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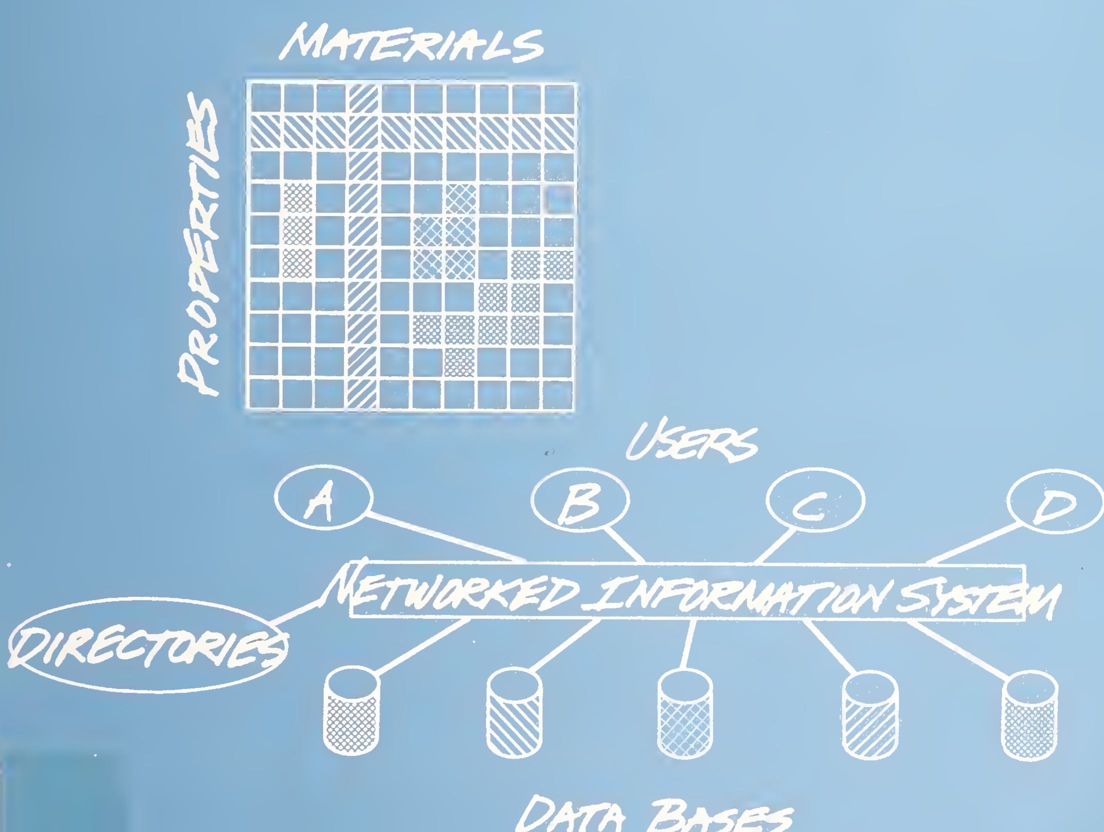
Computerization of Welding Information — A Workshop Report

T. A. Siewert and J. E. Jones, Editors



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[2] Some divisions within the center are located at Boulder, CO 80303.
[3] Located at Boulder, CO, with some elements at Gaithersburg, MD.

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For clarity, this report includes some trade names mentioned by the speakers in their presentations. No support or criticism of these products by the National Bureau of Standards is implied by their inclusion.

ABSTRACT

The Workshop on Computerization of Welding Information, sponsored by the National Bureau of Standards and the American Welding Institute, was held August 5-6, 1986 in Knoxville, Tennessee. Forty-two welding engineers, welding managers, and computer scientists gathered to discuss the necessity and design of databases for welding information. Each subject was introduced by specialists in that area. Group discussions identified the most useful topics for welding databases, in descending importance, to be

1. General welding procedures
2. Properties of the weld, heat-affected zone, and base metals
3. Procedure qualification records
4. Welding variables

In the context of these four data needs, characteristics of the databases were discussed in terms of potential users, content, and sources of information. The participants concluded that

1. A significant portion of the data needs can be met by existing information, but this information should be carefully screened and reviewed before inclusion in databases.
2. Databases should be accessible to a diverse group of potential users.
3. Databases should use the latest computer technology and be upgradable to new technology as it becomes available.

ABBREVIATIONS

AI	=	artificial intelligence
ANSI	=	American National Standards Institute
API	=	American Petroleum Institute
ASME	=	American Society of Mechanical Engineers
ASME B&PV	=	ASME Boiler & Pressure Vessel (code)
AWI	=	American Welding Institute
AWS	=	American Welding Society
CAD	=	computer aided design
CAM	=	computer aided manufacturing
CBI	=	Chicago Bridge and Iron – NACON
CVN	=	Charpy V notch
DOD	=	Department of Defense
DOE	=	Department of Energy
DOS	=	disk-operating system
EPRI	=	Electric Power Research Research Institute
EWI	=	Edison Welding Institute
FCAW	=	flux-cored arc welding
GMAW	=	gas metal arc welding
GMAW-P	=	pulsed gas metal arc welding
GPU	=	General Public Utilities
GTAW	=	gas tungsten arc welding
HAZ	=	heat affected zone
JTIC	=	Joining Technology Information Center
MPD	=	Materials Property Data
NASA	=	National Aeronautics and Space Administration
NBS	=	National Bureau of Standards
NDE	=	nondestructive evaluation
NDT	=	nondestructive testing
NMPDN	=	National Materials Property Data Network
NTF	=	National Training Fund
P groups	=	classification system within ASME B&PV code
PAW	=	plasma arc welding
PC	=	personal computer
PQR	=	procedure qualification record
SAW	=	submerged arc welding
SMAW	=	shielded metal arc welding
TWI	=	The Welding Institute (of Great Britain)
WIC	=	Welding Institute of Canada
WIN™	=	Welding Information Network (trade mark)
WPS	=	welding procedure specification
WRC	=	Welding Research Council

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1. INTRODUCTION

The Workshop on Computerization of Welding Data was sponsored by the National Bureau of Standards and the American Welding Institute to determine whether national welding productivity could be improved through the development of welding databases.* The workshop grew out of the realization that this goal is now feasible since smaller, more powerful computers have become available and affordable to small companies.

This evolution of computer technology and the revolution in the handling of welding data have raised many questions: How do companies use computerized welding data? How do they transfer their technology to others? What kinds of data do they need? Would a national on-line welding database meet their needs? If so, how should it be designed? The workshop was structured to answer these questions.

