THE RELATIONSHIP OF INDUSTRY AND THE UNIVERSITY IN THE DEVELOPMENT OF THEORY, DESIGN METHODS AND APPLICATIONS IN COMPUTER INTEGRATED MANUFACTURING

THEODORE J. WILLIAMS

Purdue Laboratory for Applied Industrial Control
Purdue University
West Lafayette,
INDIANA 47907 U.S.A.

ABSTRACT

The Purdue Laboratory for Applied Industrial Control (PLAIC) of Purdue University, West Lafayette, Indiana, USA has carried out a highly successful industry/university research collaboration in the field now known as computer integrated manufacturing for the past twenty-five years. In contrast to most university laboratories working in this area, the Purdue University effort has concentrated on the process industries instead of the discrete manufacturing industries.

This paper lays out the important research and development areas of the field of computer integrated manufacturing and indicates where a university laboratory's effort can contribute to all of these. The lists of projects given should provide considerable guidance for the university laboratory to further develop such projects.

This paper also indicates the value of an extensive post-graduate continuing educational program in providing badly needed technical education to industrial personnel. At the same time it serves to acquaint this same industrial segment with the capabilities of the university sector to contribute to the solution of their problems.

The topic of the best organizational relationship to develop between industry and the university group is also developed, again based upon the experiences at Purdue University.

It is sincerely hoped that the material included herein will be valuable to the university laboratories in establishing and pursuing their own programs.

INTRODUCTION

As noted in the title of this paper, development of a Computer Integrated Manufacturing (CIM) system easily divides itself into several main categories:

1. The Underlying Theory and Basic Technology Used
2. The Design Methods Applied
3. The Application Details and Initial Design Which Mould the System for Its Ultimate Purpose of Development and Operations (Control) of a Manufacturing System
4. Detailed Design and Commodity Programming Needed for the System
5. Construction, Installation and Commissioning of the System

In the relationship between industry and the university in carrying out this development task some natural divisions of the work readily emerge:

1. The discovery, promulgation and teaching of the necessary underlying theory and basic technology is the primary assignment of the university. Industry usually does not have either the properly trained manpower nor the luxury of working on projects whose payout is probably many years away.
2. Because of requirements of timeliness, proprietary information, fiscal and legal responsibility and ownership, the application area is the primary responsibility of industry.

The university can contribute here only in limited ways as will be noted in the text.

The second area, that of design methods, can be done by either group, particularly when industry is considered to include the so-called, design software houses, who develop and sell computer programs to help fulfill the design requirements for the proposed systems.

The university group may also wish to become involved in this area of endeavor, particularly if the limitations usually present in the university environment can be overcome. These latter are also discussed below.

The latter two categories, those of detailed design and commodity programming; and of construction, installation and commissioning of the system are traditionally exclusively the province of the using industry and its aiding contractor organization(s).

If university personnel are involved at all in these latter functions they are also almost always serving as consultants or members of the staffs of the contractor organizations just mentioned.

THE SEEMING INCOMPATIBILITY OF INDUSTRIALLY RELATED PROJECTS WITH THE NORMAL UNIVERSITY MISSION

When considering the "best of all worlds," one would believe that industry and the university would have a great desire to work together in every way possible to aid industry in its mission. From afar their missions would appear to be inextricably intertwined. Industry has a vital need for the graduates of the university to staff their plants and offices. They also have need for the knowledge generated by the university as the source of new products for manufacture and new methods of building and operating their plants. The university, on the other hand, would seem to be looking for problems from industry for possible solution by their researchers and for the funds necessary to carry on this work.

However, in real-life, the two groups are often very far apart. The problems of industry are most often "variations on a theme" long ago solved as a basic problem in the university, and thus of little or no interest to the university researcher. He, in contrast, wants to work on the latest "will of the wisp" idea in the hopes of a possible major breakthrough in a theoretical area. This latter, if it comes, is usually years away from potential industrial use. Table I continues this list to present other areas of incompatibility between industry and the university in attempting to mount a mutually satisfying research program.

Despite these problems, there are many locations where industry and academia have developed a mutually satisfying and rewarding collaboration. What has been different? Table II along with Table III lists some of the reasons these particular cooperative projects have succeeded.

