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**THE PRESENT STATUS OF THE FIELD OF
DIGITAL COMPUTER BASED INDUSTRIAL
CONTROL SYSTEMS AND THE WORK OF
THE INTERNATIONAL PURDUE WORKSHOP
IN HELPING TO PROMOTE THIS FIELD**

REPORT NUMBER 109
Purdue Laboratory for Applied Industrial Control

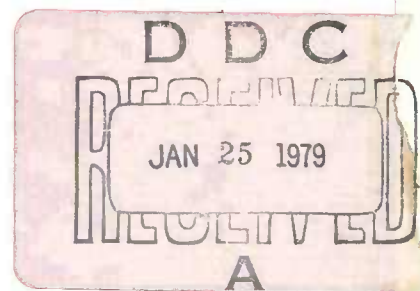
Prepared by
THEODORE J. WILLIAMS

September 1978

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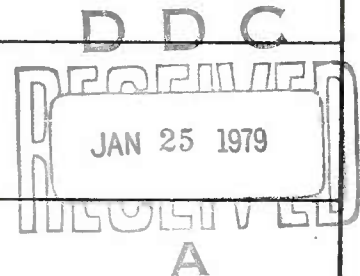
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SUMMARY

This report, prepared under Contract Number N00014-78-C-0127 with the Office of Naval Research, continues the work carried out under a previous grant (Contract N00014-76-C-0732) to better acquaint Naval personnel with the industrial digital control field and to specifically inform them of the work of the International Purdue Workshop in developing standards and guidelines for that field.

This report comprises a review of the current state of the art of the application of computers to the control of industrial processes. In doing this, it emphasizes the current trends toward hierarchical and distributed control systems.

The needs of the field for both hardware and software developments are pointed out along with a listing of the remedies developed for many of the past problems which have plagued the field. The alternatives involved in the organization of an industrial computer hierarchy are described and the currently most probable direction of movement of this field is presented.

The work of the International Purdue Workshop involves the development of standardized extensions to the FORTRAN and BASIC languages to make them suitable process control computer languages, an extensive cooperation with the DOD HOL Working Group to assure that the IRONMAN-STEELMAN specification adequately reflects industrial needs, the development of the specification for a generally accepted serial data highway for standardization, the development of guidelines for problem oriented languages and

for man/machine interfaces and the preparation of a set of glossaries for the field. The present status of this work is described herein along with the relationship to the overall development of the industrial computer field.

IMPORTANCE TO THE UNITED STATES NAVY

Normally the services do not support projects for the betterment of industry, particularly world-wide industry, except as related to the production of arms and munitions and other goods for military applications.

It is generally conceded, however, that the techniques and requirements for computer-based industrial control systems and for embedded real-time military computer systems are very similar and becoming more so all the time. It is also generally conceded that the lack of hardware and programming standards is one of the leading deterrents to progress and at the same time one of the major cost factors in the field for both areas of application.

As one of the leading organizations world-wide for the development of standards and guidelines for industrial computer systems, the International Purdue Workshop on Industrial Computer Systems can have a major effect on improving future capabilities and reducing future costs and personnel needs for all systems of this type - both civilian and military. By keeping abreast of these developments and by cooperating with the Workshop whenever appropriate the United States Navy can assure itself that it is taking advantage of the latest developments in this area for application to its own systems.

FOREWORD

This report is published as part of Contract N00014-78-C-0127 with the Office of Naval Research, United States Department of the Navy, entitled, The International Purdue Workshop on Industrial Computer Systems and Its Work in Promoting Computer Control Guidelines and Standards. This contract is effectively an extension of an earlier one numbered N00014-76-C-0732, same title.

This contract provides for this report, the coordination of Workshops meetings and help in the preparation of the extensive Workshop Minutes. We are very grateful to the United States Navy for their great help to the Workshop in this regard.

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Director
Purdue Laboratory for Applied
Industrial Control

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CHAPTER I

INTRODUCTION AND OVERVIEW OF INDUSTRIAL COMPUTER SYSTEMS

SOME HISTORICAL BACKGROUND

When one considers the pervasiveness of computer systems as installed in industrial plants of all types today, it is hard to realize that the first viable proposals for such systems were made just twenty years ago. It is equally impressive to consider the capabilities of present day installations, particularly their price/performance ratios, as compared to those first systems. These have improved by at least a factor of 40,000/1 over the first installations.