The workshop was divided into two sessions: one to define the data needs of the welding industry and the other to consider the design of possible databases. Within each session, invited speakers shared their experience and expertise, and small groups discussed the topic. At the close of the sessions, all participants discussed the recommendations and came to consensus.

To give a better understanding of databases, the workshop began with a keynote address on data management and trends. The database concepts described provided an introduction and common terminology for later discussion. Then, representatives of four companies stimulated reconsideration of the data needs of the diverse segments of the welding industry. They shared their experiences in the use of computerized data for welding consumables and power supplies, procedure- and personnel-qualification records, material properties, design, and automated welding processes, and they predicted future applications.

The participants—forty-two welding engineers, welding managers, and computer scientists—split into four discussion groups determined by their interests: thick-section welding, electrodes and welding machines, ferrous-metal welding, and pressure-vessel welding. For these applications, the groups identified potential user communities and then identified and ranked the needs of these communities. From the lists of the four groups, the workshop plenary session selected the four highest ranking data needs, which are a guide for future database development.

The topic of database design was introduced by a presentation that contrasted traditional data (alphanumeric and text) with nontraditional data (visual and auditory). Other speakers emphasized the importance of planning, especially setting realistic schedules, defining data precisely, and determining how the data will be used.

After these presentations by database design experts, four discussion groups were established to define the potential users, database content, and sources of information for the four highest ranking data needs established in the first part of the workshop.

As an introduction to the final discussion, four participants with experience in welding databases talked to the group about the design of database systems and existing databases of welding information. In the final discussion, the participants reviewed the data required by the welding industry.

*The workshop schedule, participants, organizing committee, and other supporters are contained in Appendixes A through D of this report.

2. KEYNOTE ADDRESS: OVERVIEW OF DATA MANAGEMENT AND TRENDS – *F. J. Smith (summary)*

Most commercial databases have been developed for business or financial applications. Only recently have databases been widely used for engineering and scientific data, but when they are appropriately applied, they can greatly increase engineering and scientific productivity.

A database can be defined as information that is stored in a system that enables entry, updating, editing, retrieval, and dissemination of this information. Databases compete with books, which are the primary source of information for scientists and engineers. For successful application to solutions of engineering and scientific problems, databases should emulate the attributes of books

- user friendliness
- ease of data retrieval
- graphic presentation of information
- short access time
- low cost

To offer these attributes, a database must facilitate the storage and retrieval of information. Information must be stored securely so that no loss is possible; its retrieval must be convenient, fast, inexpensive, and have provision for intelligent behavior simulation.

As data systems have evolved over the last two and a half decades, their capabilities have increased. The multitude of data structures existing in a noncommunicative environment have changed to fast systems that include single structures for multiple-file storage and menu-driven facilities for easy input, editing, retrieval, and manipulation of data. Simple intelligence functions can be included in data retrieval operations: the capabilities to search indexes quickly, collate records from multiple files, sort records and calculate values, and print complex arrays that may include data records.

Modern database systems use either a relational data structure (such as a table of information) or a hierarchical structure that presents the data in tree format, in which each data field is a subcategory of other fields. The most advanced systems enable data to be stored in a combination of relational and hierarchical structures.

Data storage capacity is limited to the available storage size of the on-line media. Recent advances in hard-disk technology have resulted in storage capacities of up to several hundred million bytes of information. The new laser (compact-disk) systems offer a storage capacity of many hundred billion bytes on removable cartridges. This large storage capacity in small disk systems, coupled with the rapid advances in processor speed and memory size, will enable microcomputers to replace mainframe and minicomputers in large-scale database applications by the early 1990s.

3. DATA NEEDS FOR THE AMERICAN WELDING INDUSTRY

3.1. Perspectives

3.1.1. Welding Consumables and Power Supplies – *H. Cary (summary)*

During the period from the early 1970s to the early 1980s, the welding-supply industry in the United States grew in annual sales volume from $500 million to over $2 billion, peaking near 1982 and dropping since then. Filler-metal sales during the same time period grew only slightly, peaking in 1980 and showing a sharp decline to pre-1970 levels during the early 1980s. Filler-metal sales have remained relatively constant since then. Thus, the overall economic picture for welding consumables and equipment continues to be very sluggish.

If the United States can achieve higher productivity, perhaps this trend could be reversed. However, for that to happen, extensive use of automation must occur first. The use of robots has grown rapidly: sales volume increased from just over $200 million in 1983 to a projected annual sales volume of over $600 million in 1987. At the same time, the use of visual systems has increased over 200 percent since 1983.

As a result of this increasing automation, the demand for information is increasing rapidly. As more sophisticated applications of automation are used, two distinct needs for data emerge: First, the complexity of welding systems requires wide dissemination of information about the equipment to enable the prospective buyer to make intelligent choices. Second, the data required to develop appropriate procedure specifications and to program the equipment for automated uses should be readily available in computerized format..

A variety of joining processes exist in the United States, including, but not limited to, solid-state bonding, adhesive bonding, resistance welding, and the more traditional arc welding. Examination of the arc-welding processes shows a trend toward more automation. Thus, we can no longer divide these processes into manual, semiautomatic, and automatic categories. Instead, the automatic application of arc welding can include machine welding or a variety of fully automatic welding, from open-loop control to fully autonomous closed-loop control. As the degree of complexity of automatic arc-welding processes increases, the need for computerized information will also increase.

3.1.2. Maintaining Procedure and Personnel Qualification Records – *G. R. Olejniczak (summary)*

The National Training Fund (NTF) derives its income from an assessed fee on sheet-metal construction, half paid by the contractor and half paid by the worker. With a portion of its income, NTF has developed a database system that maintains records of qualified welders. The system has several uses that are designed to meet the specific requirements of the industry.

In developing this database, three categories of information about welders were perceived to be necessary for the sheet-metal industry: (1) welders who are available and interested in working, (2) the current location of these welders, and (3) a record of each welder's qualification history, which can be used to establish his capabilities for each particular job.

Clearly, a useful database should contain records on most welders in the sheet-metal industry. Thus, a major problem is obtaining and entering sufficient data to form a core database and then keeping the data current. To generate the initial data, several companies funded a national program to qualify a large number of welders in a very short time.

The NTF organized this program; it purchased trailer shells and outfitted each with ten welding booths and full-time instructors. The mobile training and qualification stations provide welders with excellent, well-trained instructors in their own district. All the welders who qualify in this program fill out a standard questionnaire that is sent to NTF, where the information is included in the database.

