network and Figure 12 is a simple representation of the weights, transfer functions, and the mechanisms of network operation. As can be seen, there isno direct known correspondence between the network parameters and operation and the problem to be modelled by the network. As a consequence, there is currently a dirth of mechanisms which can be used to assign the weights and transfer functions in the network so that it can solve a problem.


(4

04

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Figure 11

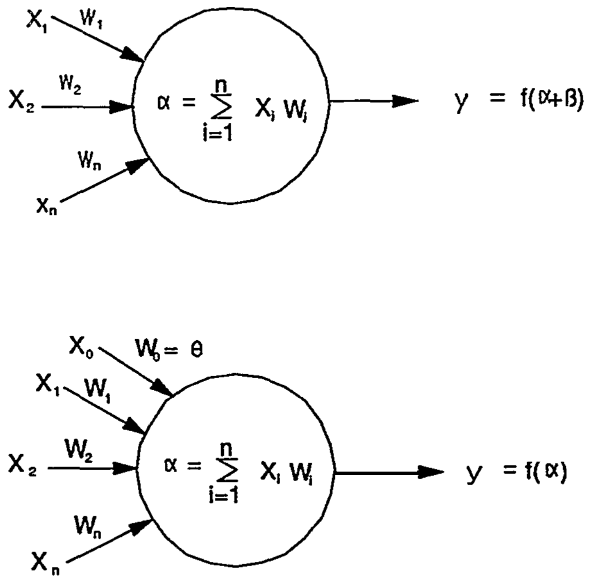

Figure 12

One of the most successful approaches that has yielded good results in developing networks is known as the "back propagation" method. In this method, the network is "trained" as a model, rather than being programmed. The back propagation method assumes that the search in weight space for an optimum, or near optimum, network conliguration can be accomplished as an iterative search using the error gradient in L, space: That is, a series of moves are accomplished on the multidimensional error surface using the maximum mean squared error gradient as the move direction at each iteration. The error in the network is defined as the difference between the desired output representation and the actual output given the current weight matrix values. By calculating the maximum gradient of the mean squared error for any given training example (set of input and corresponding output patterns), the weights are adjusted so that the net moves along that gradient direction in each presentation of the training example to the network. Using this procedure, the network slowly "learns" to associate all of the training example input patterns with the correct corresponding output patterns.

This "basic" back propagation learning process has several significant drawbacks. First, the configuration (i.e. number and relative location of hidden representation units or nodes) cannot be pre-determined and needs to be pre-assigned by using an "educated guess." Since the node conliguration can significantly affect the operation of the network, this will at best lead to a long series of re-trys and at worse to no useful network at all. Second, this process is very slow and the rate of learning (convergence to near zero error) is set arbitrarily --traditionally at a value between zero and one. No known method for predetermining the learning rate (gain term) will consistently choose an optimum value and the optimum value is significantly influenced by the specific problem being presented to the network. Third, it has been shown that it generally requires a larger network to "learn" a problem than is required to solve the problem. There is no known method of reducing the size of the network optimally after training to optimize the net performance. Finally, learning instabilities exist in nearly every problem which will cause the network to stop learning (converging). One of these instability types, known as a local minimum, has been studied and reported in the literature, but it is often not possible to overcome this problem when using the traditional back propagation method.

## The Delta Activity Network

The developers along with several Ph.D. and Masters student projects, developed a new method for training neural networks that has been shown to overcome all of the known problems with the back propagation method, while maintaining the inherent stability and known network development capabilities of the pack propagation method. This network was developed through the use of a thermodynamic model of the network operation which included both the delta energy but also the activity or kinetics of network. This methodology has led to an algorithm that is being patented. This technique, known as the Delta-Activity™ Network (D-A Net), has been used on several applications ranging from high speed signal processing to vision systems and includes the weld model system currently being used in the WELDEXCELL System.

The D-A Net has achieved learning rates as high as 1000 times that of the back propagation method while also preventing the network-from falling into learning instabilities. Research conducted on the D-A Net has confirmed the existence of at least three types of learning instabilities (local minimum being one of them) and the D-A Net algorithm can avoid all three of them. In addition, the D-A Net configures itself dynamically during the learning process and so it can produce a near optimum network size for operation, often much smaller than the network needed to "learn" the problem. By the combination of dynamic self configuration and learning instability avoidance, an operating network is virtually guaranteed for all problems.