In reviewing some of the history, some of the results, and some of the lessons learned during this period, we will use as examples several of the early systems installed by the Monsanto Company, St. Louis, Missouri. This is not to call any special attention to the work of that company. It is because this is where our familiarity lies and because, in many cases, the systems to be described here, were the first or nearly the first such systems in their classes.

Monsanto's first digital computer control project was the Luling, Louisiana ammonia plant. This project involved the use of the RW-300 computer of the Ramo Wooldridge Company - the first machine used to any extent (50) for process control applications.

After the usual development and production delays, the RW-300 was delivered at Luling on January 20, 1960 - a few days ahead of a similar system for B. F. Goodrich's acrylonitrile plant in Calvert City, Kentucky - and thus became the first chemical plant computer control system. Following much trouble with signal noise problems and an almost complete reprogramming of the control algorithm, the digital control loops were closed on April 4, 1960. This was, of course, a supervisory control system, that is, the computer changed the set points on the ammonia plant's regular analog controllers to achieve its control action and did not actually move any valves itself.

It should be noted in passing that while Luling was commonly recognized as the first chemical plant control computer it was not the first industrial computer system. That honor goes to Louisiana Power and Light Company, who installed a Daystrom computer system for plant monitoring at the power station at Sterling, Louisiana, in September 1958. The first industrial control computer system was that of the TEXACO Company at their Port Arthur, Texas, refinery with another RW-300 with the attainment of closed loop control on March 15, 1959, approximately a year ahead of Luling. (Incidentally, they had bought the computer directly from TRW on first proposal rather than going through the one year's justification study as carried out by Monsanto - hence the one year lead).

After a bit of drum trouble immediately after the loops were closed, the Luling computer performed for well over a year without a hitch, easily making the promised five percent

gain in production and, in this respect, demonstrating its ability to beat the best plant operating crew over the long period.

Thus Monsanto's management was primed when their engineers came back in the Fall of 1961 to ask for two new projects - computers for the proposed new Chocolate Bayou petrochemical complex and for the Texas City DDC experiment, both again becoming firsts of their class.

Both of these new projects are now history - the four computer system at Chocolate Bayou became the first hierarchical computer control system, a word which is now all the rage in discussing potential plant computer control systems. The Texas City experiment started the DDC Discussion, a topic which has probably generated as many technical society speeches and arguments as any other in the industrial control area which we could name.

SOME EARLY LESSONS

These first three projects of the Monsanto group had within them several hard lessons for us and for our industry in regard to future applications. Some we have recognized, some were not so immediately evident, or they were ignored by the industry when first brought to their attention.

1. The Chocolate Bayou specification caught the computer industry completely unprepared to tackle a project that big. As a result, the Monsanto programming

group even had to write their own assembler program for the Honeywell H290 computers finally chosen for the project. It is not certain that an adequate programming system is available even today for the kinds of overall plant control systems which potential users might dream up.

2. The H290s proved to have a fatal flaw. Their germanium circuitry was very temperature sensitive. Thus the computer system failed every time the air conditioning equipment failed - which was frequent. While things are much better today, our computer systems are still often dependent upon the performance of mechanical devices whose reliability is much less than that of the electronics of the computer itself.
3. The Texas City DDC system was able to handle only 10 control loops because the drum memory of the computer was so slow thus pointing out the need for inexpensive core memory based machines (-the minicomputer!).

Monsanto's next project, the Chocolate Bayou biodegradable detergents project of 1964, the first large scale plant DDC project, had two additional lessons:

1. The Westinghouse P50, the first minicomputer, while a core based computer was still too slow for the task we wished solved. This was because it had no hard-wired multiply function, a victim of Westinghouse's desire for economy.

2. The system was an initial technical failure, and probably a continuing political one, because the reed relays in the output matrix system would stick. This caused several plant valves to operate at once on the same signal instead of just the one desired! Another victim of cost savings and hardly the kind of thing to let plant engineers sleep at night.

This type of failure was easily repaired by using mercury wetted relays in place of the reeds. But it took place only after the political damage to eventual acceptability had already been done. Thus the technical successes of this project: the incremental DDC program, or the "velocity algorithms", and the redundant, self-switching, computer system never received their deserved credit for the advancement they brought to the field.