The Purdue Laboratory for Applied Industrial Control of Purdue University, in West Lafayette, Indiana, USA, is one of those university research organizations which have enjoyed a long history of cooperative work with industrial sponsors. Founded in 1966, the Laboratory continues this mission until today. During this period the Laboratory has worked with many different groups of industrial companies, on several different projects, and under all of the various sets of conditions listed in Table II and Table III.

TABLE I
SOME INCOMPATIBILITIES BETWEEN INDUSTRY AND UNIVERSITY GROUPS IN CONDUCTING JOINT PROJECTS

I. TIMING AND SCHEDULING PROBLEMS

1. Once Funding Has Been Granted for a Project, Industry Generally Expects a Very Rapid Response ("They Wanted It Yesterday").
2. Industry Personnel Are Commonly Assigned to a Project Full-Time and Can Thus Devote Their Full Attention to It Until Completion.
3. University Personnel, on the Other Hand, Generally Do Research and Development Work on a Part-Time Basis and Usually on a Lower Priority to Their Other Tasks (Teaching on the Part of Faculty - and Classes and Examinations on the Part of Student Assistants).
4. The Above Leads to Considerable Friction Regarding the Scheduling of Projects and the Establishment of Their Completion Dates.

II. PROPRIETARY DATA VS. FREEDOM TO PUBLISH

1. Because They Are Generally the Supplier of the Major Part of the Funding of the Project, Industry Hopes to Make Commercial Use of the Findings of Joint Research Projects, At Least for as Long as Is Required to Recoup Their Costs. This Leads to the Desire for Proprietary Rights to the Project Results at Least for a Given Period of Time.
2. The University Researcher on the Other Hand Usually Achieves His Professional Reputation and Eventually his Professional Advancement Through His Research Publications. Hence He is Anxious to Publish the Results as Soon as Possible to Avoid Being Superseded by Another Researcher Who May Be in Competition and Able to Publish First.
3. This Is Obviously a Direct Conflict of Interest in the Disposal of the Results of a Study. The Common Remedy Is Usually a Prearranged Moratorium on Publication of Research Results to Allow Industry Some Time Toward Commercialization, Commonly Two to Five Years.

III. RESEARCH DATA VS. COMMERCIAL PRODUCTS

1. In Order To Be Able to Achieve the Rapid Commercialization of a Product or Procces, Industry Requires That Research Be Carried Far Beyond That Point Where the Researcher Is Satisfied "With Proof of Concept" Results.
2. The Diversity Just Noted Is Particularly the Case Where the Research Involved Happens To Be the Basis for a Doctoral Thesis Project. Here the Result Desired for the Thesis for the Degree Is Traditionally the Development of New Knowledge. No Further Academic Credit Is Given for Work Toward Commercialization.

IV. DOCUMENTATION AND TRAINING

1. Related to the Point Just Covered the Graduate Student is Interested Only in Writing the Results of His Work to the Degree Acceptable by His Research Supervisors. Therefore, It Is Generally in Highly Mathematical Terms, Liberally Sprinkled With Acronyms and With a Minimum of Prose Explanation.
2. Unless the Industry Individual Who Must Use the Above Results Has Been Very Closely Following the Above Work, He Will Have Extreme Difficulty in Deciphering It and Making Early Use of It. As a Result the Work Must be Effectively Repeated for Understanding of The Report or It Is Put on the Shelf and Ignored.

TABLE II

THE REASONS FOR THE SUCCESS OF SOME MAJOR INDUSTRY/UNIVERSITY COOPERATIONS

1. The University Researcher or Research Group Involved Possessed a Unique Combination of Skills and Experience in Industrial Type Problems and Both Industry and the Researcher Involved Wished to Exploit This Capability.
2. The Problem Tackled Was One Which No Single Company Was Likely to Investigate On Its Own Because of a Unique Breadth of Experience and Knowledge Required; The Magnitude of the Project; The Overall Risk; Or, the High Future Potential But Lack of Immediate Applicability of the Potential Results.
3. The University Umbrella Offered the Industrial Personnel a Milieu Where They Could Discuss Mutually Important, Non-Proprietary Problems Without Fear of Anti-Trust or Restraint of Trade Accusations. The Presence of the University Researcher as a Neutral, Uninterested Party Removed the Governmental or Commercial Concern Involved.
4. The Problem Tackled Was One Which Every Industry Had (Such as Environmental Pollution) and Research Results Would be Mutually Applicable Without Any Special Benefit to Any One Industrial Participant.
5. Government Funds May Be Involved to a Much Higher Degree than the Industry Funds, But the Government Insists on Industry Participation to Assure the Eventual Applicability and Use of the Research Results Obtained. In This Way Industry is Able to Leverage Its Rather Minimal Funds Through Government Cooperation to Reduce Its Own Monetary Involvement and Subsequent Risks.