3.1.3. Computerization of Welding Data and Design Engineering – *F. C. Breismeister (summary)*

The extensive data needs of the welding industry include not only general information about welding consumables and welding procedures but also a large amount of specific information about the metallurgy and process control of welding. Materials data, such as those provided by the National Materials Property Data Network, could be used to great advantage if they were readily available. The benefits of developing these data are more serviceable, more durable products, which could make American products more cost effective. Materials data should include properties of the base metal, the heat-affected zone (HAZ), and the fusion zone. Mechanical test data should include toughness and fracture mechanics criteria as well as corrosion test results. Welding-procedures data should include information regarding process controls and residual stresses in addition to welding procedures. Information about analyses of weld discontinuities would reduce repairs and thereby aid productivity.

Computerized welding services have many advantages: Systems can be designed to make data acquisition and dissemination more uniform and consistent, and therefore, the user can make more informed and consistent decisions. A computerized database that interacts with other computerized systems, such as computer-assisted design, will result in better welding design. Computers can be used to track productivity, quality, and rates of rejection. Improved control over welding processes is possible through computer monitoring.

The quality of data contained in any information resource is important for two principal reasons: (1) If the user relies on the data for design applications, poor quality data may result in poor quality design and possible catastrophic failure. (2) The use of computerized data is important in increasing the productivity of the United States. Computerized database systems that contain faulty data or data in an unusable form will discourage the use of computerized systems and thus reduce, rather than enhance, the productivity of the U.S. welding community.

Numerous databases of qualified welders (developed by training schools, testing companies, and government agencies outside the United States) are not useful. The fact that 40 to 60 percent of welders from these sources fail routine entry-level tests indicates that information from these organizations is not reliable, perhaps because they don't have accountability or responsibility, that is, a vested interest in the production of quality welds. If computerized lists of welders tested by third parties are used, it is prudent to require an additional screening test. Engineers and designers are concerned about and responsible for weld implementation so that hardware will perform as intended. Welder performance is frequently critical to product performance. Therefore, engineers are not likely to accept the qualification of welders by outside organizations. Computer lists of welders are not likely to enhance productivity unless the sources of qualification data are directly accountable for the weld quality.

The data included in a computerized system must be appropriately evaluated. Users need to be trained to use common sense in interpreting computerized data, just as they would in using noncomputerized reference information. Too often they accept it uncritically simply because it comes from a computer.

Computer-aided design extends far beyond the task of aiding mechanical drawing preparation; it is beginning to encompass all aspects of design, including the choice of the materials and processes to be used in fabrication.

Computerized information resources must be designed to provide data to other computerized systems. The data (graphic and photographic as well as alphanumeric information) should be available as a shared resource and in a format appropriate for sharing.

The capability to emulate human intelligent decision making is an important aspect of advanced computerized information systems. In the near term, expert systems, drawing upon the human expertise stored in computerized knowledge bases, will be able to interrogate databases and provide information as well as conclusions about that information to users. Such systems are within the capabilities of small desktop computers today, and these advances in artificial intelligence should be incorporated into advanced computerized welding information services.

Bechtel Corporation has an internal database of procedure qualification records (PQRs) containing approximately 1,200 records. They have also built a prototype expert system to help extract PQRs from the database. The expert system will be extended to help an engineer use the extracted PQRs to write a welding procedure and develop a welding procedure specification (WPS). The system is currently based on ASME Boiler and Pressure Vessel Code, Section IX.

The expert system is written in the LISP computer language and is "rule-based." In the future, the expert system will be expanded to materials other than those covered in ASME Section IX and additional rules. Examples of rules for this extended expert system are those regarding preheat and post-weld heat treatment in excess of code requirements, restraint, and hydrogen. From information gained by the Bechtel expert system project, some conclusions can be obtained.

Expert systems based on knowledge and rules, rather than specific data, are in use. One system is already sorting through ASME Section IX rules and converting PQRs into welding procedure specifications (WPSs). Although the system eliminates errors, it is not as cost effective as experienced welding engineers using more traditional computer sorts of PQRs and word-processing equipment. Expert systems may allow junior personnel to function subject to review by the engineer. Simple expert systems are not the solution to complex welding-engineering problems, because the rules in the system are frequently too narrow in scope and inflexible — not tempered by judgment. Without good judgment, productivity may not be increased; computerized decision making could prove to be costly and counter productive.

In addition to the PQR database, several other opportunities exist for developing databases in welding. These include

- Base material data
- Weld metal data
  - Corrosion
    - of base metal, weld metal, HAZ
  - toughness
    - at varying temperatures
    - as a function of welding conditions
    - as a function of heat inputs
    - K_{Ic}
    - fatigue
  - Alloys other than steel (e.g., Al, Ti)
  - hardenability and cooling-rate data
    - basic data
    - predictability
  - residual stress
    - predictability of fitness for service
    - flame-straightening data
- Joining and bonding of composites
- Investigation

- Effect of productivity variables
  - electrode extension
  - polarity
- Cooling-rate data (e.g., those found in the Welding Journal in the 1940s)

The capability to store and quickly retrieve data from computerized systems presents great opportunities. All opportunities cannot possibly be foreseen at this moment, but a partial list includes

- Standards for data acquisition
  - better uniformity
  - better consistency
- Computer-aided manufacturing (CAM)
  - integration with computer-aided design (CAD)
  - monitoring procedures in real time
- Nondestructive testing
  - data storage and retrieval
  - data interpretation
- Production information
  - productivity
  - quality
  - reject rate
  - process monitoring

As the computerization of welding data increases, we must be concerned to a greater extent with data quality. Data must be screened and evaluated, and quality assurance and control procedures must be implemented. We also need to use greater "engineering intelligence" and "common sense" in interpreting the data that are extracted. Finally, it is not at all clear how the development of consensus welding standards can increase productivity, which is the thrust of the workshop. This is almost inconsistent when one considers how industry and institutions are planning to address the task.

The approach of using multiple sources of noncontroversial data and having them accepted by consensus indicates that the resultant welding procedures will, in fact, be commonplace. This almost precludes issuing welding procedures that are on the frontiers of development. Because the information in such procedures will be commonplace, there is virtually no chance that the productivity in the United States will advance. The availability of these commonplace U.S. data will likely advance productivity in less developed countries.

Organizations in the United States generally have the welding procedures they need to fabricate or manufacture their established product lines. These are supported by test data to the extent necessary. A rehash of these data by a computer or a committee won't boost production. What is needed are new data that push the frontiers and the broad, prompt dissemination of the new data so that productivity can be increased. In contrast, consensus general welding procedures are likely to stifle production gains by inhibiting innovation.