CENTRALIZED VERSUS DISTRIBUTED SYSTEMS

There is one area of controversy in our field today (perhaps by now almost a past controversy) which the early systems described above did not encounter. This is the question of centralized versus distributed systems for a large project. Should you use a single large computer for the project? Or should you use a set of several smaller machines each carrying out part of the overall task?

The Chocolate Bayou project did become the first distributed system, as well as the first hierarchical one. This was mainly because there were no computers powerful enough to handle the whole task as envisioned at that time. Not because any of those involved then really were blessed with any extraordinary foresight!

Proponents of the single centralized system have claimed the possibility of a better optimization of plant operation as their major selling point because all plant information was available at one point in this type of system. They were, however, faced with higher requirements for reliability, a more complex programming problem, and a more expensive data system, especially if the intermediate possibility of remote multiplexers was not used.

Proponents of the distributed system faced higher computer mainframe costs, especially in the early days, and the problem of assuring data availability for optimization functions. They could on the other hand promise a somewhat more relaxed reliability problem and a much simpler data system.

The concept of the centralized system was pushed vigorously, by IBM in particular, in the late 1960s. This was because their offering for process control, the IBM 1800, was an expensive computer which could only be adequately justified for such large complex systems. Also at that time, the minicomputer had not yet assumed its ultimate place and had not yet made the eventual distributed system practical.

The microprocessor has essentially solved any controversy which might still exist here. Its low cost and relatively limited capability has made the distributed system a natural answer. At the same time, capable data transmission systems are available (at least in concept) to transmit any needed data throughout the system and thus counter the previous drawback of such schemes - the availability of needed data for an adequate overall plant optimization capability.

THE BASIS FOR TECHNOLOGICAL DEVELOPMENT
OF COMPUTER CONTROL SYSTEMS
IN THE PRODUCTION INDUSTRIES

Technological development in the computer field is driven by two major factors: (1) the needs of the Defense agencies for ever more sophisticated computing devices to maintain weapon and counter-weapon superiority and (2) the tremendous rate of development in the design and production of solid-state integrated circuit elements.

Computer technology has been a major recipient of innovation and growth from both of these drivers of present day technology and will continue to so benefit for the foreseeable future. Process control and other industrial applications of computers, being a relatively small fraction (approximately ten percent) of the computer field, thus is a beneficiary but not a driver of the technology (24).

Process control has indeed had an input into the requirements for computer systems (necessary speeds, and word

lengths, memory sizes, reliabilities, allowable costs, etc.) but as a second order effect. That is, we have influenced the characteristics of the systems which would have been built anyway but we probably did not spark or generate their production in the first place. This secondary role of industrial computer systems in computer system development is not a difficult one if we can continue to influence the design of equipment used for general applications, i.e., we can assure that the general standards finally accepted will not be detrimental to the needs of industrial computer systems. Since we do not believe that our needs (beyond level one, see below) are that much different from other applications, we have no real fears concerning this.

What then determines the appearance and spread of a technological change in the industrial computer control field? The major factors in approximate order of their importance then become:

1. Knowledge of successful applications in related industries which are transferrable to the industry or application in question.
2. A desire on the part of a company, or of a unit within a company, to achieve an important innovation ahead of its peers.
3. The potential economic or technological payout of the proposed installation.
4. Familiarity with the new technique on the part of

the engineering, production, and management personnel of the company in question.

5. Proven performance of the technique in terms of reliability, accuracy, and maintainability.

The first factor, especially when reinforced by the second, can result in the appearance of demonstration installations in one or a few companies. However, the new application will not begin to spread toward becoming a common practice throughout an industry unless Factor 3 is first demonstrated. Further, this common practice will only be assured when the last two factors have also been achieved.

We submit, therefore, that the rate of application of computer control systems in any particular industry can be tracked, i.e., a technological forecast can be made by following the progress of the above five factors in regard to a particular technique or a particular piece of equipment developed by the computer and instrumentation industries and by following the rate of its application to the companion industries of the subject industry. This, along with the innovative steps taken by that industry's leaders in following the larger companion industries, will give us the starting point and a measure of the degree of increasing acceptability which it will achieve.