TABLE III

SOME COMMON CHARACTERISTICS OF SUCCESSFUL INDUSTRY/UNIVERSITY COOPERATIONS

1. Unless the Conditions of Item 1 of Table II and Item II-3 of Table I Are Present, the Industry Representation is Generally From a Consortium of Companies Who Each Pays a Relatively Small Fee - the Whole Becoming Sufficiently Large to Fund a Reasonably Sized Project.
2. There Is Almost Always One Person in Each Company Involved Who, For Whatever Reason, Is Willing to Fight for Funding of the Project Within His Own Company. Unfortunately, If This Individual Loses His Interest or Need, Again for Whatever Reason, the Sponsorship Fails and Must Be Renegotiated or Dropped. For the Same Reason, Change of the Researcher on the University's Part Will Generally Have the Same Result.
3. Because of the Instability of the Necessary Criteria of Item 2 Above There Must be Constant Effort on the Part of the University Research Leader to Continually Renew the Membership of the Industrial Consortium, Either From Wholly New Companies or New "Angels" Within Current Sponsors.
4. Most Problems Eventually Get Solved or Are Superseded by More Interesting Ones, Thus There Is Also a Constant Need for the University Research Leader and Often the Leaders of the Industrial Consortium as Well to Adjust and Change the Research Mission of the Consortium to Maintain Industrial Interest in Sustaining It.

DEVELOPMENT OF BASIC TECHNOLOGY

As noted earlier, basic research and development of the theories and basic technologies related to the field of computer integrated manufacturing are the natural fields of endeavor of the University and its research staff. Since many of the topics are of a very long range nature and may have little immediate payout, the major problem with them is that of interesting any of the several funding agencies in producing the funding for their promulgation. Table IV presents a listing of some potential categories of research of this type.

TABLE IV

A LIST OF SOME IMPORTANT BASIC RESEARCH AREAS RELATED TO COMPUTER INTEGRATED MANUFACTURING

I. CIM Reference Models or Architectures.

II. What Is the Best List of Those Generic Tasks Which Are Carried Out By All CIM Systems ?

III. What Is the Best Way of Defining the Place of the Human In the Overall CIM System ?

IV. Development And/Or Collection Of A Set Of First-Principle Models For the Major Industrial Processes.

V. Continued Development Of Application Methods For the Many Theoretically Promising But Little Applied Advanced Control Techniques.

VI. Specifying the True Place and Potential of Artificial Intelligence Techniques In Industrial Applications.

CIM REFERENCE ARCHITECTURE AND MODELS

There are already a large number of proposed CIM Reference Architectures and Models in the literature. However, none of them, to this author's knowledge, can yet supply the types of answers to potential users needs as are expressed in Table V. Note that as used here the terms CIM Reference Architectures and Reference Models are considered to be synonymous.

It is noted that all of the questions of Table V are related to the structure, task elements, and life history of the CIM System, all topics which are real life aspects of the systems and therefore those for which a model or architecture in the above sense should be able to be written. However, note that none of the existing literature offerings are able to do this. Some few can answer part of the questions but none, to this author's knowledge, comes close to answering them all. Thus continued research in this area is needed and readily justifiable.

TABLE V
WHY DO WE NEED A CIM REFERENCE ARCHITECTURE ?

