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A National Forum on The Future of Automated Materials Processing in U.S. Industry

The Role of Process Models, Artificial Intelligence and Computer Integration

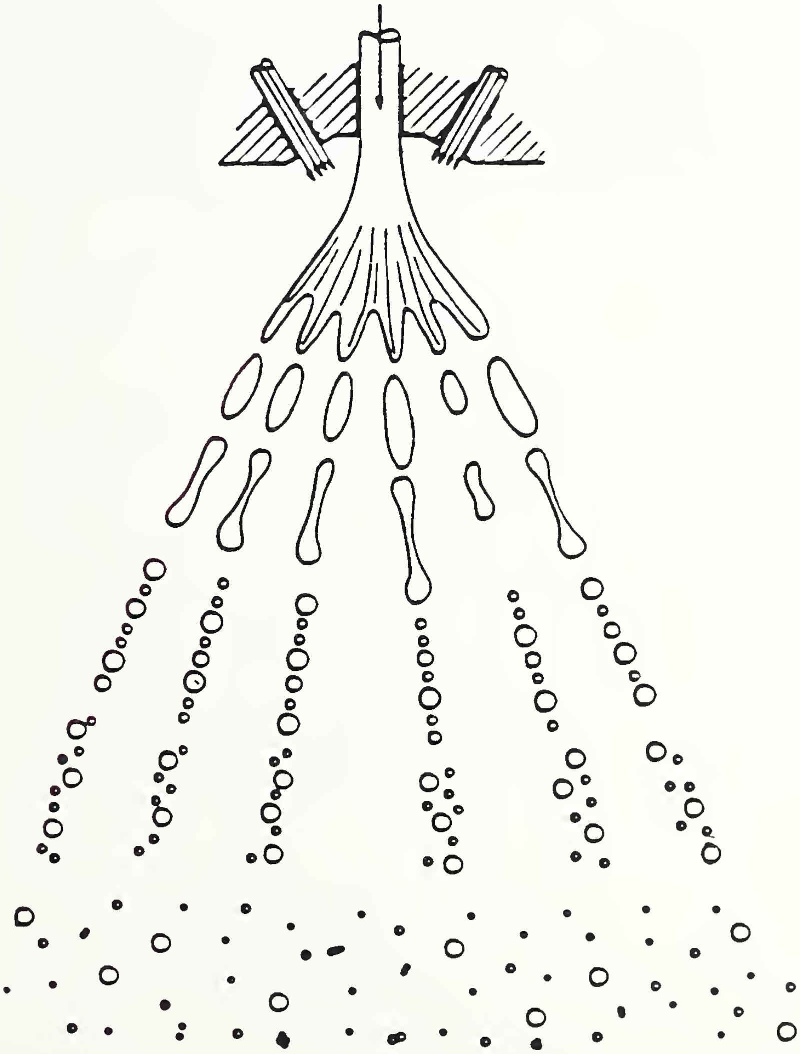
Report of
Workshop II

Held:
May 19-20, 1986

Edited by:
Howard M. Bloom
Norman R. Kuchar

Sponsored by:
Industrial Research Institute and
White House Office of Science and Technology
Policy, Committee on Materials, Working Group
on Automation of Materials Processing

In Cooperation with:
General Electric Company and
National Bureau of Standards



cover One of several possible models of the liquid jet break-up process that takes place during the production of rapidly solidified metal powders by the inert gas atomization of liquid metal. Process models of this kind constitute an important part of the knowledge base which is needed in the development of an automated materials processing facility.

A NATIONAL FORUM ON THE FUTURE OF AUTOMATED MATERIALS PROCESSING IN U.S. INDUSTRY

The Role of Process Models, Artificial Intelligence and Computer Integration

Report of Workshop

NATIONAL BUREAU OF STANDARDS
GAITHERSBURG, MARYLAND

May 19-20, 1986

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INTRODUCTION

This workshop, "A National Forum on the Future of Automated Materials Processing in U.S. Industry - The Roles of Process Models, Artificial Intelligence and Computer Integration", was the second of two workshops sponsored by the Industrial Research Institute and the White House Office of Science and Technology Policy, Committee on Materials, Working Group on Automation of Materials Processing. The first workshop, held in December, 1985 was devoted to the role of process sensors.

Together, the workshops addressed several technologies which can play important roles in improving the competitiveness of U.S. process industries through automation. The goals of the workshops were threefold: to assess the state of the art in key technologies needed for process automation, including sensors, process modeling, artificial intelligence and computer integration; to identify broad issues and generic needs for advancing these technologies and applying them in U.S. industry; and to develop information and recommendations for National direction aimed at enhancing the competitiveness of U.S. process industries.

One of the consequences of the rapid pace of technology is the introduction of a wide variety of new materials into engineered systems. Composites are replacing metals in weight sensitive applications; single crystals of electronic and optical materials are being grown for use in computer chips and solid-state lasers; and rapidly-solidified metal powders are being compacted into complex shapes.

These new materials may have desirable properties, but often their processing is far from mature. In many instances, these materials are only one step from the research laboratory, so that the production facility becomes, in effect, a process development laboratory. The process data base is sparse; few experts exist; and process sensors and controls are rudimentary. Not surprisingly, variabilities in the output are common, leading to problems of low yields, high costs, failures, and long-term lags in the engineered systems.

But, such problems are not confined to exotic, new materials in advanced systems. Many of the same problems are found throughout U.S. materials processing industries, in the old-line, basic industries as well as in the newer, high-tech areas. Too often, steel and castings and diecast aluminum parts contain porosity; the yields of some pressed glass lamp lenses are disappointingly low; and the pacing factor in getting a new TV design into production is often the many iterations required to get the molds for the plastic case to perform adequately. Such problems drive up costs and the reduce the ability of American industries to compete in both domestic and foreign markets.

The two-day workshop was meant, by its size and structure, to encourage a discussion of these competitive problems as well as of some potential solutions by representatives of a broad cross-section of process industries, academic institutions, and government agencies.

In the workshop, plenary sessions were held each morning; in these sessions, experts addressed the state-of-the-art and needs in the technical areas of process modeling, artificial intelligence, and computer integration as applied to materials processing. Following these presentations, parallel workshops, each focussing on a specific topic and under the direction of a discussion leader, were held. The discussion leaders then prepared summary reports and recommendations, which were presented in plenary sessions at the end of each day. At the end of the second day, a panel of representatives from industry, academia and government summarized the consensus views of the entire workshop.

This report includes the written reports of the workshop discussion leaders and panel members, as well as a section on workshop conclusions prepared by the workshop cochairmen.