CHAPTER II

A REVIEW OF THE STATUS OF THE FIELD OF INDUSTRIAL COMPUTER CONTROL TODAY

WHAT IS OUR STATUS TODAY?

As one reviews the situation existing today, he can immediately come to several conclusions regarding the state of the art of our technology for computer control. First, let us look at the hardware area:

1. The technology already exists in the form of developmental and experimental units to carry out essentially any capability which we have presently proposed for the field of computer control.
2. In most cases this technology has not yet been reduced to a set of commercially viable and competitive products for the market place. We speak here of such things as complete microcomputer systems (not just microprocessors); serial dataway systems, particularly optical-fiber systems; man/computer interfaces; so-called digital sensors; etc.
3. In many cases, the rate of reduction to practice is being held up by the standardization process, i.e., some agreement must be made as to which of several competing techniques will be that which is finally chosen. I speak here not of formal standardization procedures, such as those of ISA or of ANSI, but a

simple consensus of the vendor and user community alike to pick one or the other from a group of competitive technologies. Of course, formal standardization can solve this problem but it tends to trail rather than to lead the consensus technique for achieving standards.

The unfortunate part of much of this is that the competition in most cases is between techniques or devices of comparable capabilities. Thus almost any decision in each case, even a purely arbitrary one, would probably suffice. The problem is to get that decision made in the first place.

While we have said that sufficient technology exists today on the laboratory bench to do anything we may wish to accomplish, we do have to assure ourselves that our chosen standard does not hamper continuing development and invention unduly. Thus we have to be certain that only that minimum standardization is carried out which is absolutely necessary to achieve our purpose.

A way is open to accomplish exactly this. That is, by standardizing interfaces only. Here we will specify the hardware connection (numbers of pins, pin placement, etc.); the electrical connection (signal level, signal type, etc.); and the information protocol (codes, message length, checking scheme, etc.) All of these, as we have said, can be fairly arbitrary selections from among a wide choice of possible candidates, and most of these would make satisfactory choices,

even if not strictly the best from some specific viewpoint.

Let us then look at the field of programming next.

The programming situation today is still in terrible shape even after all the developmental effort of vendors and users alike over the last twenty years. We have, however, come to some tentative, although still not universally held, tenets, concerning this area:

1. Basic systems programming must be done, if at all possible, in high level, machine and applications independent languages.
2. Such programming should all be done by the systems vendor, but it must be documented in such a way that it is readily interpretable, as necessary, by the knowledgeable user.
3. User programming, on the other hand, should be done in a manner which appears to the user as "the simplest way possible". It should be carried out in a specific applications oriented language or other programming system such as a set of forms or a question and answer system. It must also be as easily interpretable as possible by rather low-level, user company personnel. You will notice that I have specifically used the terms: "which appears to the user as the simplest manner possible". Unfortunately such user simplicity is usually attained only with very great complexity on the part of the developer. Likewise, the final programming system

itself will be very large and very complex.

4. To avoid carrying unnecessary memory overhead in on-line machines, the programming of Item 3 above should be carried out on off-line or "host" computer systems. These may be of the same or a different model than that which is being used on-line. The generally much higher capability of these host systems will permit rather elaborate, interactive, computer-aided, programming systems. All users with a sufficient workload to justify them should take advantage of such systems when they finally appear.

THE MICROPROCESSOR

I need not tell any of you that the microprocessor has taken the whole computer field by storm. It is by far the most popular topic of research, of potential application, of research reporting, and even of mere journalistic speculation in the field today. There is no question, that many wonderful things are going to be done to us, as well as for us, by and in the name of microprocessors in the relatively near future. I'm sure that we won't like all of them.

I particularly fear that we will be, and are, making all the old mistakes over again. We are using prototype systems, which are too slow and have too small a memory, without an adequate programming system, to carry out tasks which are too large, and using too few people to try to accomplish them. Sound familiar? It has happened at least three times before,

with each of the previous three generations of computer systems used for industrial applications.

The biggest question I see facing us is: What type of system will we settle on? How will we use it? We can symbolize this by developing two categories of system for examples. The first is an eight-bit microprocessor based system which comes to the user almost completely preprogrammed for a specific application, a turn-key system albeit a small scale one. The second is what is effectively a very inexpensive mini-computer, a sixteen-bit microprocessor with full programming and peripheral capability. There will, of course, be a wide range of systems in between these two extremes, but they do serve to focus out attention here and to help us to raise the question which needs to be answered.