3.1.4. The National Materials Property Data Network – *J. G. Kaufman (summary)*

Recently, a private nonprofit organization was established to operate as a computerized gateway to a variety of material-property-data sources with helpful software to enhance the utility and ease of operation. The aim of this National Materials Property Data Network (MPD Network) is to offer direct access to numeric data rather than access through bibliographical references that require additional literature searching. The MPD Network will also provide metadata support – additional details about the data, including terminology, units, nomenclature, abbreviations, and graphics. The references include characterization of the data and databases, indicating quality and reliability.

3.2. Discussion Groups

To develop a list of welding data needs based on the perspectives given by the speakers, the participants joined a discussion group that reflected their interests. Participants suggested and then voted on topics for each group, ranking them in the order shown below:

Proposed Topics (in descending rank)

1. Thick-section (4.763-mm, 0.1875-in) welding
2. Electrodes and welding machines
3. Ferrous-metal welding
4. Pressure-vessel welding
5. Thin-section welding
6. Reactive-metal welding
7. High-energy processes
8. Nonferrous-metal welding
9. Nonpressure-component welding
10. Other types of welding

Since a discussion group of ten participants seemed to be the optimum size for individual participation, the workshop was divided into four groups, one for each of the top four topics. Notes from these groups follow.

3.2.1. Group 1—Thick-section welding

3.2.1.1. General

The group discussed the following issues:

- Material properties required
  - mechanical properties
  - physical properties (including dimensions)
  - corrosion resistance
  - weldability or P groups
  - product form (including dimensions)
  - postweld heat treatment
- Material properties needed for the base metal, HAZ, and weld metal
- The nature of residual stresses and how this information should be addressed
- User guidance to the database

3.2.1.2. Potential users and their needs

User	Data Needs
designers	mechanical properties product form
fabricators	variation of mechanical properties with welding parameters PQR information joint design major code rules shrinkage and distortion information preparation processes needed prior to welding cladding materials
structural engineers	mechanical properties of weld metal postweld-heat-treatment and residual-stress-relief data residual-stress information flaw detection and sizing; NDE criteria
welding engineers	same as for fabricators
underwriters and regulators	all of the above
codes	all of the above
manufacturing engineers	machinability of base and weld metals productivity deposition rate welding-operator qualification costs of filler metals costs of machining plant safety considerations (e.g., dangerous by-products) inspection considerations and standards inspection processes (for selection of the appropriate process for a specific kind of inspection)
purchasing personnel and estimators	shelf life of electrodes suppliers and the location of filler and base metals foreign equivalents for filler and base metals—indexed on composition
researchers	same as for fabricators

3.2.1.3. Ranked data needs

The data needs of all users were ranked according to priority:

1. Materials—base, HAZ, and weld metal
   - mechanical properties
   - physical properties
   - corrosion properties
   - chemical properties
   - weldability or P groups
   - product form (including dimensions)
   - base, HAZ, or weld metal
2. Welding variables
   - process
   - joint design
   - postweld heat treatment
   - productivity data, deposition rate, . . .
3. Process quality capability
   - inspection consideration and standards
   - selection of inspection process
4. Shrinkage and distortion—residual stresses
5. Flaw detection and sizing; nondestructive evaluation
6. Commercial considerations
   - suppliers and their location for filler and base metals
   - foreign equivalents for filler and base metals
   - cost of filler and base metals
   - machinability of base and weld metals
7. Dissimilar materials
   - clad materials
8. Major code rules
9. Safety
10. Welder qualifications

3.2.2. Group 2—Electrodes and welding machines

3.2.2.1. General

Initially the discussion group identified eleven data needs of people who work with electrodes and welding machines:

1. Base-metal type and thickness; weldment design
2. Joint design and surface preparation
3. Quality level (NDT); specifications and codes
4. Economics (including relationship to lot sizes)
5. Weld location
6. Atmospheric conditions
7. Welding position
8. Welding process
9. Welding power type
10. Electrodes and weld metal
11. Shielding and flux material

The group decided that some of the topics were outside the principal thrust of electrodes and welding machines. Consequently, the following topics were chosen for further definition and discussion:

- Electrodes
  - SMAW
  - GTAW
  - GMAW and SAW (and fluxes where appropriate)
  - FCAW (flux, powdered metal)
- Power sources and supplies
  - constant current—ac or dc
  - constant voltage
- Equipment
  - wire feeders
  - guns—FCAW, GMAW, PAW
- Procedures and processes—arc welding—SMAW, GTAW, GMAW, FCAW, SAW, PAW

3.2.2.2. Ranked data needs

Data needs were ranked within the context of two major topics:

A. Electrodes and filler metal
1. Initial composition—AISI, AWS, or foreign specification
2. All-weld-metal composition
3. Deposition efficiency and rate
4. Procedure guidelines
   position
   travel speed
   heat input
   hardenability
   current range
   filler-metal diameter
5. Position capabilities
6. Mechanical properties
   toughness
   ultimate tensile strength
   yield strength
7. Heating requirements
   preheat
   interpass temperature
   postweld heating
8. Weld microstructure
9. Cost
10. Moisture pickup (content) and shelf life
11. Arc atmosphere

B. Power sources and supplies
1. Output rating
2. Duty cycle

3. Electrical characteristics
    phase (primary)
    primary voltage
    primary amperage
4. Characteristic curve
5. Pulse
6. Wave form and symmetry
7. Type of arc-voltage measurement

3.2.3. Group 3 – Ferrous-metal welding

3.2.3.1. General

Discussions centered around two basic questions:

What data are needed?
Who will use the data?

3.2.3.2. Potential users

Potential users of the data were categorized:

- owners
- designers
- fabricators and manufacturers
- engineers, supervisors, and welders
- code writers
- researchers

3.2.3.3. Ranked data needs

Data needs were ranked in the context of two categories:

A. Properties (including statistical spread) of weld metal, HAZ, and base metal
1. Mechanical properties
    ultimate tensile strength
    yield strength
    ductility
    toughness (K_{Ic}, CVN)
    hardness
    creep
    fatigue
    stress rupture (most lacking in HAZ data)
2. Corrosion rates and fatigue
3. Material properties (of equal rank)
    physical properties – modulus, conductivity, density
    formability
    machinability
    hardenability
    wear and abrasion characteristics

4. Additional metallurgical characteristics
   cleanliness
   composition
   prior history, including thermal treatment or deformation

B. Welding procedures
   1. Procedure qualification records (PQRs)
   2. Heat treatment
   3. Care of electrodes

3.2.4. Group 4—Pressure-vessel welding

3.2.4.1. General

The group defined pressure vessel as a container with an internal pressure that was anything other than atmospheric. The group also defined the thickness to be considered:

thin section = 2 to 20 mm (0.08 to 0.8 in),
thick section = 20 to 300 mm (0.8 to 12 in).