The workshop had 75 participants, with 49 being from industry, 12 from academia, and 14 from government.

WORKSHOP CONCLUSIONS

1. There is a need for enhanced and more standardized interfaces between elements of a materials processing system: databases, artificial intelligence (AI) tools, process equipment, process controllers, modeling and simulation tools. There needs to be a reference model that is generic for materials processing systems.

2. There is a need to educate the manufacturing community of how expert systems solutions to real world problems have been successfully delivered and implemented.

3. There is a need to clarify the role of AI methods in relationship to the process model approach and to understand how to select the best method or combination of methods for a particular problem.

4. There is a need for increased training at the university level to provide future practitioners in the fields of factory automation, expert systems, and process modeling.

5. Opportunities for "joint-venturing" and cooperation must be sought and maintained among industry, government, and academia.

6. Strong emphasis should be placed on the identification of process models as the first step towards automation.

7. There is a pressing need to close the loop of factory automation by sensors, process models, and control, with artificial intelligence as an agent of implementation.

8. The issue of real-time control of materials processing needs to be addressed from a viewpoint of systems integration and fault-tolerant operation.

Howard M. Bloom
Norman R. Kuchar

WORKSHOP REPORTS ON PROCESS MODELING AND ARTIFICIAL INTELLIGENCE: USES AND NEEDS

LIMITATIONS AND NEEDS OF PROCESS MODELS

Discussion Leader: Charles L. Tucker, III
University of Illinois

I. Current Capabilities

A wide variety of materials processing operations can be modeled as problems involving solid and fluid mechanics, transport of heat and matter and other field problems. This produces a mathematical model which is a set of partial differential equations. Numerical methods such as the finite element method can solve these sets of equations for realistic geometries and calculate fields of velocity, temperature, stress, etc. Problems with free or moving boundaries are much harder to deal with, and three-dimensional problems can be handled at the cost of substantial computer time. Most computer models of this type require an expert to set up the problem and interpret the results.

II. Needs

A. Relate Process Model Results to the Properties of the Product.

Some process models predict the microstructure of the finished product or identify the occurrence of manufacturing defects. These are the exception; they should become the norm. Research needs to accomplish this are:

1. Gather data for material properties under processing conditions. (Example: metal solidification requires the heat capacity and thermal conductivity of the liquid metal, but data is normally available only for the solid.)

2. Build quantitative models of the effects of processing on material structure. We often know qualitatively what the effects are (faster cooling produces finer microstructure; flow aligns polymer molecules, etc.). Process models demand quantitative relationships which are both accurate and simple enough to include in calculations. Such models may be correlations of experimental data or be constructed from theories of structure development.

3. Construct intelligent postprocessors. It seems possible that AI techniques could aid in interpreting the large amounts of data produced by a process model. This is a relatively difficult AI problem, and the AI program must incorporate knowledge about both the manufacturing process and the process model.

B. Connect Process Models to Process Control

Relatively complete process models take longer to compute than the real process takes to run, and so cannot be used inside a control loop. They can be used to identify viable operating set points for the process. They can also be used to tell what sensors will be most useful and where to place them. The research need is:

1. Develop closed-loop process models. By this we mean process models which compute fast enough to use inside a control loop. Normally these would be simplified or extracted from the more complete off-line process model.

C. Make Process Models Into Better Design Tools

Process models not only require experts to use them, they are analysis tools rather than design tools. One can turn an analysis into a design tool by making it interactive and inserting a human into the feedback loop. However, other avenues should be explored:

1. Construct intelligent preprocessors. This software would enable the casual user to set up runs of process model software. This is a relatively easy AI problem as the domain (a piece of software) is well defined.

2. Build, design and optimization into process models. There are several ways one might do this. For example, a sensitivity analysis can easily be incorporated into a finite element program that uses Newton methods. This can provide direction as to how to change the parameters to move in the desired direction. When AI techniques are used instead it will probably be necessary to redesign the software; one cannot simply "add AI" to existing programs.

LIMITATION AND NEEDS OF AI FOR MATERIALS PROCESSING

Discussion Leader: Donald M. Esterling
George Washington University

I. AI as an Aid to Material Processing

Materials is an inexact science. The relations between process variables and the resulting and/or underlying microstructure are only incompletely characterized. This can be an obstacle to the deterministic modeling of processes, but present an opportunity for the heuristic modeling available through AI techniques.

Classical expert systems approaches should be of value across the entire spectrum of materials processing including: materials selections, part design, process planning, scheduling, on-line control, quality control and maintenance. Design and selection involve accessing and evaluating often large data bases. Process planning, scheduling, and maintenance involve a number of decision steps, with the requisite knowledge often vested in relatively few individuals. The sensors used for on-line control may, at times, provide conflicting data and an interpretation is required. Quality control requires a pass/no pass decision usually in the face of incomplete knowledge. All of these problem areas can, in principal, be addressed by AI techniques.

There is often a need to make a decision regarding materials processing in a relatively short time. While a large-scale computational model might provide a satisfactory answer the compute time may not always correspond to the real time available. A heuristic model may provide a less exact answer, but one that is available in time to be of use.

The ability of an AI system to acquire new knowledge or learn will be of benefit to existing AI implementations when and as materials processes are changed. The AI system should assist that updating process.

Much of the evaluation of a materials process and its attendant failure modes requires an analysis of microstructure. The interpretation of the patterns contained in a micrograph requires a skilled materials scientist. This is an interesting areas to investigate the application of AI techniques, but may prove to be too complex for current methodology.

Finally, just the process of implementing an AI system can be valuable in itself as an aid to thinking carefully about the problem at hand.

II. AI Needs And Limitations

There was a strong concern regarding the lack of "user-friendliness" in existing AI systems. Currently they require an expert to create/implement such a system. AI, which has a goal the facilitating of user interfaces, should consider application of AI techniques to itself to provide an expert systems shell which does not require special skills (e.g. in LISP or PROLOG) to implement. The need for such an interface has been addressed by at least one vendor (Interface Corporation), who was represented.

The successful application, particularly beyond the prototype stage, of AI can be very expensive. One estimate was a sizeable fraction of a million dollars and several man-years. Small to medium sized companies do not have such resources available to commit to this project, making AI only available to large corporations. While small prototyping can be of manageable expense, the total integration/application onto the factory floor is not inexpensive.

Given the expense associated with implementing AI systems, a metric to gauge AI performance or enhancement would be of use.