To Be Truly Valuable a CIM Reference Architecture Should Be Able To Supply Answers or Solutions to All or Most of The Following Questions, Requirements or Situations:

1. The Architecture Should Present a Method For the Breakdown of All System Functions to Their Inherent Generic Functions and Tasks. These Should Be Accomplished With a Minimum Number of Basic Building Blocks. Conversely it Should Be Possible to Build Up the Overall Functions From These Ultimate Basic Building Blocks.
2. The Method Should Be Able to Show All Existing Relationships of Those Entities Represented By the Blocks or Modules Used for Modelling.
3. The Place Of the Human Being in the CIM System Should Be Able To Be Explicitly Shown, Functionally and Organizationally.
4. The Architecture Should Explicitly Show the Evolution of a CIM Program From Initial Concept to and Including Operation as a Completed System.
5. It Should Model the Interfaces Between Humans and Information Systems, Humans and Manufacturing Systems and Between Information and Manufacturing as Well as Between Foreign Elements and Other Members Within Any System.
6. Modelling of the Effect of Adaptation or Change in the System in Terms of Limitations, Effects, Etc., Should Be Possible.
7. It Should Be Able to Show the Limitations Imposed by Specific Designs on the Generic Requirements for the System.
8. It Should Provide a Basis for the Development of Needs for Standards for Various Aspects of a System and Be Able to Indicate Their Relative Value.
9. Most Important an Architecture Provides a Common Basis for Discussions of a CIM System and Thus Assures a Full and Accurate Interpretation by All Discussing Parties of All Points Under Discussion.

It Should, In Short, Be Able to Map Concepts, Answer And/Or Illustrate Questions, as Well as Provide a Means of Comparing Disparate Systems, Alternate Implementation Schemes For the Same Systems, and Rival Development Methods and Techniques.

While Developed Specifically for CIM Programs, This Scheme Should Also Readily Cover Discussions of Other Aspects of Manufacturing Enterprises and Probably Other Types of Enterprises as Well.

GENERIC CIM TASKS

Most CIM Reference Architectures and Models designate those CIM tasks and functions related to information management and control in the CIM System as being generic. Many of them proceed to list such groups of generic tasks and functions. However, these lists vary widely from one research group to another and, even allowing for different semantics, still include different topics. That is, all or part are either incomplete or redunda-

The development of a list, agreed to by others as being generic, would be extremely valuable to the CIM field. While this topic may border more on the subject of standardization than research, it is included here in the hope that further research might help to make the final work of adoption of the list by others much easier.

The list is needed in the CIM field to make possible the ready transportability of application systems from one factory to another and hopefully even from one industry to another. The extent to which the list can be all inclusive and acceptable by practitioners in the several industries will define the extent to which the above portability can be developed and carried out.

THE HUMAN IN THE CIM SYSTEM

Human Relations and the place of the human being in a CIM System is probably the basis for more research, and certainly for as much publication today as any other aspect of the field.

Unfortunately, because the subject strikes too close to home for all of us since we are humans ourselves, these publications all seem to have more of a political and/or a social cause agenda to them than a purely scientific one. It is very difficult to find a paper in this area for which the political or social bias is not very evident.

In this writer's opinion, this part of the CIM field is crying out for the formation of a group of researchers, of all callings, whose **joint voice** could be recognized as unbiased as possible, and which as a whole could investigate and **rule** on the "true" answer to the many controversial questions being raised in this area.

Perhaps this joint group could work out relationships which show the relative economic gain or cost, as the case may be, of the use of various social/organizational structures which have been proposed for the operation of the factory. Some of these are: hierarchical, matrix, self-supervised work teams, partnership, etc.

Likewise the differences in economic versus social cost or gain from the various extents of potential automation use in similar factories would be important information to have. Again, it must be provided that these analyses could be carried out in such a way as to remove the affects of any political or social bias.

With the above two sets of information, however difficult they may be to obtain, actual costs and/or benefits of the many social action programs proposed by legislators or social action groups could be truly evaluated - a badly needed capability in all industrial countries, whether developed or developing.

MODELLING AND SIMULATION TECHNIQUES AND THE MODELLING OF SPECIFIC PROCESSES

This is a field of seemingly almost unlimited extent at first appearance because of the large number of possible subject industries, and the wide variety of processes in each of them. However, closer study will reveal that the basic processes (as in the unit operations of the field of chemical engineering) are repeated over and over again in each industry in turn.

Each has its own idiosyncrasies, of course, but with slight modifications, the basic model of the generic process can still be largely used.