The preponderance of publicity today is for the former type of system, especially when you consider the many consumer products now under development for the automobile, for home TV games, etc. Even for our field there are many proposals of this type. However, except for the most obviously simple cases, I personally think their use may be a mistake in the long run. It will remove from the user company engineer the ultimate decisions as to the type of control he will apply, how it will interface with other adjacent and related units, and how it will be coordinated for maximum process benefit by his overall plant control scheme, whatever that may be.

Of course, you say that all of this can be accomplished,

if the preprogrammed units have some minimum accessibility; if they use an accepted standard interface technique; and if their speed of operation, etc., is compatible with the overall system. This is true, but to my pessimistic nature probably not directly attainable from a large part of the multitude of vendors who will be offering such devices.

The ideal answer for our purpose here would be a device of the second type listed above which had, as options, a large set of the preprogrammed functions just mentioned as available singly with the Type One system. The device would then become something like the equivalent of one of the new Honeywell TDC 2000 systems with a capability both for a selection of pre-programmed functions and the possibility of user programmed additions. Such a system would have all of the features listed above. But note that even the TDC 2000 does not provide all of this since it is not user programmable in the sense that we mean that facility here.

RELIABILITY AND MAINTENANCE

(I.E., AVAILABILITY)

As an individual, my greatest disappointment with the progress of the digital control field has been that of the history of the reliability of our systems - as designed, as purchased and as installed. In all three areas we have continually made the same mistakes over and over again and we have continued to cause ourselves the same traumas, likewise

over and over again!

The Saturn-Apollo Project of NASA showed what can be done in this area, admittedly at great cost at that time. After having gone through a dismal reliability record in the Vanguard, Mercury, and Gemini Programs, the managers of Saturn-Apollo resolved that reliability would be their prime goal. As a result, everyone of those missions was launched and carried out within a fraction of a second of their schedules which had been published months before. Their recovery from unforeseen mishaps was equally spectacular - witness Apollo 13.

The technology for an equally fine record in our own industry has been available to us but not applied for many reasons. Some of the resulting failures we have already enumerated such as:

1. The use of prototype systems which had not been adequately proven out prior to the installation in question.
2. The use of unreliable components, such as reed relays, germanium circuits, inadequate shielding, and filtering of inputs, etc.
3. Incomplete and unproven programming of systems prior to installation.

In addition to the remedies for the failures just mentioned we have had other capabilities which were available. Such as:

1. Fail-safe systems of various sorts including

redundant computers and other components.

2. The possibility of a full check-out of both hardware and software at the vendors location prior to shipment and installation.

It would seem, as I have implied above, that most of these errors, especially the repeated ones, were preventable, and thus inexcusable. In addition, they have resulted in severe acceptance setbacks for the whole field. They were caused by inexperience, by haste, by poor planning, by chance taking and by improper financing.

Maintenance of a system is necessary, even for the most reliable, since it must fail somehow, some day. Again much work has already been done in this area and the way to achieve easy maintenance of properly designed systems has been adequately demonstrated by many installations. As before, failure in this area, mainly through poor design practices, is inexcusable since it is unnecessary.

To make this area even more amenable, there are many research programs being carried out today looking into the possibility, not only of personnel guided diagnostics of systems failures, but also of self-diagnostic techniques. This is particularly so where redundant systems are available to permit checks on their failed companions. Such techniques, when perfected, promise a whole new outlook on this whole field.

PERSONNEL REQUIREMENTS

It is interesting that all during the past recession we at the University have experienced no decrease in the demand for those of our graduates who had automatic control training and, in particular, had worked on our industrial based projects. At the same time, inquiries concerning our knowledge of other possibly available persons in the automatic control and automation field showed no decrease. My information also indicates that the companies supplying control equipment and computers were hit the least by the recession. All of this reinforces a situation that has been a factor in this field for a long time - there are insufficient, well qualified personnel to go around. Therefore the very great expansions of applications in this area which are predicted for the future can only occur if easier, simpler, and faster means are developed for specifying, developing, programming, installing and implementing these systems. As mentioned earlier, programming seems to offer the major problem area.