Better methods need to be developed to acquire knowledge from experts. Currently this is a somewhat inexact science, and successful approaches need to be disseminated.

AI is only one tool. A successful implementation of AI into materials processing requires an integration of these techniques with the entire materials processing system. Vendors of AI are encouraged to work closely with the users of AI to achieve this integration rather than viewing AI as something apart from the system itself. Further, the users may wish to move from one expert system to another, depending upon the problem at hand or the degree of satisfaction with the existing system. Interfaces/integration between different experts systems need to be developed to facilitate moving from one expert system to another.

One should not expect too much from AI. When the user has a very focused problem and limited knowledge domain, the chances for success are enhanced. AI should not be viewed as a panacea, but as one important strategic tool that can be applied to materials processing.

NEEDS FOR PROCESS DEVELOPMENT

Discussion Leader: Ralph T. Wood
General Electric Company

I. Introduction

A "process" can be defined as a method for reproducible transforming a material from one form to another (in composition, state, geometrical shape, etc.) so as to achieve a desired result. One of the major problems of the process industries is that many processes are incompletely understood, so that reproducible results are difficult to obtain. This leads to production problems such as low yields, high levels of rework, continuing efforts on process redesign, and an inability to scale the process rates or equipment sizes to meet changing production needs.

II. Process Development Today

Today, new processes often have their origins in laboratory experiments, divorced from the production floor and conducted by scientists and technicians. Success on this laboratory scale is thought to prove feasibility of a production process.

From the laboratory, the process then is transferred to another technical group, responsible for pilot scale development. This is a production-oriented task and carries with it implications for maximizing yield and minimizing costs. However, this process design is usually divorced from the product which the process will serve.

In many cases, even partial success at the pilot level is the signal to proceed to full production. The scale-up is highly empirical and carries high risk. Usually, many technical problems remain unsolved, leading to continuing efforts, over many years, to try to control the process and its output. These efforts are made more difficult by a lack of qualitative and/or quantitative process models which might form a basis for guiding the work.

Process development as a technical area faces many problems. Traditionally, production research has represented a relatively small effort, so that basic theoretical and technical underpinnings are immature or lacking. Generic methods for addressing process development problems do not exist. There has been little emphasis on achieving a quantitative understanding of the process and its parameters, i.e., through the kind of models which have served product design so well. Variabilities in the properties of the initial and processed materials exacerbate process development. The rudimentary nature of many process sensors makes data collection and analysis difficult.

III. Needs

One of the basic needs of process development is management understanding of the problem. Management's focus too often is on the product, but process problems have significant impact on production cost and quality. Solution of process development problems can have a major long-term business benefits.

On a technical level, process understanding is the key to reducing the duration and costs of process development. Understanding of the significant process variables and parameters leads to an understanding of the methods needed to control the process. Process understanding can be achieved through several technologies, including:

> Process models (quantitative and qualitative)
>
> Supporting empirical data for model development and validation
>
> Artificial intelligence (expert systems)
>
> Process sensors
>
> Improved understanding of material properties and their variabilities, for specification and control purposes.

Many of these elements can be combined, together with the knowledge of process experts, with the aid of presently available expert-system shells to achieve new levels of process understanding.

Better integration of process design and development with product design and development is also needed. The relationships among the material properties, the process parameters and control limits, and the product performance must be better understood.

Once process understanding is improved, better process controls can be developed. Control strategies can be formulated based on the process models and on system control simulations. Often, multi-variable rather than single-variable controls will be needed.

Despite the need for analytic process models, process development will always require facilities for process testing. However, pilot facilities must become highly instrumented, and this instrumentation must be carried forward into the full-scale production facility if a high level of process monitoring and control is to be achieved.

WORKSHOP ON AI FOR PROCESS PLANNING AND CONTROL

Discussion Leader: Dr. Robert L. Moore
LISP Machine Inc.

The workshop was formed by 14 members representing a wide variety of industrial and government organizations. The general conclusions are summarized as follows:

I. Current Capabilities

On-line expert systems with response time in seconds or longer. Whether these are real-time is a matter of required response speed in the domain of application.

Single loop and simple multi-variable control.

Adaptive (learning) with parameter identification.

Model-based control in some applications.

Negative trend - process engineering staff in industry have been trimmed from large companies.

II. Desired Capabilities

Complex multi-variable control.

Adaptive learning - non model based.

Integration of models, sensors and expert systems.

More easily installed expert system tools.

Use of existing computers for expert systems if possible.

Technical bridges between disciplines.

Closed loop expert systems (vs. advice).

Expert systems for sensors (integrity etc.).

Expert systems to adjust models.

A national effort at technology sharing.

III. Where to use Expert Systems

Use models if have good analytical models.

Use expert systems where models are heuristic rather than analytic.

IV. Suggestions

Set up a National Bureau of Standards cooperative effort to set guidelines, bench marks, define generic approaches.

NEEDS FOR PROCESS QUALITY ASSURANCE AND DIAGNOSTICS

Discussion Leader: Robert C. Frimodig
Pratt & Whitney Aircraft

I. Needs

In both basic and advanced materials processing industries, there is substantial need to expand and improve the use of process modeling and artificial intelligence for quality assurance and diagnostics. These needs are expected to grow and will be largely driven by competitive market forces and increased recognition of the major role that quality excellence plays in the overall improvement of productivity and profitability.

It was agreed to center discussion on addressing in generic terms, the kinds of general actions and philosophies relating to the use of process modeling and AI that are needed to help achieve the dramatic quality improvement desired within U.S. industry. Consensus of the group was that these initiatives must be focused on building quality into the process such that the resulting part or product is "made right the first time".

II. Uses

While many different aspects of this overall need were discussed, the key areas where modeling and artificial intelligence will contribute are felt to be:

identification of critical parameters

improved understanding of process and product for entire life cycle.

process control on a "real time" basis

integration of design, manufacturing and vendors

process refinement and optimization

improved diagnostic to predict and prevent system errors, establish preventative maintenance, etc.

support of sensor technology - application, feedback, calibration systems, and adaptive control

capacity planning and economic studies

In summary, it was felt that use of process modeling and artificial intelligence technology for quality improvement represents an area where the United States has both the unique opportunity and the wherewithal to excel. This very important issue deserves priority and will require collaboration of government, industry and the academic community.

SESSION SUMMARY ON PROCESS MODELING AND ARTIFICIAL INTELLIGENCE: USES AND NEEDS

Session Chairman: Herbert B. Voelcker
National Science Foundation

I. Current Capabilities

Pose a wide variety of processing problems as solid mechanics, heat transfer, fluid mechanics, etc. (PDE's).