Most were interested in thick-section vessels.

3.2.4.2. Potential users

Potential users of the data were defined; the type of data associated with the user corresponds to the types listed in section 3.2.4.3.

- Fabricators—type-A data
- Suppliers—type-B data
- Individuals in the welding community—type-C data
- Manufacturers (if data were available on disks)—type-D data

3.2.4.3. Ranked data needs

A. Structures
   1. Pressure vessels
   2. Piping and tubing

B. Materials
   1. Carbon steel
   2. Low-alloy steel
   3. Stainless steel—P6, P7, P8
   4. Nickel-base alloys—P41, P42, P43, P44
   5. Aluminum
   6. Copper-base alloys—P31, P32, P33, P34, P35
   7. Reactive metals—titanium, zirconium

C. Processes
   1. SMAW
   2. GTAW
   3. SAW
   4. GMAW and GMAW-P
   5. FCAW

D. Codes
1. ASME B&PV I, IIc, III, VIII, IX
2. ANSI B31.1, B31.3, B31.4, B31.8
3. API 1104
4. API 620, 650

E. National database needs
1. General WPSs for a broad range of materials
2. PQR test data
3. Weld metal properties
   fracture toughness (J_{Ic}, K_{Ic})
   Charpy V-notch toughness
   tensile strength
   elongation
   crack-tip-opening displacement
4. Welding-related code requirements
5. National register of qualified welders by code and geographic location

3.2.4.4. Perceived Uses of a Welding Database

Discussion-group participants were asked how they would view the databases and how they would use them. Responses:

- Database for special applications dealing with material properties and fracture
- Program to identify components in plants—serialize, identify location, welding procedure, qualification of welder
- Special information relating to precious metals
- Common database from which to draw (particularly to make repairs and modifications to structures)
- Database to maintain history of structures
- Source of current news about everything in the world of welding
- Database to track welders (qualifications, materials, WPSs) with capability to compare different welding codes
- Database of standards for all sizes of organizations to follow
- Procedures for welding specific kinds of materials and drawings with verification, including both WPSs and PQRs

3.3. Highest Ranking Data Needs

Following the four separate discussion groups, the participants convened to hear the group chairmen present a summary of their group's discussion. The lists of data needs from each group were combined and ranked by all participants. The top four needs identified were

1. General welding procedures
2. Properties of materials
3. Procedure qualification records
4. Welding variables

4. DESIGN OF THE WELDING DATABASES

Invited speakers began the second session by giving the participants a basic understanding of the session's topic, Design of Welding Databases, and a description of state-of-the-art capabilities that could be incorporated into the database design. With this background, small discussion groups were able to outline a design and anticipate problems in implementation.

4.1. Database Design Considerations

4.1.1. Traditional and Nontraditional Data—*J. E. Jones (summary)*

Database systems that are used in business are designed to allow storage manipulation and retrieval of "traditional" data, which consist mainly of numerical information, character information, and text and associated items. The principal use of database-management systems has been for business purposes; consequently, those systems are generally designed for the traditional forms of data.

Data that are useful for engineering and scientific applications include the traditional forms of data, but several other kinds of information are also needed: graphics, images, recorded speech, annotated speech, motion images, and knowledge.

Graphics illustrate trends and relationships between parameters. These data are generally stored in the form of an image, but they also may require added software for manipulation of the information.

Images may be explanatory drawings or photographs that are used to present information that often is difficult or impossible to represent in other ways. Image information exists in three principal forms: (1) binary (black and white) images, which are the simplest to store and retrieve, (2) gray shade images, which require nearly an order of magnitude more memory and storage capacity than binary images, and (3) color images, which, for most applications, consist of three gray-scale images that represent the blue, green, and red components of a full-color image.

Recorded speech that is digitized can be stored and reproduced using digital computers. Speech can be used effectively to present information to a database user in a very efficient manner.

Annotated speech is voice information that is stored simultaneously with text or graphics and which, when reproduced in combination with the text or graphics, becomes an excellent method of conveying concepts and ideas.

Motion images are graphic or image information that can be retrieved so that displayed objects move relative to each other. The information may consist of sequential photographic images which, when displayed at a rapid rate, present a moving scene. Graphical images can also represent moving objects by sequential redisplay of some portions of a drawing in different locations on the image plane.

Knowledge information consists of formulae and other representations. This type of data is useful in describing relationships between objects or representing knowledge. Knowledge information is discussed in more detail in section 4.3.4. of this report.

These nontraditional forms of data have not been extensively used in databases mainly because they require fairly extensive processing and memory capacity for storage, manipulation, and display. Only recently have computer systems had sufficient capacity to use these nontraditional data. Both hardware and software are rapidly advancing, enabling easier use of such data.

4.1.2. Database Design—*J. Rumble (summary)*

In a discussion of database design, definition of terminology is important. Therefore, two basic words that describe the elements required for storage, manipulation, and retrieval of information are defined:

Database is a computerized collection of related data that can be used without knowledge of its storage details.

Data system is a collection of integrated databases.

Building a database includes four primary elements: planning, design, selection of software and hardware, and implementation. These elements are listed in decreasing order of the time they require.

1. *Planning.* The key to successful database planning is to keep in mind how the system will be used. The users of the system and their needs must be defined. This examination should provide answers to four basic questions:

What data are needed?
What are their sources?
How will the data be used?
Who will use the data?

2. *Design.* Design is a technical activity that transforms the data content into three views: external, logical, and physical. The external view is that seen by the user. The logical view represents the data organization and structure, which can be network, hierarchical, or in the more advanced systems, relational. The physical view of the data is the structure of the data as it exists in the computer system. The result of the design process is an understanding of all data to be included and their relationship.

3. *Selection of software and hardware.* This step should follow the design stage so that the chosen software and hardware will most closely meet the demands of the database and its user community. Generally, technical databases should be designed by a group that contains technical people. Computer scientists often do not fully understand technical data or the uses for technical data.

4. *Implementation.* A well-defined schedule should be developed for the implementation step. The schedule should include development of a prototype database that can be tested with the potential users of the database and modified. The earlier in the implementation step that the prototype is developed, the better the implementation will progress. This prototype should be designed to be disposable and quickly discarded and replaced. It is valuable for the design of user interfaces and the development of additional interface ideas. Finally, it saves time and other resources to buy prewritten software.

A significant effort expended during implementation is in the administration of the database. Development of manuals and training systems may require up to 30 percent of the effort of building a database. Follow-up activities—continuous replanning and examination of changes that need to be implemented—are essential and time-consuming. They are also disheartening if accompanied by unrealistic expectations. Typically, expectations exceed the capability of the database to fulfill them during the early stages of implementation.