There are several caveats in this field, however. These are expressed in the Proprietary Information and Documentation and Training sections of Table I. It has been very disturbing to this author to see how many times the same industry and even the same company has contracted over and over again with different University groups for the same process model and has ended up using none of them. This recurring problem within this area of industrial research needs to have a solution proposed - perhaps more education of the potential users in the use of each model, collectively and individually, is the only long-term answer.

Another related topic is that of gathering the prime examples of the similar models for each basic process from the mass of literature available. These could then be promulgated to industry along with the necessary basic and applications training to assure that the models in question achieve understanding and ready application by their potential users. However, the reader must realize that this latter is not a new idea. Perhaps before getting too deep into it one should find out why others did not succeed in similar endeavors.

CONTROL TECHNOLOGY AND ITS APPLICATIONS

Like the field of mathematical process models, the literature is replete with publications related to the mathematical theory of automatic control. Nonetheless only a minimal amount of this literature ever seems to get applied to real processes in industry. There are many reasons for this:

1. A large part of the literature can be classified as minor variations on a theme and therefore not worthy of industry concern.
2. Much of the literature is related only to mathematical extensions of linear system theory and is usually written using very small systems as examples. Given the nonlinear, non monotonic, and multivariable nature of real industrial systems, the lack of application of these is understandable.
3. Many techniques are so grossly inefficient of computer power that even today they are impractical and will probably remain so for the foreseeable future.
4. Given all this, there still remains a wide body of the control literature which should find application in industry but does not. It is in these areas where applications research in cooperation with industry should prove very promising.

It must be kept in mind in setting up a research program in the area of Item 4 above, that there are many very well-known university and industrial automatic control laboratories specializing in various topics in this research area. Care needs to be taken to avoid setting up a direct competition with them because of the effort needed to reach a competitive quality status with them. Literature search must show that there is a potentially important application area available, (1) where the current or potential research staff has an active interest and (2) which is not already occupied by a well-known and productive research group.

THE PLACE OF ARTIFICIAL INTELLIGENCE

At the outset of the discussion of this topic the author must confess the fact that he is not particularly enamored with the field of artificial intelligence. It has always seemed to him to be attributing capabilities to computer systems that are not inherently there, particularly given the totally deterministic nature of the operation of the computer itself. Of course, random number generators, etc., are possible, but even these are algorithms.

These views are obviously not shared by a large segment of the automatic control research field as evidenced by the fact that artificial intelligence and its various potential application regimes are by far the most popular areas of research today in the automatic control and automation field. But, despite the vast amount of work going on, it seems that little true application potential has yet been proven, except for several areas of application of expert systems.

EXPERT SYSTEMS

Even expert systems seem to be showing major successes only for static systems and in areas like diagnostics where a database of facts for formulating the rule base needed is available.

The many attempts to extract a viable rule base through interviews of a group of human experts seem to have been, on the whole, unsuccessful. This lack of success is due to several well–known reasons:

1. Lack of sufficient knowledge of the application area by the knowledge engineers conducting the interview - They didn't know how to ask the right questions!
2. Lack of knowledge of the requirements for the expert systems on the part of the interviewees – They did not know how to prompt the interviewers or what knowledge to volunteer!
3. A lack of complete knowledge of the process being modelled on the part of any one interviewee.
4. A reluctance on the part of some interviewees to give up their "life's work" to the expert system, and possibly face a loss of their livelihood to the computer system - The company's reward system was not sufficiently investigated prior to establishing the expert system project!

The potential use of expert systems technology to derive operational management procedures by the reduction of current plant operating data, particularly to allow the system to extrapolate from current operating levels, seems fraught with the same problems which were encountered earlier when these same capabilities were sought from statistical methods. There was no way with the inherently linear method involved to predict the true non-linear behavior of the system when operated in regions beyond these actually tested. There is nothing visible in the current technology known to the author which promises to solve that latter problem.

Despite the above there is a great potential for the development and use of the type of expert system whose successful development was mentioned earlier, those developed from established sources of data, such as engineering handbooks; existing engineering designs; codification of governmental regulations, company policies, union rules, etc.; codified operational procedures; alarm management techniques, and a vast number of other sources of established data. However it would seem that the field of expert systems has already advanced far enough that the preparation of such expert systems would shortly or eventually become a service function rather than a research function.