Solve on realistic domain shapes
(moving boundaries hardener)
(3-D takes much longer)

Find fields of:
- velocity
- temperature
- stress
- strain

II. Needs

A. Relate process model results to the properties of the product (microstructure, final shape, defects, etc.).

1. Need better material models (quantitative)
   - experimental data at process conditions
   - understand micromechanical behavior
   - models simple enough to use in calculation

2. Build sensitivity analysis into model
   - measure sensitivity of output to inputs
   - operate in stable/insensitive region
   - possible in current FE techniques

3. Intelligent postprocessing
   - interpret reams of data
   - difficult AI problem
   - must incorporate knowledge built into model (currently hidden in code)

B. Connect Process Models to Process Control

1. Models tell what/where to sense

2. Off-line control - model finds set points, program for control inputs

3. Closed-loop models
   - fast enough to go inside loop

  - usually simplified/extracted from complete (but slow) off-line model

C. Make Models into Better Design Tools

1. Integrate with CAD (esp. geometry)

2. Intelligent preprocessing
   - help set up simulation
   - good AI problem: well defined domain

3. Keep models interactive
   - develop simpler models
   - faster computation

4. Make design/optimization easier
   - frame model and develop code with optimization in mind
   - best results may require rebuilding software: "can't just 'add AI'"

WORKSHOP REPORTS ON COMPUTER INTEGRATION ISSUES

COMPLEX MATERIALS PROCESSING AS A SYSTEM

Discussion Leader: Lewis D. Roth
Inference Corporation

I. Session Focus and Approach

This workshop was not preceded by a plenum session address on the state of the art. As a result, the initial discussions aimed to focus the workshop on an appropriate target. The overall focus was on where expert-systems and CIM tie in to what we already can do in material processing.

"Complex materials processing" meant different things to the workshop participants. Three points of view surfaced:

A. That complexity referred to the material system; eg. multi-constituent alloys, micro-alloyed systems, composites, laminates, complex temperature environmental stress-state interactions, meta-stable systems, etc. The technological issues included: functional structure-property-processing models; database availability, quality, and interfaces; knowledge representation for utilization by expert systems.

B. That complexity, was related to the number and type of tasks involved in designing and developing a unit process, ensemble of processes, or manufacturing cell. The issue of process control was raised. Questions on whether processes could be controlled purely by heuristics were also advanced. The ability to merge process model analytical data with heuristic controls also needs study. The issue of functional knowledge representation was raised again.

C. That complexity referred to the integration of the technological issues as defined in definitions 1) and 2) with business issues, such as data processing, and management information systems.

The workshop participants had diverse expertise and backgrounds (aluminum, steel, composites, electronic components, industrial hardware, plant management, AI tools). This precluded a focus on problems related to individual material systems or processes. The ensuing discourse dealt with the complexity issue as described in item 3). Solutions to issues raised by 1) and 2) were beyond the capability of a short workshop. Nevertheless, they are important and need to be addressed by those specifically knowledgeable in those technical domains.

II. Where Are We Today?

Material processing systems are uniquely engineered to meet the requirements of the case. There is no generic approach to complex material processing system design. It varies from industry to industry.

III. Group Observations, Experience, Thoughts

Whatever "system" proposes a solution to the material processing question, it must address both business and technological issues and constraints.

No one expects that a single, large expert system could be devised that could encompass all the possibilities that could be encountered. The emphasis of solving smaller problems and successfully delivering them was endorsed. The concept of a meta-system (expert-system overseer) was considered to have potential.

No one in the workshop had ever successfully connected an expert system with large external databases. The integration, communication and interfacing of AI tools to Computer Integrated Manufacturing (CIM) systems was a major concern. Little was known about how different AI tools approach this problem.

Robust planning and scheduling expert-systems ranging from top management tasks to unit processes was pointed out as having a large immediate benefit to CIM development. Shop-floor schedules have significant impact on which process, sub-process, or manufacture line is to be used for a particular work order.

It is easier to install new technology and methodologies at green field sites. It was felt that only at green field sites would a top-down approach to implementation of an integrated business and technological CIM system be viable. It was also felt that this is still a formidable task even for large organization with a lot of capital. Such an approach may be valid for non-applications specific cases such as a Manufacturing Automation Protocol (MAP) but not for more specific processes. The bottom up approach (unit process by unit process) is expected to prevail for the foreseeable future.

IV. What We Would Like To See

A. Connect Shop Floor With Management Information Systems/Data Processing

Management information systems (MIS) and data processing (DP) cannot take advantage of the huge amount of information available from distributed computers and computer networks on the shop floor. Conventional programming does not provide enough software flexibility to take advantage of this information. MIS/DP has little or no integration with software development capabilities back to MIS/DP, since the AI approach provides for incremental software development.

B. Designer as Expert Information Managers

Customer design requirements drive product, component, and processes specifications. Backward integrated approach needs to be considered at the design phase. Materials processing and material selection are not usually designed along with part, either due to lack of expertise by the designer, or lack of getting that expert information to the designer in a form that can be used. The related models, AI tools, simulations, which aid the designer in dealing with customer requirements need to be applied at the design phase. The designer is an information manager. Information can be provided through expert-systems. This information is equally useful to management personnel as well.

C. Shared Databases

Databases are often unavailable. Where they are available, there are questions about qualification of data, database maintenance, and format of data. AI tools which provide features to access real world databases are needed. Expert systems will need to take advantage of these databases in real-time.

D. Trained Professionals

Lack of accredited manufacturing systems curricula in universities and job esteem in industry guarantees future shortage of manufacturing systems professionals.

V. Needs For Improved Development

Specific models describing trade offs between processes and properties, for different materials systems. Embedded economic models within process models and vice versa.

Enhanced and more standardized interfaces between and within the following categories: Databases, Database Management Systems, AI Tools and Shells, Process Equipment, Process Controllers, Modelling and Simulation tools. Additional standards were recommended in the area of interfaces for: hardware, software, and communications protocols.

Professionals who have educational background which is synthesis of the above technological and business areas.

Education of manufacturing culture to inform them of how expert system solutions to real world problem have been successfully delivered and implemented. These applications could be used to ease the transition of the manufacturing culture to new technologies and approaches. There is a lot of AI technology developed that is not fully exploited because of wait-and-see attitudes.