In building a database, four ingredients must be considered: (1) A good database must be user driven. (2) The database should take advantage of the common sense and experience of the users. (3) The database should be based on modern software practices. (4) Any database will require an extended period of time to construct—it cannot be built in a month.

Important initial, as well as continuing, aspects of database building are data entry and updating, expensive tasks that require considerable resources. Verification of the data and use of standards for data representation are imperative.

4.2. Discussion Groups

Four discussion groups were formed to review the four most important data needs, which were identified in the first discussion groups.

4.2.1. Group 1 – General welding procedures

4.2.1.1. Potential users

The group identified the potential users of the welding-procedures database:

Primary Users	Other Users
Welding engineers	Engineers in manufacturing
Welding foremen or supervisors	Draftsmen
Welders and welding technicians	Design engineers
Quality-assurance engineers	Welding distributors
Quality-control engineers	Customers and buyers
	Manufacturers of filler metal and equipment (such as power sources)

4.2.1.2. Content

In addressing the amount of data that is required for a reliable data source, the group discussed

- the number of welding procedure specifications (WPSs) that are needed to cover a specific area
- the quantity and degree of coverage that would represent a sufficient database to provide 90 percent of the needs in the area of sheet-metal work, ASME code welding, pipe welding, and structural welding

The consensus of the group was

Area	Number of WPSs Required
sheet-metal work	15
ASME-code welding	50
pipe welding	150
structural welding	about 100 to 150

4.2.1.3. Sources of information

The primary source of welding procedures information is probably government laboratories, followed by military contractors. Other sources are public and governmental utilities, EPRI, and government contractors, such as contractors for the Air Force, the Bureau of Reclamation, and the Army Corps of Engineers. Technical societies and associations could also contribute to the system. Through their research, universities, electrode manufacturers, and technical welding institutes throughout the world also develop welding information. Finally, the welding industry would be another valid source of information, provided that a nontraceability function could be incorporated into the database (see 4.2.1.4.). An especially important consideration is the validity of the data from these sources.

4.2.1.4. Liability considerations

The subject of data sources included a discussion of strategies for convincing companies to release information for the system. The problem is to obtain WPSs and PQRs from the industry in such a way that the liability of using them does not extend to their suppliers. Suggested solutions to this problem included disclaimers, limitation-of-liability laws (which could be in the form of laws or guidelines from Congress), complete anonymity of sources, Department of Commerce guidelines, tax breaks, technical-society administration, studies to defend the competition, and promotion of the system by the government.

4.2.2. Group 2 – Material properties

4.2.2.1. Potential users

Potential users consist of

- welding engineers
- design, product, and other engineers
- other technical people

4.2.2.2. Content

The users of a welding-oriented properties database would be particularly interested in two types of data:

- data that are specific to welding and generally not available from other sources
- data aimed at other applications but useful in welding applications (These data are needed for completeness of the database, but they are not necessary.

The following five categories of welding data have significant areas of missing information:

- weldment versus all-weld-metal properties
- fracture-impact toughness of HAZ
- test detail (precise location of HAZ in CVN specimens)
- material history (temper embrittlement)
- welding history and filler-metal traceability

The specific size of the database that is needed to provide an adequate datasource was not addressed. Instead, the group felt that the size of the database should be sufficient to provide state-of-the-art data coverage for materials as well as materials-testing data.

4.2.2.3. Sources of information

The group listed the following sources of data:

- welding institutes (AWI, EWI, WIC, TWI, . . .)
- MPD network
- manufacturers
- literature
- failure-analysis groups
- producers of materials
- universities
- research laboratories
- utilities
- users
- government
- code bodies
- consultants

4.2.3. Group 3 – Procedure qualification records

4.2.3.1. Potential users

The group felt that large fabricators have databases of procedures that are sufficient to cover most of their current needs. However, as the use of materials changes and as greater code acceptance of the standard PQRs in the database increases, even the large fabricators will find a PQR database useful. Initial users are expected to be

- contractors (small and large)
- fabricators (small)
- welding engineers
- industries with existing databases (to fill gaps in their data)
- consultants
- inspection laboratories and agencies
- academics (limited)

4.2.3.2. Content

The database content should include the information on the WRC Welding Procedures Committee forms. Specifically, testing data should be included with the PQRs. An acceptance consensus must be established for PQRs on three issues: standardization of PQR information, codified acceptance of these standard PQRs, and standard forms for PQRs. State and federal regulations (including military standards) should also be incorporated into the PQR database standard.

The group was concerned with "gaps" or "holes" in the data. The database administration should interact with industry and government to obtain data that could be used to fill the gaps. The database should be designed in a modular format so the gaps can be filled easily. Gaps in existing data that must be filled are

- effect of joint misalignment and overlaps
- PQRs for materials thinner than 5 mm (0.2 in)
- PQRs for exotic materials

Although generation of the database will be a massive task that will be more difficult as its size increases, a large database is needed to provide a size that forms a "critical nucleus" for the user. The PQRs entered should cover a very broad scope and include as many codes as possible. If possible, the initial database should include 10,000 to 20,000 PQRs.

4.2.3.3. Sources of information

Principal data contributors were identified:

- Welding Procedures Committee (WRC) (including code acceptance)
- industry
- national laboratories (DOD, NASA, DOE, and their contractors)
- bureaus and associations (e.g., National Construction Association, National Pipe Welding Bureau)
- state agencies

4.2.4. Group 4—Welding variables

4.2.4.1. Potential users

The potential users of a welding variables database are diverse:

- welding engineers
- designers
- quality-control and quality-assurance engineers
- researchers
- process engineers
- managers
- design engineers
- regulating bodies

4.2.4.2. Content

The group decided that the appropriate scope was "all the data needed for a good weld." Although some disagreement existed with respect to the specific amount of data coverage represented by that expression, it was felt that providing too much data was better than supplying too little. It was estimated that the minimum size for an effective database was 5,000 data records.

This discussion group approached the issue of gaps in the data in terms of their causes rather than their types. They determined the causes to be

- validation
- lack of access to proprietary data
- incompleteness of records

4.2.4.3. Sources of information

Data sources identified for welding variables were also diverse:

- cooperative-research societies (especially for PQR data)
- published literature (domestic and foreign)
- manufacturers' literature
- government (domestic and foreign)
- internal documentation from users and suppliers
- patents
- university research

4.3. Case Histories of Database Systems

Three speakers presented information about existing database systems and assessed their usefulness. These talks were presented before the final discussion session of the workshop so that workshop participants would be aware of experiences with existing systems and be able to benefit from this knowledge in the final discussion and in making their recommendations. Some case history information had been presented earlier by Mr. Breismeister; his talk is summarized in section 3.1.3.