NEURAL NETS

Neural nets are a very intriguing idea, and deserve much of the current interest which they have enjoyed. However, there are several caveats concerning their use which current research has not yet dispelled:

1. Neural nets as modelers of physical system must follow the behavior of that system. Thus they are inextricably tied to the dynamics of that system and dare not extrapolate ahead of the systems' own operation. Thus they should only be used on known endothermic or inherently stable processes. Their se on potentially unstable or, particularly, on known exothermic processes would seem to be extremely dangerous.

2. Neural nets seem to be faced with the inherent problem which faced all statistical modelling routines - How many variables should one use in the analysis? What form of response should be used? What interactions between these variables should be tried?

   While neural nets can potentially answer some of these problems, they are all ultimately limited to the capability initially included in their design. How do we know a priori that any analysis has been complete enough. Any neural net like the statistical procedure will only give the best model it can within its own capabilities, it has no intelligence to reason further.

A PROPOSAL

It is this author's firm belief that artificial intelligence methods cannot ever take the place of deterministic, first-principles modelling and design methods. Combined together (deterministic plus artificial intelligence techniques) we can, perhaps, achieve better models, operating procedures, etc., faster. Certainly the AI techniques when tempered with the more classical procedures can give much more accurate and useful systems.

The research problem then is to develop an accurate mapping of the usefulness of the current AI technology and of other new procedures as they are developed versus the needs of the industrial automation field for all kinds of technology. This would serve to promote industry's confidence in the use of AI techniques where they truly fit and avoid the expense and disappointment of attempting to use them in areas for which they are not suited.

DESIGN AND DEVELOPMENT METHODS AS TOPICS FOR PURSUIT BY THE UNIVERSITY LABORATORY

In their contacts with its industrial sponsors, personnel of the Purdue Laboratory for Industrial Control were continually told by their industrial counterparts that what they, the industry, wanted was methods and techniques for doing the job themselves.

In other words, despite the contrary indication from the titles of the Laboratory's reports in Appendix II, industry would rather have had us work on first-principles modelling methods and simulation techniques, for example. This rather than to develop the actual models ourselves, which is what we usually did.

The reason for this is simple, it is the problem of proprietary information and commercial advantage discussed earlier. Industry wishes to develop its own models of its processes and equipment and keep these secret from its competitors. This, of course, works totally contrary to the university's desire to publish their research results to obtain credit for their work and its results and to prevent others from repeating the same work over and over again as the industry procedure would require.

This incompatibility in desires on the part of industry versus the performance of the university laboratory was engendered by two factors:

1. The need for positive research results from student thesis projects, usually readily answered by undertaking specific modelling topics, and
2. A lack of innovative topics in the field of modelling techniques and simulation to be used by the students for their research topics.

Since there is no way that one can command innovation but one can always pick from a nearby inexhaustible list of potential modelling topics, our response was obvious despite some disappointment on the part of our industrial partners. They understood our dilemma, of course, and always aided us in tackling modelling tasks which were important to us. Nevertheless we could have served them better if we could have developed topics in the other area of investigation.

There are four major areas where methods and technologies important to industry need further development. These are: design methodologies; the above-mentioned process and equipment modelling and simulation technologies; production scheduling methods; and process planning techniques. All are vitally important to the industrial automation or computer integrated manufacturing field. Of course, all of the major divisions of the computer science field necessary to industrial automation are also candidates for research work.

The field of sensors is another area which is a rich source of potential research topics. Again these are not included here since each separate sensor research investigation is an entity unto itself because of the special conditions which are almost always present.

THE SPECIFIC NEEDS OF THE METHODS FIELD

The types of research topics which most need study in each of the four areas specifically mentioned here can be summarized as follows:

1. Design methods are needed which allow designs to be verified while they are still on the computer system. That is they need to be tested against their design specifications and goals, such as by on-line simulations of mathematical models while still under development. These could check dynamic performance, missing or incorrect functioning, etc. Designs for physical devices could have mockups build by electronic means to prove dimensionality, lack of internal conflicts, etc. [12].