LINKAGES BETWEEN PROCESS MODELS AND ARTIFICIAL INTELLIGENCE
(Workshop Group I)

Discussion Leader: Daniel E. Whitney
Charles Stark Draper Laboratory

I. Summary

Of approximately twenty workshop participants, only two had direct experience implementing AI systems of any kind. Thus the discussion reflected the views of industry people, the group that might need such systems. These views can be characterized by a mixture of

interest
puzzlement
skepticism

That is, in general the participants felt that before the promise of AI can be realized, much additional progress must be made. Such progress should include

clarifying and expanding the concept of "process model"
clarifying the role of AI methods in relation to other possible modeling techniques
clearly differentiating AI methods from others
understanding how to select the best method or combination of methods for a particular problem

The Workshop's contributions to these challenges are as follows:

II. Possible Definitions of "Process Model" - not mutually exclusive

A. a parameter description of process behavior, usually mathematical, capable of relating sometimes unmeasurable performance variables to control variables and disturbances.

B. a description of the process that allows one to trace relationships between variables and to deduce behavioral consequences of changes in variables.

C. a description of the process that either approximates its true behavior or represents part of it.

Comments: Definition 1 is usually a typical physically based mathematical model. Definition 2 may be a non-physically based input/output or black box model containing numerical curve fits as well as quasi-verbal statements or graphical representations. Definition 3 expresses the fact that no model can be correct or complete. Artificial intelligence is probably included within definition 3.

III. Range of Possible Modeling Techniques

The group identified three main classes of models, each with a set of possible uses:

Model Class	Possible Uses
Equations, closed form analytical expressions, such as partial differential equations or finite element models	Product design Process design Process control, including model-in-the-loop
Statistical, experimental, operations research, statistical decision theory	Data analysis Decision support Strategic planning
Heuristic, approximate,fuzzy	Fill gaps in other models and modeling methods Save time or money Help formulate problems Make interpretations or judgments

Comments: These methods, like the definitions, are not mutually exclusive. When the available equations are too approximate or too incomplete, they might be augmented by statistical data or fuzzy set representations of heuristics. For some situations we have a good model, for others we do not, and for a third class of problems we are blocked from formulating a traditional model by factors such as cost, time, cost/benefit, signal/noise, lack of a sensor to make a needed variable observable, and so on. An important issue is to identify which class a particular process really belongs to. This will help identify cases where AI or other heuristic methods can contribute.

IV. Differentiate AI from Other Methods

The group identified the following generic uses for AI methods:

- A tool for dealing with heuristics
- A way to represent non-numeric ideas
- A way to represent discrete, qualitative, or "type" distinctions
- A procedure for codifying and solidifying knowledge or identifying gaps in knowledge
- An aid in selecting what model to use

Comments: Other techniques can provide similar services in some cases.

Not discussed deeply but on participants' minds are several issues common to AI and other model types. These include:

- systematic methods of formulating models
- model verification methods
- interfacing model types
- obtaining real time response

Of these, only the first two are priority, long-term issues. The others are secondary, will be solved in the course of creating real applications, or should be postponed until more fundamental issues are resolved.

LINKAGES BETWEEN PROCESS MODELS AND ARTIFICIAL INTELLIGENCE
(Workshop Group II)

Discussion Leader: Bevan P. F. Wu
IBM Research Division

I. Summary

Presently most micro and macro conventional process models are analytical in nature. They are not built for interactive usage. The data generated by these models usually requires interpretation from experts to be useful for average users. Furthermore, few of these models have explicit knowledge built in to help average users in model applications, such as real time process control which requires reduced form of output within a specified time interval. The above characteristics of the conventional process model make the task of establishment of solid correlations between process models and product properties difficult, if not impossible.

One potential solution to the above mentioned problem is the application of AI technology as a bridge to link the present conventional process models with related knowledge bases. By doing so one makes the conventional process models " intelligent", i.e., there are explicit knowledge of performing both analytical and synthesis activities in a relatively easy manner, we are reaching the goal of integrated intelligent process modeling. The goal of integrated intelligent process modeling appeared to be needed by the majority of the discussion participants.

The term "bridge" or "linkage" does not have to be a physical item, in many cases it is just a concept. A concept of integrating necessary knowledge with any conventional process model with both explicit and implicit knowledge. The integrated intelligent models will have both analytic and synthetic capabilities. There is no need for linkage between process models and AI.

II. Functional Requirements

For the sake of completeness a set of functional requirements of the linkage between conventional process models and relevant knowledge bases are given as follows:

A. It is a high speed communication link.

B. It can convert conventional process model output data into easily understandable knowledge for users.

C. It can convert user decisions through models into necessary input data for conventional process models.

D. A figure of merit for the so called "linkage" should be measured by its knowledge transmission efficiency, KTE, which is defined as

$$\text{KTE} = \frac{\text{Usable knowledge transmitted in bytes per second}}{\text{Total bytes transmitted by the linkage per second}}$$

E. The AI technology, software and hardware used to achieve the above requirements should be transparent to users.

SUMMARY OF CONSENSUS VIEWS

SUMMARY OF CONSENSUS VIEWS: INDUSTRY

Donald E. Koontz
AT&T Bell Laboratories

During the last two days, we have heard excellent talks on a wide range of topics closely related to factory automation. The Workshop sessions have been demanding of the participants. The leaders managed to galvanize the diverse backgrounds of experiences of the participants into informed, consensus views of the background issues and problems which need to be addressed.

The reports of this conference, and those developed at the "Sensors for Automated Materials Processing", University of Santa Barbara, California, December 26-17, 1985, provide an excellent comprehensive view of the background material and issues which need to be addressed for increasing the vitality and competitive stance of U.S. Industry in the national interest.

At this juncture, we, as managers, engineers, academicians and scientists, are in agreement. The converts are talking to the converts! The consensus view is that there are many problems. A lot of effort will be required to provide solutions. Everything looks go! Full speed ahead.

There certainly is an alternate view which must be considered. How will management of U.S. Industry respond? Most certainly, the response will be mixed. Some companies are moving aggressively to modernize their manufacturing capabilities. many others appear to be assuming a wait and see posture. Unfortunately, there will be organizations vital to U.S. Industry which will have great difficulties adapting to improved manufacturing capabilities because of financial limitations or cultural barriers.

One need, therefore, is to take the next step and assess the response of industrial management to the issues and problems which have been delineated in these two conferences. It is important for key management personnel to understand the potential capabilities and benefits versus cost. The potential for improvement includes new materials, new products, better materials and products, safer materials and products, and the opportunities to design and manufacture at lower cost to enjoy the benefit of greater flexibility and bargaining power in the marketplace. The cost will ultimately be greater than anticipated. It is also important for the same Captains of Industry to consider the costs and penalties of not adapting and improving their manufacturing postures.