There are several obvious programming techniques by which this can be done. Some are very desirable. Some, less so.

1. Standard programming languages, particularly applications oriented ones.
2. Modular programming systems with much of the program such as the I/O, the operating system including interrupt handling, etc., interchangeable between machines.

3. Completely preprogrammed packaged systems for specific processes held proprietary by the vendor.
4. Programming aids such as interactive graphic techniques to simplify the work involved.

Of the above, it is Item 3 which this author feels to be the least desirable, particularly if the resulting program is kept proprietary to the vendor involved. This means that the user cannot learn how his process is operated by the computer, nor can he make any necessary modifications to the system.

CHAPTER III

COMPUTERS FOR ENERGY CONSERVATION APPLICATIONS - A READING ON THEIR GENERAL APPLICABILITY

GENERAL

How then can computers contribute to the energy conservation battle? The answers to this are two. First, by helping create energy efficient designs for our homes, our transportation vehicles and our industrial plants and second, by carrying out a better control of their energy utilization while in operation.

The first method of use can only contribute to new systems which are not yet built or to major modifications of existing ones. For the vast majority of those already built the computer can contribute only through the medium of a more capable and probably more sophisticated control system to insure a high efficiency of energy utilization during the operation of the systems.

Since, as many of you know, my own specialty is the use of computers for industrial plant control, we wish here to discuss that aspect of the second half of the answer just given above.

Studies of energy management systems for industrial plants have shown two major areas for energy savings through the use of advanced control systems including computer control.

Both relate to the efficiency with which the plant utilizes the energy necessary for its operation. These are: (1) the improvement of and maintenance of the efficiency of the energy usage of a particular piece of plant operating equipment such as a boiler or a distillation column, and (2) the coordination of the levels of operation of major plant complexes and especially of adjacent plant units to be certain that a compatible schedule is being maintained, to insure that downstream units respond properly to upsets propagated to them and that upstream units compensate for stoppages, breakdowns, etc., of those following. This latter coordination function then effectively increases the energy utilization efficiency of the group of production units operating as a whole.

To be economically viable, the energy savings control functions must be a part, but only a part, of an overall general economic optimizing control system for the entire plant which insures that the plant satisfies the particular plant optimization criteria picked by management for use at that particular moment in time. The usual choices are made from among these three:

1. Maximum production for the sold out plant.
2. Minimum cost for the plant operating at less than full production, including minimum fuel and/or minimum raw materials.
3. Maximum quality where appropriate.

It is well known that these are often mutually exclusive.

Energy savings must be factored into all three as dictated by fuel costs, fuel availability, conservation desires and governmental requirements.

In general we can expect no miracles or breakthroughs in energy savings due to the automatic control function alone (whether computers are involved or not). These breakthroughs, whatever they might be, must come from changed process designs or new less energy intensive ways to accomplish the same function, i.e., from the first class of computer usage mentioned earlier, that of plant design.

Automatic control of a large modern industrial plant, whether achieved by a computer based system or by conventional means, involves an extensive system for the automatic monitoring of a large number of different variables operating under a very wide range of process dynamics. It requires the development of a large number of quite complex, usually nonlinear, relationships for the translation of the plant variable values into the required control correction commands. Finally, these control corrections must be transmitted to another very large set of widely scattered actuation mechanisms of various types which, because of the nature of the manufacturing processes, may, and often do, involve the direction of the expenditure of very large amounts of energy. Also, plant personnel, both operating and management, must be kept aware of the current status of the plant and of each of its processes.

In addition, such an industrial plant is faced with the continual problem of adjusting its production schedule to match its customer's needs, as expressed by the new order stream being received, while maintaining a high plant productivity and the lowest practical production costs. This is handled in most cases at present through a manual, although computer aided, production control system along with an in-process and finished goods inventory judged adequate by plant personnel.

It has also been repeatedly shown that one of the major benefits of the use of digital computer control systems in industrial plants has been in the role of a "control systems enforcer". In this mode, the computer's main task is to continually assure that the control system equipment is actually carrying out the job that it was designed to do in keeping the units of the plant production system operating at some optimal level. That is, to be sure that the controllers have not been set on manual, that the optimal set points are being maintained, etc.