4.3.1. WPS Database History – *J. E. Sims (summary)*

In the mid-1970s, a computer system was initiated to store and sort WPSs. Roughly 4,000 to 5,000 records were put in the system. The system was only a sorting system; it extracted a WPS on the basis of certain parameters, such as HAZ hardness and materials. The system was only moderately useful, principally because a computer scientist, rather than a welding engineer, designed and implemented it.

In the early 1980s, the WPS database, which currently contains between 8,000 and 10,000 records, was developed. The originals of all the records are also maintained in a paper record file, since not all the data from a WPS (for example, graphics information, such as drawings or signatures) could be stored on the computer. Currently, this system is working inadequately; however, the storage on the mainframe computer is more than 66 percent full and does not offer all the flexibility that would be useful for such a system.

The data are sent to individual accounts by a time-share system, where they can be manipulated as needed. A word processor is used to generate the final WPS. The system has also been used to make some predictions, such as preheat temperatures.

4.3.2. Welder-Qualification Database – *G. R. Olejniczak (summary)*

The National Training Fund has set up a database to maintain qualification information on sheet-metal welders. The system was designed so that a nationwide search could be performed to find one or more qualified welders for a specific job. The system maintains records on the personal information about a welder (e.g., name, address, social security number) and the qualification history. It will also calculate the date last welded and calculate the qualification expiration date.

The system is designed to search for welders that are qualified to perform a specified welding procedure. The system can search the records of procedures in several fields including:

- code
- welding process
- base metal
- thickness
- coating on steel
- position
- filler-metal classification
- electrical characteristics
- gas flow
- wire-feed speed
- travel speed and direction

4.3.3. A Fully Integrated Database System for the United States—*J. E. Jones (summary)*

The American Welding Institute initiated a program known as the Joining Technology Information Center (JTIC). Within JTIC, a multifaceted database system project is under way. The project includes development of many databases. This database software includes databases with pre-entered and maintained data files as well as databases that are designed as operating shells in which companies enter their own data.

This integrated system is known as the Welding Information Network (WIN^{TM}). WIN includes: (1) filler and base metals and their chemical and mechanical properties; (2) histories of welder qualification and the quality of welds by each welder; (3) welding-procedure information, including WPSs, PQRs, and pre- and postweld heat-treatment information; (4) design information, including joint-design graphics and welding symbol information; (5) corrosion-resistant and wear-resistant material information, such as ferrite content and prediction for stainless steel welds.

In addition to their integrated nature, the databases are all designed to operate in the distributed computing environment of the desktop computer, turning those computers into welding engineering work stations. Thus, the welding engineer who has a desktop computer can use all the capabilities of the system without the need to learn several different command structures.

Intelligent-query capability is being added to all the databases. With it, the users will be able to extract raw data and receive computer assistance in making decisions about the information. This intelligent-query system consists of a series of expert systems that can access any, or all, of the databases needed to generate decision support information for the user. It is one of several ways that artificial-intelligence techniques can be applied to the distribution of welding information.

Information services consist of (1) the problem to be solved, called the *problem space* and (2) the solution tools that can be used to solve the problem, called the *solution space.* Various cases can exist with respect to the overlap of the solution space and the problem space. Following is a brief description of each of these cases:

Case I: Poor overlap. The solution tools have not been chosen to address the problem appropriately.

Case II: Insufficient coverage by solutions of the problems. Good match of the solutions with a small portion of the problem.

Case III. Overkill of the problem with the solutions. Often the solutions chosen in this case also do not match the problems well.

Case IV: The solution tools cover only problem areas and nearly solve all the problems. This is typical of the most ideal solution that most applications ever achieve.

Case V: The solution tools cover all of the problem areas but only exceed the requirements by a small amount. This is the ideal situation, but it is seldom achieved.

The solution tools that are available for the problem of welding information storage and dissemination fall into five basic categories:

1. Conventional database software
   - relational software
   - hierarchical software
   - advanced combined systems
2. Flexible systems
   - modular in design
   - integrated with other systems
   - user-acceptable (better than user-friendly) systems
3. Advanced technologies
   - fast, high-resolution imaging
   - speech recognition and synthesis
   - PCs with advanced architecture
4. Artificial intelligence (AI)
   - expert systems
   - information understanding
   - multimedia presentations
   - intelligent-menu technology
5. Expert-system technology (branch of AI)
   - intelligent data searches
   - interpolation and extension of data concepts
   - application-oriented design support
   - natural-language linking

Artificial-intelligence techniques offer the most promising capabilities for supplying computerized welding information. Although AI is not a new field, its use in small computers is relatively new. This is due to the dramatic increase in the capabilities of electronics that make small desktop computers nearly as useful as large mainframe machines. In addition, the development of several expert-system shells that allow development and delivery of expert systems on small computers has greatly enhanced the ability to apply expert system technology. Although the use of expert systems is mainly an evolutionary change, the combination of the three factors – expert-system technology, good software shells, and fast miniature electronics – represents a revolutionary change in the area of computers for engineering. This revolution has been called "the important one" when referring to the computer revolution that took place during the 1970s.

In taking advantage of this revolutionary technology, the American Welding Institute has begun a massive effort to develop advanced, hybrid expert systems that consist of knowledge bases coupled with an entire series of databases. The integration of the databases, knowledge bases, and expert systems into one package (WIN), will give engineers tremendous computing power for decision making. At the time of the workshop, AWI had nine expert systems under development. Many more are planned. These systems operate on any desktop computer that is based on DOS, although for speed requirements, AWI recommends the use of 80286 processor-based machines.

4.3.4. Development of an Expert System for Welding—*A. Kuhne (summary)*

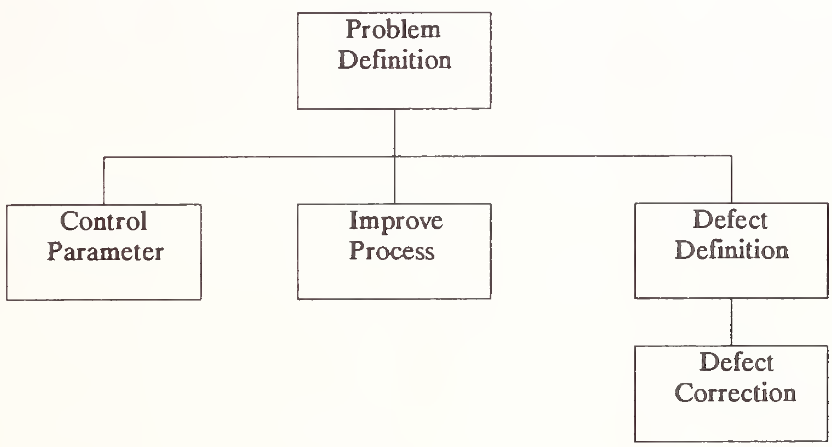
An *expert system* is a repository of knowledge that can be retrieved in a useful form. Thus, an expert system can be thought of as a type of advanced-technology database. Possible topics that a welding-related expert system could address include

- Construction and design
- Parameter recommendations
- Cost control
- Weld-defect control

A variety of tools are available for building large or small expert systems. The large systems contain 500 to 1,000 rules, whereas small systems generally contain less than 400 rules. Small systems can usually be developed in desktop computer systems.