Development and application of process models, process control instrumentations, sensors, computer technology and artificial intelligence will not be a magic elixir to cure all ailments. These items are tools. They are necessary attributes to well-controlled manufacture, but they are not sufficient!

The work at the Bureau on automation is impressive. The initiative on the part of Bureau personnel to establish IGES, PDES, and TASK as voluntary national and international computer interface standards is laudatory. The posture of the military and Department of Defense in advocating the use of these voluntary standards by their contractors, and in encouraging contractors to automate and improve manufacturing capabilities, are a very positive and powerful influence.

SUMMARY OF CONSENSUS VIEWS: UNIVERSITY

Yong W. Kim
Lehigh University

Two days of concentrated discussions, both in formal presentations and in workshop groups, have brought out several consensus points of significant interest. They are:

I. Strong emphasis is placed on the need to identify and state process models as the first and foremost important step towards automation of materials processing factories. A process model means different things depending on the nature of a given processing activity and on the level at which an individual is operating. It may be as simple as a sequence of manufacturing steps in a factory or as complex as predicting the product performance, such as structural strength, wear and corrosion resistance, crystalline defect density and other such bulk properties, from the knowledge of ray material properties and of the thermal, fluid dynamical and mechanical cycles of materials processing by means of a system of partial differential equations. In whatever form, such a process model serves as a road map toward automation and helps define the roles of sensors, logistics of control and the place and level of involvement of artificial intelligence tools.

II. Artificial intelligence, as visualized in the context of factory automation at present, means an expert system assigned to a narrowly defined task which normally would require one half to two hours of an expert's time. Implementation of such an AI device should require about $500K or less. This definition simply is a reflection on the industry's assessment of the technically feasible and economically viable avenue to factory automation.

III. Artificial intelligence has many niches in the process model-sensors-control triad of automation, ranging from digestion of vast amounts of empirical process data into simple rules of thumb, arbitration of conflicting sensor outputs, reductions of numerical results from process models into simplified look-up tables to control decision making, system integration and process development.

IV. A strong consensus exists of the need to develop more basic experimental as well as theoretical data connecting the microscopic properties of materials to bulk product properties. Especially, physical properties of materials in extreme thermal states, such as in molten metals, and of those undergoing phase transitions are scarce and yet of critical importance in charting the optimum process control route.

There are several points of observation and comments that are worth making of the issue of factory automation and the Forum.

I. Given that the driving force of the two forums, one earlier at UC-Santa Barbara and the present one at NBS-Gaithersburg, are to give the U.S. industries an advantage in worldwide competition, the questions to ask would be: Are we doing everything necessary for that edge? What is so unique about the present scenario?

II. It is important to recognize American impatience as a key strength of U.S. industry and take a step back from trying to emulate the mental and cultural patterns in Japan or other foreign countries. Strong, result-oriented plans should be put forth for factory automation with three to five year time tables, rather than seeking much longer term solutions.

III. Artificial intelligence as visualized in the form of expert systems is intrinsically unsatisfactory in the sense that an expertise is non-linear in character and yet it is being machine-adapted through a linear process of interrogation. The second generation approach of linear process of interpolation into the expert data base should provide some improvement. New developments in non-linear dynamics, fractal geometry, renormalization group and other physics tools of studying non-linear phenomena need to be brought into the AI research.

IV. Factory automation must succeed and succeed soon, regardless of the future breakthroughs in the AI research. It is therefore prudent to chart the strategy of factory automation without being contingent upon any future AI developments. Artificial intelligence has a certain frantic personality with a large unresolved agendum, namely, the ability to learn, and the goals which extend far beyond the scope of factory automation. On the other hand, artificial intelligence has a strong appeal to the talented intellectual audience whose attention is needed for the successful transformation of the U.S. industries. Universities can contribute constructively in maintaining a mutually supportive connection between the two thrusts, provided that the relationship of the industry and government to the universities is one of upholding each other's interests. Funding agencies can help through a hierarchy of sensible funding priorities in this regard.

V. Finally, there is a pressing need to close soon the loop of factory automation by sensors, process models and control with artificial intelligence as an agent of implementation. We heard at the Santa Barbara Forum that sensor development needed good process models and here there are cries for better mathematical models (and more computing power) for implementation of artificial intelligence. However, the most successful way of enlarging the body of knowledge and making progress is to look at the total problem iteratively. Sensors are essential in process model development and successful models can show how to manage with a minimum number of sensors. The same is true of artificial intelligence and control. It is therefore more productive to go through the loop many times imperfectly, rather than postpone the progress until a perfect solution comes about.

SUMMARY OF CONSENSUS VIEWS: GOVERNMENT

Ralph P. I. Adler
Army Materials Technology Laboratory

These views and comments regarding topics covered in this Automated Materials Processing workshop hopefully represent those of my colleagues in the community of government engineers and scientists with perhaps a slight bias toward DoD interests. First of all, measured by our interest and the amount of DoD sponsorship, it is obvious that we are encouraging the utilization of computer augmented methodologies by the engineering and manufacturing disciplines to increase our industrial processing productivity and product reliability. There are many forms of computer augmentation such as CAD/CAM, high speed computation of complex representations of process models, and the exploitation of Artificial Intelligence/Expert Systems -- AI/ES -- (for design, diagnosis, testing, or control). Whatever the specific approach chosen, the benefit will result in a better quality, perhaps lower cost product for the consumer. From a national perspective we will markedly increase the competitiveness of our American manufacturing industry at the same time raising their productive capacity without being capital intensive.

Our motivation for encouraging computer augmentation is to help all our producers consistently make better quality products right the first time. With less iterations during the product development cycle and better process control, less material will be diverted to the scrap pile; this natural rise in productivity of those plants using computer augmentation should be readily quantifiable and act as a cost effective stimulus to the remaining plants to follow suit. The payoff for the DoD is an effectively modernized vendor industry capable of producing more complex, higher quality components and systems with significantly reduced procurement lead times. This DoD-wide thrust intends to develop technology that will be integrated into a Manufacturing Sciences Program package that has already been started by the Air Force. All this work will have to be of a high quality and be generic enough for useful technology exchange. We do not intend to sponsor work to help individual organizations get a leg up but to provide information and software capable of intra-industry technology transfer. This is already happening for larger organizations with adequate resources. However we do have some concern as to how to implement similar computer enhancements within smaller companies which lack or have limited access to computer facilities in order to properly utilize much of this generic technology that is being developed.