## Weld Model Neural Network

A network was trained to model a flux cored arc welding (FCAW) process. The network model has inputs of voltage, current, and travel speed. The outputs of the network, for a fillet weld on an L joint are: arc stability, penetration, vertical and horizontal leg lengths, amount of spatter, bead appearance, bead undercut, and ease of slag removal. Figure 13 is a schematic representation of a weld bead depicting the morphological features which are network outputs. Twenty-eight welds were produced and examined to obtain the training set for the D-A Net.

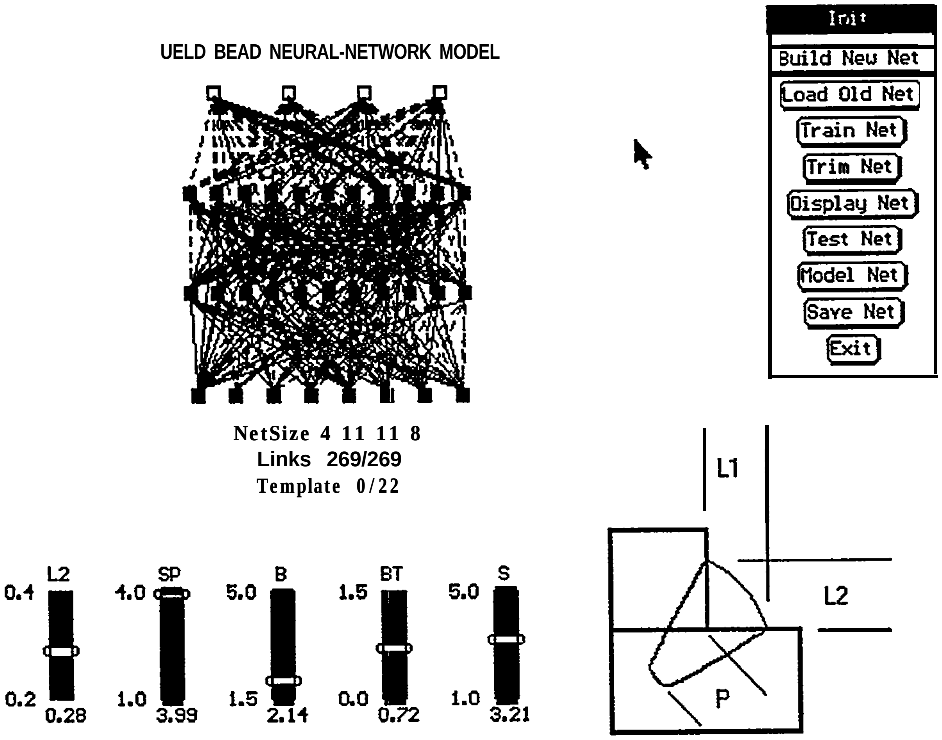

Figure 13

Figure 14 shows the user interface to the network running on a DOS based computer using a 386SX processor. On the screen are several mouse sensitive slide bars that can be set by the user or observed by the user. The fust row of slide bars are mouse sensitive and represent voltage (V), current (I), and travel speed (T). These can be moved to new values by using the mouse to "slide" the bar. The resultant weld is shown in cross section in the graphic window to the right of these slide bars. As the user moves these slide bars, the weld bead graphic moves in real time. In addition, the seven slide bars in the second row show the values of the output of the network. This represents a very powerful planning tool for the welding engineering workstation. Also shown on the screen is a tool for the welding engineer to use to design a control scheme (which could be used to design an intelligent welding process controller). The final row of slide bars has a set of small boxes next to each slide bar. By using the mouse the user can choose the relative importance of each of the output parameters of the network, the top box indicating greatest importance and the bottom box representing no importance. Once the importance factors are set, the user can use the mouse to set values of these output parameters. Then an integrated inverse network finds the values of voltage, current, and travel speed that will result in the chosen output parameter values, weighted to the importance values. Figures 15a through 15f shows a sequence of workstation screens indicating a typical session with the D-A Network weld model.