A small expert system was developed with support from a private company to enable welders to control and diagnose welding defects. The system is designed to control welding parameters in the GMAW process and is based on visible defects. This system is designed as a series of rules; the diagram below shows its organization.

It is an example of the more advanced technology that is becoming available for the storage, manipulation, and retrieval of information.



5. FINAL DISCUSSION

In the final discussion, the participants reviewed the lists of data needs on the basis of the presentations. Microelectronics engineers, aerospace engineers, and attorneys were added to the list of potential users.

Two topics that were not addressed earlier were discussed in the final session:

The cost of computerization of welding information. Two issues became evident: Data entry and verification are expensive and will continue to be so. Engineering data must be standardized to the greatest extent possible and entered under the supervision of a welding engineer.

Welding environment. Two items of interest should be included: wind velocity and safety issues.

The use and dissemination modes for the data were discussed. First, two categories of users were identified:

- Companies that already have databases and would use a new one only to "fill in the holes"
- Companies that currently have no access to databases of welding information

Second, dissemination modes for the data were discussed and listed in the order of their sophistication:

1. Distributed computer tapes or diskettes (laser disks might be desired someday)
2. Phone – remote connect of PC to main system
3. Phone – transmission to an operator who completes the interaction
4. Mail – printed data sent to interested parties

6. SUMMARY

During the workshop, welding professionals and computer scientists obtained a better understanding of one another's problems and capabilities. Guidelines were established for the creation of a national welding data system.

Lists of users of welding information generated early in the workshop attest the diversity of the welding industry. The lists of welding information required by these users were also extensive and overlapping, substantiating that sharing information through a national database would be worthwhile. To guide database developers, the participants were able to identify the most important and widely used information: general welding procedures, material properties, procedure qualification records, and welding variables.

Sources of welding information include research laboratories, professional societies, national and international welding institutes, and the welding industry. The reliability of the information included must be assessed. The initial database should include all reliable information that is available within its established scope. The welding community must strive to generate reliable data that are needed but currently unavailable.

The database system should be designed to be accessible to most users, to take advantage of the latest computer technology, and to be capable of potential upgrading as computer technology advances.

A cooperative effort by the American Welding Institute, the National Bureau of Standards, the National Materials Property Data Network, and the American Welding Society was initiated. It includes a project to provide the U.S. welding community with the data that were given the highest priority by the workshop participants. The database of welding procedures is being developed first; prototype inquiry systems will be demonstrated at subsequent AWS national conventions.

APPENDIX A. WORKSHOP SCHEDULE

August 4, 1986

5:00 – 7:00 p.m.	**Informal reception and registration, Quality Inn**

August 5, 1986

8:30 a.m.	**Welcome** *H. H. Vanderveldt (AWI)*
8:45 a.m.	**Overview of Data Management and Trends** *F. J. Smith (U. of Conn.)*
9:30 a.m.	**Examples of data needs from various perspectives** Welding Consumables and Power Supplies *H. Cary (Hobart Bros.)* Maintaining Procedure and Personnel Qualification Records *G. R. Olejniczak (NTF)* Computerization of Welding Data and Design Engineering *F. C. Breismeister (Bechtel)* The National Materials Property Data Network *J. G. Kaufman (NMPDN)*
12:00 noon	**Lunch** (the participants were encouraged to form small groups for continued discussions over lunch.)
1:00 p.m.	**Discussion groups** One group for each category or industry Leader and recorder for each group Each group will produce a list including • Ranked data needs for their industry or interest • Users for each data type • Existing or planned databases (especially those available to others)
4:00 p.m.	**Report by group leaders**
4:30 p.m.	**Rebuttal by all participants** • Additional data needs for another group (since individuals can only attend one group) • Overall ranking of needs by a show of hands
5:00 p.m.	**Adjourn (discussions continue at dinner)**

August 6, 1986

8:00 a.m.	**Traditional and Nontraditional Data** *J. E. Jones (AWI)*
8:30 a.m.	**Database Design** *J. Rumble (NBS)*
9:00 a.m.	**Discussion groups, to define data characteristics of the top four needs** Each group will produce a list including • Potential users • Content • Sources of information
11:30 a.m.	**Report by group leaders**
12:00 noon	**Lunch**
1:30 p.m.	**Case histories of database systems** WPS Database History *J. E. Sims (CBI–NACON)* Welder Qualification Database *G. R. Olejniczak (NTF)* A Fully Integrated Database System for the United States *J. E. Jones (AWI)* Development of an Expert System for Welding *A. Kuhne (Carnegie–Mellon)*
3:00 p.m.	**Discussion – final additions to lists of data needs** (trained operator at a central location or sale of floppy disks, user training courses, manuals)
4:30 p.m.	**Adjourn**

APPENDIX B. PARTICIPANTS

Breeden, Gary	Group Four
Breismeister, Fred	Bechtel National
Cary, Howard	Hobart Brothers
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APPENDIX D. ACKNOWLEDGMENTS

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The Workshop on Computerization of Welding Information, sponsored by the National Bureau of Standards and the American Welding Institute, was held August 5-6, 1986, in Knoxville, Tennessee. Forty-two welding engineers, welding managers, and computer scientists gathered to discuss the necessity and design of databases for welding information. Each subject was introduced by specialists in that area. Group discussions identified the most useful topics for welding databases, in descending importance, to be

1. General welding procedures
2. Properties of the weld, heat-affected zone, and base metals
3. Procedure qualification records
4. Welding variables

In the context of these four data needs, characteristics of the databases were discussed in terms of potential users, content, and sources of information. The participants concluded that

1. A significant portion of the data needs can be met by existing information, but this information should be carefully screened and reviewed before inclusion in databases.
2. Databases should be accessible to a diverse group of potential users.
3. Databases should use the latest computer technology and be upgradable to new technology as it becomes available.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

computerization; database; mechanical properties; procedure qualification records (PQRs); welding information; welding procedures

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