Another concept that we are wrestling with is how to best use selected domains of AI as productivity enhancing tools. From the conversations I have participated in it appears that the ES domain should receive more emphasis since it is most adaptable to our objectives. Furthermore within the ES domain, there is a real question as to what level of man-machine interface should be located. Should we have a higher level expert advisor system that might be easier to set up initially; should we have a real expert system where a well trained but not totally experienced person can be made into a pseudo-expert supported by the expert system? Clearly some tradeoffs will have to be made. Since it would require less effort to build an expert advisor system, perhaps this should be the first demonstration phase but with the software architecture being generic enough for the system to be expandable to all user levels at later phases. Specifically for materials processing we look at ES as a flexible tool for design and control -- even adaptive process control.

Another area that needs addressing is the shortage of qualified personnel especially in the AI arena. For the long term this must be accomplished by increasing the number of faculty/departments teaching AI curricula since given the opportunity I believe that many students would be attracted to this field. For the short term, means of retraining some of our engineering work force could also be planned by industry. To date both the Army and the Air Force have already initiated programs to train government personnel in AI.

Another area that came up here, and with which there is probably a bit of controversy, is in process modeling. Whether one uses the microscopic or macroscopic approach, we need to get some resolution soon. The macroscopic approach seems to be working, but there are still some open questions to be answered. Another related issue is that better materials property values are needed as parameters in the solution of the analytical representation of processing systems. Often these values are extracted or even extrapolated from handbooks or must be experimentally determined hopefully, but not always, by standardized procedures to assure that values are reliable and consistent between various organizations. Even if people were willing to publish their experimentally measured property values, at present no common repository exists to store such valuable information. An independent organization with appropriate instrumentation and using widely accepted techniques and procedures could fulfill such needed data generation and/or storage functions. NBS would be a logical choice; there must also be professional societies or trade institutions that could provide these services; if not, DoD agencies such as mine might be convinced to perform such functions using the precedent that they already perform analogous services by maintaining engineering standards and military specifications.

Overall we in the government sector are encouraged by the progress that we see here both from industry and academia. Despite funding uncertainties we intend to keep on sponsoring worthwhile Automated Materials Processing Programs with well defined objectives because we know that such investments will have a high payoff.

SUMMARY OF CONCLUSIONS RAISED AT THE LAST SESSION

Eliot Steinberg
Industrial Research Institute, Inc.

The closing session was a presentation of overview comments by a university spokesman, government spokesman and an industry representative. Respectively, comments were offered by Dr. Yong W. Kim, Professor and Department Chairman, Physics Department, Lehigh University; Dr. Ralph Adler, Army Materials Technology Laboratory; and Dr. Donald Koontz, Head, Chemical Process Control & Automation, AT&T Bell Laboratories.

All of the panelists emphasized the need for training at the university level to provide future practitioners in the fields of factory automation, expert systems, artificial intelligence and process modeling. It will indeed take a true partnership of each element -- industry, government and academia -- if we are to use these new tools to make the U.S more competitive on a global scale. Opportunities for "joint-venturing" and cooperation must be sought and maintained by the three sectors. The Conference provided unique opportunities to expose knowledge-gaps and areas needing cooperative efforts.

APPENDIX A: WORKSHOP PROGRAM

WORKSHOP PROGRAM

Monday, May 19

8:00 am Registration
National Bureau of Standards
Green Auditorium, Adminstration Building
Coffee/juice/danish

I OVERVIEW
Session Chairman:
Theodore H. Hopp
Leader, Machine Intelligence Group
National Bureau of Standards

8:45 Welcome/Introduction
George Sinnott
Associate Director, National Engineering Laboratory
National Bureau of Standards

9:00 Workshop Goals
Norman R. Kuchar
Manager, Process Technology Branch
General Electric Corporate Research and Development

9:15 Summary of Workshop on Process Sensors
H. Thomas Yolken
Chief, Office of Nondestructive Evaluation
National Bureau of Standards

II MODELING AND AI FOR MATERIALS PROCESSING: STATE OF THE ART AND TECHNOLOGY NEEDS
Session Chairman:
Vincent V. Horvath
Manager, Advanced Manufacturing Systems
Bethlehem Steel Corporation

9:30 Keynote Address: A User's View of the Issues and Needs in Materials Processing Technologies
Peter R. Bridenbaugh
Vice President, Research and Development
Aluminum Company of America

10:15 Break

10:40 Process Modeling Overview
Robert A. Brown
Professor, Department of Chemical Engineering
Massachusetts Institute of Technology

11:15 Artificial Intelligence Overview
Thomas Lozano Perez
Associate Professor, Computer Science
Artificial Intelligence Laboratory
Massachusetts Institute of Technology

11:50 Process and Tooling Design Overview
Harold Gegel
Senior Scientist, Materials Laboratory
Air Force Wright Aeronautical Laboratories

12:25 Process Control Overview
David Hardt
Professor, Department of Mechanical Engineering
Massachusetts Institute of Technology

1:00 Lunch

III SIMULTANEOUS WORKSHOPS ON PROCESS MODELS AND AI: USES AND NEEDS

1:45 Limitations and Needs of AI for Materials
Processing Discussion Leader:
Charles L. Tucker III
Associate Professor, Mechanical Engineering
University of Illinois

Limitations and Needs of AI for Materials Processing
Discussion Leader:
Donald Esterling
Professor, Mechanical Engineering
George Washington University

Needs for Process Development
Discussion Leader:
Ralph T. Wood
Manager, Face-Pumped Laser Project
General Electric Corporate Research and Development

Needs for Process Control
Discussion Leader:
Robert Moore
LISP Machine, Inc.

Needs for Process Quality Assurance and Diagnostics
Discussion Leader:
Robert C. Frimodig
Manager, Quality Integration
Pratt & Whitney Aircraft

3:45 Break

IV WORKSHOP REPORTS ON PROCESS MODELS AND AI: USES AND NEEDS
Session Chairman:
Herbert B. Voelcker
Deputy Director
National Science Foundation

4:00 Limitations and Needs of Process Models
Limitations and Needs of AI for Material Processing
Needs for Process Development
Needs for Process Control
Needs for Process Quality Assurance and Diagnostics

5:00 Adjourn

7:00 Dinner

Tuesday, May 20

V COMPUTER INTEGRATION ISSUES IN AUTOMATED MATERIALS PROCESSING
Session Chairman:
Robert Hartzel
Texas Instruments, Inc.