WELO BEAD NEURAL -NETWORK MODEL

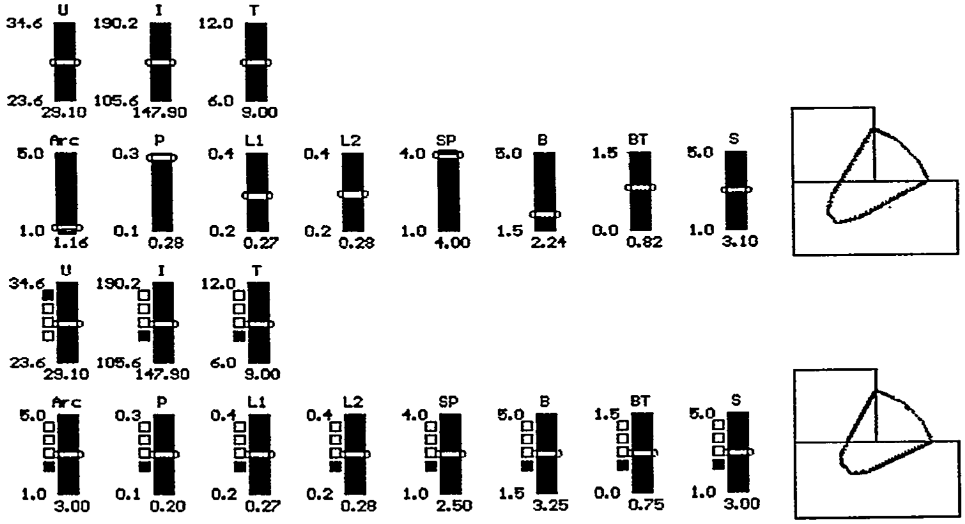

Figure 14

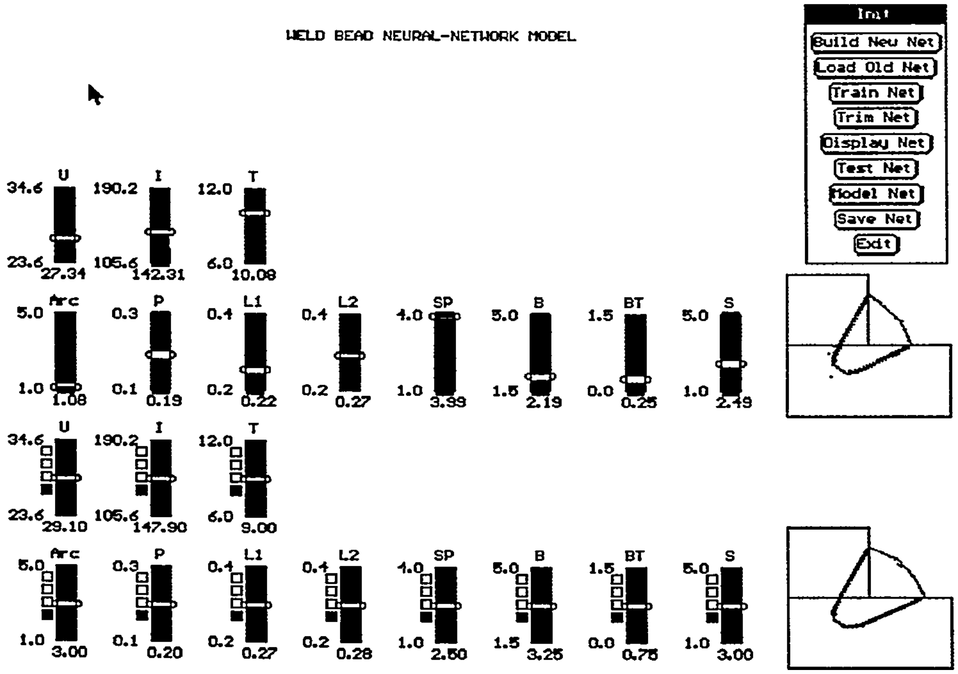

Figure 15a

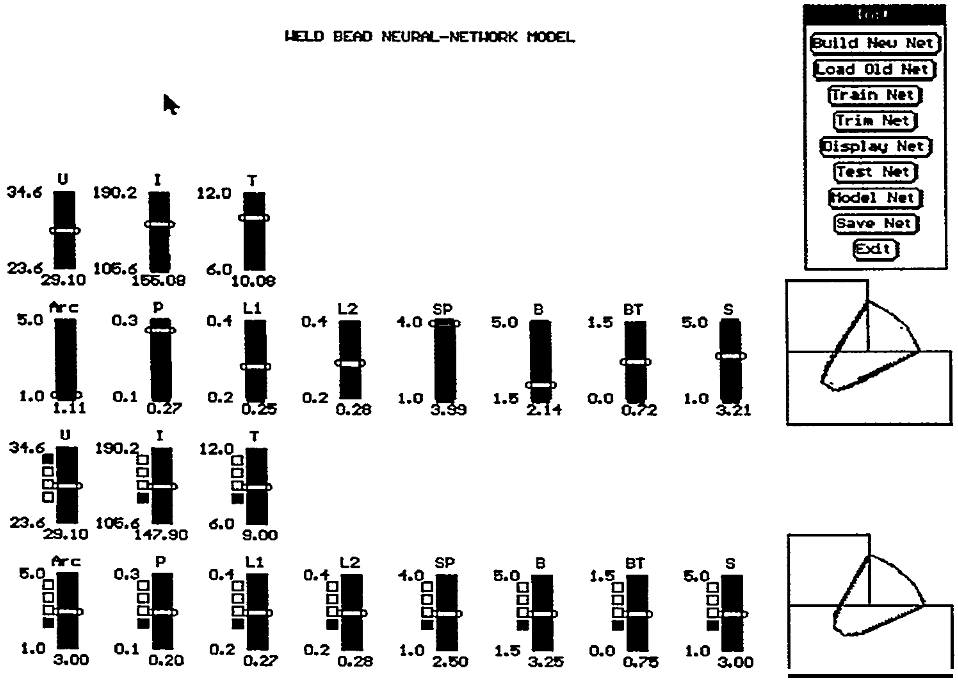

Figure 15b

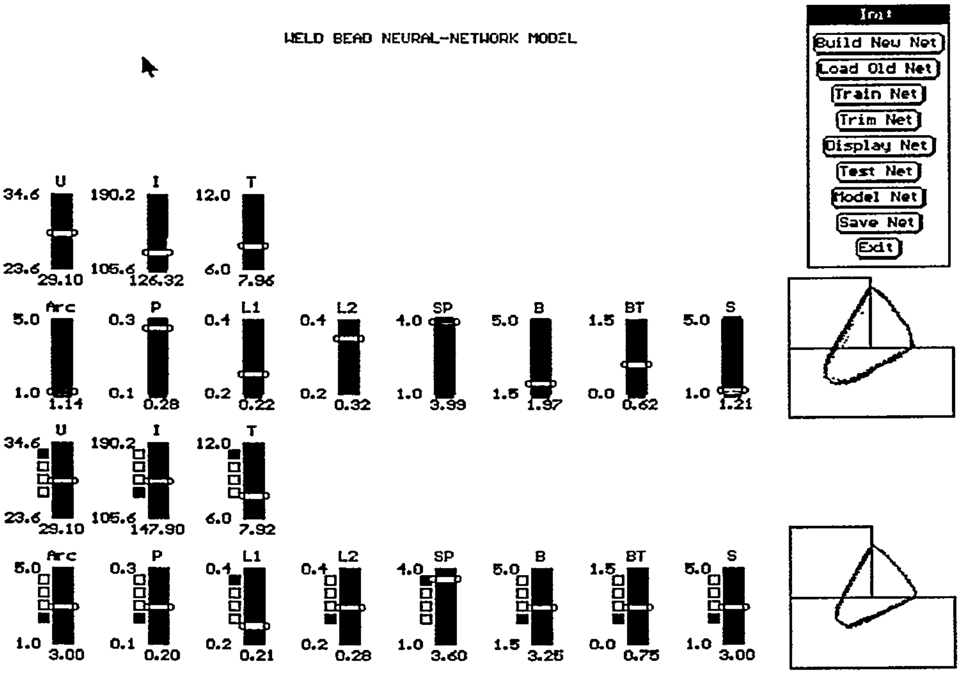

Figure 15c

## CONCLUSION

It is clear that an advanced engineering workstation can provide a welding engineer with a significant productivity tool. The application of advanced computer tools to welding engineering allows a virtually paperless engineering environment in which the engineer has, through these tools, all of the necessary reference data and information to completely plan and engineer a weld. The work that previously would take several days can now be accomplished in a matter of minutes. In addition, the engineer has tools available such as the D-A Net weld model that were never feasible before; consequently, much better engineering will be possible using the WELDEXCELL System. Finally, the system offers the capability to electronically download welding schedules, both for manual as well as automated welding, to the shop floor or robotic workcell. This eliminates the need for large amounts of paper and much faster throughput and communication between the shop floor and the engineer. The result is a significant increase in productivity and quality of welded components in the shipyard.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the United States Navy Office of Manufacturing Technology, without which this project would not have been possible. Puget Sound Naval Shipyard has provided technical assistance, beta testing of the software, and will be the site of installation of the first WELDEXCELL System. In addition, the United States Naval Sea Systems Command and their contractor for project management, CASDE Corporation, have contributed to the overall success of the program.

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