2. Modelling and Simulation Techniques require ever higher capacities in terms of numbers of variables, range of variation of variable parameters, speed of computation, methods of choice of future trial parameters, etc., which are allowed. All of these are necessary to permit a more thorough testing and exercise of models. This will help assure faithfulness of a model under development and an ever increasing number of test cases to help to increase the probability of attaining optimal results of optimization studies.
3. Production Planning and Scheduling is effectively an optimization study with a very large number of variables and conditions. The needs here, like those just discussed, are for vastly increased problem dimensionality and much larger number of allowable trial cases to help prove the attainment of the optimal result for the particular investigation at hand.

4. Process Planning requires a marriage between computer–aided design and database development techniques. What is needed is an automatic method for working out the best manufacturing methods for any new product design which may be developed. Next the computer system must automatically convert this set of manufacturing steps into the set of control instructions for the manufacturing equipment to produce the new product. These latter could be loaded into the operational database of the plant CIM system and called up whenever that product needed to be produced. For safety purposes, these sets of operating instructions would have to be verified on the computer via simulation or equivalent techniques to avoid any possible damage to the manufactured equipment because of erroneous instructions.

OTHER CONTINUING PROBLEMS OF INDUSTRY REQUIRING ADDITIONAL UNIVERSITY INVESTIGATION AND COOPERATIVE WORK

In addition to the major classes of research topics which were described in the earlier chapters, there is a number of other topics which though uncoordinated are also important to the well-being of the computer integrated manufacturing field and should be discussed as possible places for research endeavor. Two among these will be discussed as potentially important services of the university team to industry. These are reliability studies and continuing education for future workers in the CIM field.

SYSTEM RELIABILITY OR TOTAL OPERABILITY

Enormous strides have already been made in the reliability field, mainly through improvements in the design, manufacture and use of integrated circuits for the system electronics. There are also numerous application techniques which can contribute to overall system reliability, availability, mean-time-between failures and other measures for improving the continuous non-stop performance of industrial control systems.

Whatever the method used to assure such action is called, industry wants its control systems to run effectively forever without any significant lowering of their ability to carry out their assigned mission. Notice, we did not say that components or whole units could not fail, they will of course. The need is for the ability of the control system to carry on its mission regardless of the type or severity of the failure which has occurred.

With unit element reliability in the capable hands of the "chip" or basic circuit makers, the type of work to be studied by the university applications laboratory would be the promotion of higher overall system availability. This could be done by studying the following among others: elimination of potential failure points in system structure;developing operating strategies to counteract any failures which might occur; and evaluating the proper location and operation of redundant units for maximum effectiveness in reducing system vulnerability.

The achievement of plant control systems which effectively "never fail" (to carry out their mission) can have enormous effects on the way industrial plants are operated. It is noted that much of the technology to achieve this is already in place. The remaining factors are demonstrations that such a continuous operation is indeed achievable and then installation of confidence in the minds of management that this is indeed the case.

CONTINUING EDUCATION

CIM and its related technologies have burst rapidly on he industrial scene in the past few years. The result is that there is a very great lack of information concerning CIM and its ramifications in the minds of engineers and managers in the various industries. There is also an even greater lack of the skills necessary to plan, design, implement, and operate CIM systems in their plants.

As units of enterprises whose basic existence relies on their mission to train and educate, the university-based industrial control applications research laboratory is uniquely qualified to fulfill the resulting need to its own benefit as well as to those of the industries whose employees are being trained.

Short Courses

One of the very first activities of the Purdue Laboratory for Applied Industrial Control in the early years of its existence was to mount a major program of short courses (one to two weeks in duration) to train industrial engineering personnel in the technologies needed to apply digital computer based control systems in their companies. These were highly successful and attracted a large number of students from all over the United States and several foreign countries as well.

They were discontinued in 1971, not because of lack of available students but because of a lack of personnel to staff the teaching program as well as our growing research program and because many other American universities were following our example and generating major competition to our program. It was also felt (wrongly as it turned out from later analyses) that the locations of some of these other schools near popular vacation sites might give them an advantage in attracting future students.

Nevertheless, these early offerings in the short course area went far to showing our industrial partners the abilities present in the staff of PLAIC and our capabilities in the applied industrial control research area. Thus they helped greatly in recruiting industrial sponsors for our research programs.

Initial Management Preparations for a Computer Integrated Manufacturing Plant

An especially important class of continuing education services which the university can perform is that of the education of industrial company managements to make them "CIM literate," as discussed below.