8:45 Keynote Address: The Automated Manufacturing Research Facility as a Model for Computer-Integrated Manufacturing
Howard M. Bloom
Chief, Factory Automation Systems Division
National Bureau of Standards

10:05 Break

10:25 Data Exchange in Materials Processing Systems
Bradford M. Smith
National Bureau of Standards

11:00 Linkages Between Process Models and AI
Melvin K. Simmons
Knowledge Based Systems Branch
General Electric Corporate Research and Development

VI SIMULTANEOUS WORKSHOPS ON COMPUTER INTEGRATION ISSUES

11:35 Complex Materials Processing as a System
Discussion Leader:
Lewis D. Roth
Inference Corporation

Linkages Between Process Models and AI
Discussion Leader, Workshop Group I
Daniel Whitney
Charles Stark Draper Laboratory

Discussion Leader: Workshop Group II
Bevan P.F. Wu
Program Manager, Manufacturing Research
IBM Research Division

1:00 Lunch

1:45 Session VI Continues

VII WORKSHOP REPORTS ON COMPUTER INTEGRATION ISSUES
Session Chairman:
David Rogers
United States Steel Corporation

2:35 Complex Materials Processing as a System
Linkages Between Process Models and AI

VIII SUMMARY OF CONSENSUS VIEWS
Session Chairman:
Eliot Steinberg
Industrial Research Institute

3:35 Panel Discussion By Representative From:

Industry
Donald E. Koontz
Head, Chemical Process Control & Automation
AT&T Bell Laboratories

University
Yong W. Kim
Professor and Chairman, Physics Department
Lehigh University

Government
Ralph P.I. Adler
Army Material Technology Laboratory

APPENDIX B: LIST OF WORKSHOP ATTENDEES

Ligh Abts, Rexnord Inc.
Laszlo Alder, Ohio State University
Ralph P. I. Adler, Army Materials Technology Laboratory
Dan Backman, General Electric Company
George Birnbaum, National Bureau of Standards
Kenneth C. Blaisdell, Johns Hopkins University
Howard M. Bloom, National Bureau of Standards
Irvin M. Bohr, Black & Decker
Peter R. Bridenbaugh, Aluminum Company of America
Robert A. Brown, Massachusetts Institute of Technology
Leo Buchakjian, General Electric Company
James R. Cook, ARMCO Inc.
Ron Crowe, Honeywell Inc.
Marvin Denicoff, Thinking Machines Corporation
J. Duane Dunlap, Aluminum Company of America
Dayton Edon, LTV Aerospace and Defense Company
Friedrich T. Elliot, LTV Aerospace and Defense Company
Richard K. Elsley, Rockwell International Corp.
Robert W. Elwood, Naval Supply Systems Command
Donald Esterling, George Washington University
Robert Fanning, Aluminum Company of America
James K. Fisher
Robert C. Frimodig, Pratt & Whitney Aircraft
Gary Garitson, Cummins Engine Company
Harold Gegel, Air Force Wright Aeronautical Laboratories
R.G. Gilliland, Aluminum Company of America
Robert E. Green, Jr., Johns Hopkins University
Thomas W. Gurley, Goodyear Tire & Rubber Company
Gary Hagnauer, Army Materials Technology Laboratory
David Hardt, Massachusetts Institute of Technology
Robert Hartzell, Texas Instruments, Inc.
Larry Hollingshead, Cincinnati Milacron
Theodore H. Hopp, National Bureau of Standards
Vincent V. Horvath, Bethlehem Steel Corporation
John R. Howell, John Deere and Company
D. F. Hubbard, Carnegie Federal Systems Corporation
L. Hulthage, Carnegie-Mellon University
Robert L. Jenkins, David Taylor Naval Ship Research and Development Center
Albert Jones, National Bureau of Standards
Yong W. Kim, Lehigh University
Donald E. Koontz, AT & T Bell Laboratories
Norman R. Kuchar, General Electric Company
Joseph R. Lane, National Materials Advisory Board
Norman Lillybeck, John Deere and Company
Stephen C-Y Lu, University of Illinois
John F. Maguire, General Electric Company
Samar Marwaha, Honeywell Inc.
Annop Mathur, Honeywell Inc.
Donald McMahon, Allegheny Ludlum Steel Corporation
Ron Miller, Aluminum Company of America
John C. Murphy, Johns Hopkins Applied Physics Laboratory
James. L. Nevins, The Charles Stark Draper Laboratory

William T. O'Hara, Air Force Wright Aeronautical Laboratories
Donald H. Petersen, LTV Aerospace and Defense Company
Andrew Pettifor, Rockwell International
David Price, Pratt and Whitney Aircraft
Yapa Rajapakse, Office of Naval Research
C. David Rogers, United States Steel Corporation
Lewis D. Roth, Inference Corporation
Ron Schmid, 3M Company
William Setzer, Aluminum Company of America
Melvin K. Simmons, General Electric Company
Eliot Steinberg, Industrial Research Institute
C. W. Taylor, General Motors Corporation
R. B. Thompson, Iowa State University/Ames Laboratory
Charles L. Tucker III, University of Illinois
Terry Vanderloop, 3M Company
Herbert B. Voelcker, National Science Foundation
Daniel E. Whitney, The Charles Stark Draper Laboratory
B. P. Wilkenson, Aluminum Company of America
Richard Williams, United Technologies Research Center
Ralph T. Wood, General Electric Company
William E. Woolam, Southwest Research Institute
Bevan P. F. Wu, International Business Machines
H. Thomas Yolken, National Bureau of Standards

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Industrial Research Institute
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New York, NY

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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)*

This workshop was the second of two workshops sponsored by the Industrial Research Institute and the White House Office of Science and Technology Policy, Committee on Materials, Working Group on Automation of Materials Processing. The first workshop, held in December, 1985 was devoted to the role of process sensors. Together, the workshops addressed several technologies which can play important roles in improving the competitiveness of U.S. process industries through automation. The goals of the workshops were threefold: to assess the state of the art in key technologies needed for process automation, including sensors, process modeling, artificial intelligence and computer integration; to identify broad issues and generic needs for advancing these technologies and applying them in U.S. industry; and to develop information and recommendations for National direction aimed at enhancing the competitiveness of U.S. process industries. The workshop was organized to encourage a discussion of competitiveness issues and of potential solutions by representatives of a broad cross-section of process industries, academic institutions, and government agencies. This report includes the written reports discussion leaders and panel members, together with a section on workshop conclusions prepared by the workshop co-chairmen.

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

artificial intelligence, automation, competitiveness, computer integration
materials processing, process models, process industries, r & d policy

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