Experience with American companies has shown that many management personnel are ill-equipped in terms of their knowledge of CIM, its benefits, its costs, its requirements for successful implementation, etc., to make the necessary plans and decisions regarding the use of CIM techniques in their companies.

While there is a multitude of consulting and CIM vendor companies who are happy to tell company managements how their organizations (the vendors) can install CIM systems in the clients' plants, they are all selling their own company's services.

What these managements really need are the services of truly knowledgeable, but truly unbiased, educators to teach them real basics of CIM system capabilities, requirements, costs, benefits, stumbling blocks, etc. In this situation, the university, if it has personnel with the proper background, would be perceived by the potential industry management students as having no ulterior motive and therefore as presenting the real facts of the situation.

Such training courses should cover economic factors, personnel needs, the effects of various plant cultures, training needs, and all the other ramifications of CIM beyond merely the technical factors involved.

CONTINUING FUNDING NEEDS AND RELATED PROBLEMS

SOME RAMIFICATIONS OF OPERATING A UNIVERSITY RESEARCH LABORATORY

A university research laboratory has all the problems of a small business in terms of its operations, particularly in terms of its sustained life and growth. Staff (here professorial research advisors, graduate students and support staff) must be recruited; the products of their efforts must be sold (here the research projects and their resulting research reports); facilities must be procured and kept in operating condition (here manifested as equipment purchases and installation, maintenance personnel, and overhead for buildings and utilities) and continued life assured (here by developing new projects, securing research grants from government sources and assuring the quality of the research work carried out).

In the United States, a research professorship is often characterized as a "hunting license" to allow one to go out and raise research funds in the name of the university to sustain their research laboratory. Save for relatively rare exceptions, all research funds in a university in the United States must be raised from external sources. The American professor is very envious of his European counterpart who (as we understand it) is granted a lifetime research budget along with his appointment as professor. We understand that there are fewer full professorial titles in European universities but we also note that all laboratory directors appear to have such titles. Thus we consider ourselves equivalents.

In most cases faculty research advisors receive a fraction of their stipend from each graduate student thesis they supervise. These funds, commonly 10% per student project, come from the research grants supporting the student involved, hence also from the laboratory's budget. Usually the laboratory director is required to also procure a fraction of his own salary and benefits, commonly 50%, as part of his funding procurement activity.

Another aspect of the university milieu which complicates the university laboratory's funding requirements is the time characteristics of a graduate student's program. Each graduate student must complete a certain number of advanced course hours and pass a series of examinations before being allowed to proceed with his/her research studies. Normally the student spends the first two to three years on his/her studies followed by two years of concentrated research work. The student commonly receives his/her research stipend throughout his/her graduate study period regardless of his/her actual activities at any point in time. Obviously the laboratory director must factor the periods of research inactivity into his/her spending plans and into his/her schedule for completion of various projects.

THE IDEAL SITUATION

If the laboratory director could have his/her choice what would he/she wish for his/her laboratory's research program and funding sources to look like?

As we have noted several places in this report there are many very desirable characteristics to have in the laboratory's structure:

1. Continuing industrial sponsorship is very necessary. It would be most helpful if these sponsoring companies were from a variety of industries to give a broad experience base to the program.

2. Representatives appointed by the companies themselves should form an Advisory Board who meet at least four times a year to actively criticize the laboratory's research program and its results. They should take a very active role in advising the director on important research which the laboratory should undertake. They should also actively support the laboratory's proposals for government funding for the work by endorsement letters to and personal visits and interviews with decision making personnel of the funding agencies.

3. The sponsoring companies should pay an established annual fee for sponsorship. The act of paying is more important than the relative amount since funding agencies wish proof-of-interest on the part of sponsors and money "talks loudly" here.

4. The sponsoring companies should provide summer or cooperative period employment to the graduate student researchers to be sure they know and understand the industrial milieu. This is particularly important for foreign students who would have no other chance to get this experience.

5. Sponsors should provide actual plant data for analysis by the students while investigating their research topics. Here again it is a major learning advantage for the students to have real plant data for their analyses.

6. It would be helpful if total industrial funding were in the range of 50-60% of total research funding expended. This provides a smoothing function for the wildly fluctuating government funding base, and provides a cushion for any periods when government funding is difficult or impossible to obtain.

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