Often the tasks carried out by these control systems have been ones which a skilled and attentive operator could have readily done himself. The difference is the degree of attentiveness which can be achieved over the long run.

As stated earlier, all of this must be factored into the design and operation of the control system which will operate our plant, including the requirements for maximum energy

savings. As the overall requirements, both energy and productivity based, become more complex, more and more sophisticated and capable control systems are necessary. To achieve these the field will gravitate more and more toward digital computer based systems to carry out the needed work.

In order therefore to obtain the kind of control responses just mentioned above we need an overall system with the following capabilities:

1. A tight control of each operating unit of the plant to assure that it is operating at its maximum efficiency of energy utilization and/or of production capability based upon the production level set by the scheduling and coordination functions listed below. This control reacts directly to any emergencies which may occur in its own unit.
2. A coordination system which determines and sets the production level of all units working together between inventory locations. This system assures that no unit is exceeding the general area level and thus using excess energy or raw materials. This system responds to the existence of emergencies or upsets in any of the units under its control to shut down or systematically reduce the output in these and related units.
3. A system capable of carrying out the scheduling function for the plant from customer orders or

management decision so as to produce the required products for these orders at the optimum combination of time, energy, and raw materials suitable expressed as cost functions.

Because of the ever widening scope of authority of each of these requirements in turn, they effectively become the distinct and separate levels of a superimposed control structure, one on top of the other. Also in view of the amount of information which must be passed back and forth among the above three "levels" of control, it appears obvious that some sort of distributed computational capability organized in a hierarchical fashion will be necessary. It is this organization which will be the further theme of this report.

THE CONTRIBUTION OF COMPUTER CONTROL TO INDUSTRIAL ENERGY SAVINGS

What can we possibly expect from the automation or control function (here obviously computer control in the context of this audience) in terms of its contribution to the solution of the energy problems of our nation?

It has been fairly well established that the energy usage of the United States is today about 75×10^{15} BTU's per year. This is a number which is hard to visualize until one equates it to the 3.2 billion tons of coal or the 10 billion barrels of oil needed to produce it.

Industry uses 25% of the above total, or the equivalent

of 800 million tons of coal or somewhat more than three billion barrels of oil. Thus even a small savings in industry's needs can be a major savings of these precious fuels.

We have now had extensive experience in the application of computer based control systems in a variety of industries and have made a detailed economic analysis of the savings which have been possible from many of them. The vast majority of those reported were evaluated prior to the start of the energy crisis of 1974 so their results are expressed in other terms than energy savings. A consensus of these capabilities over those possible with conventional (i.e., non computer based) control systems has shown an average economic gain in the neighborhood of 5-6%, for the first type of control application mentioned earlier, i.e., improving the efficiency of the individual processing unit. Although much less information is available at present, it appears that the coordination function can contribute an equal savings.

As was stated earlier, plant optimization criteria may be of three types: maximum production, minimum cost (fuel, raw material, etc.) or maximum quality, which are usually not mutually compatible. If the energy savings criteria can be used this would give the possibility of saving up to about 12% of the industry use or about 3% of the total U.S. energy requirement. This translates to about 90 million barrels per year if expressed as oil or an equivalent amount of coal.

Of course, all of this is not available for fuel savings.

First, an optimization criteria calling for maximum production will save little or no fuel and may even increase it. Likewise many computer systems are already installed to carry out unit control and optimization. Thus, some of that savings has already been realized.

Therefore we are probably reduced to gains in the neighborhood of one-third of the maximum potential, or of about 30 million barrels of oil per year, which might be assigned as the fuel saving potential for the installation of digital computer based hierarchy control systems for industrial plants in the United States.

Again we must caution that all of these control systems will not be installed since they may not be economically viable for many small plants or those which are very old. Even so, the potential is still a very large number and worthy of much further study.

CHAPTER IV

HIERARCHICAL COMPUTER CONTROL SYSTEMS - A MEETING PLACE OF THEORY AND PRACTICE

TYPES OF HIERARCHICAL ORGANIZATIONS

There has been much discussion in the literature of the systems engineering field concerning the physical organization of a hierarchical computer control system and the distribution of the required functions between the levels of the hierarchy itself and among the several computers which might inhabit a particular level. The major point of contention in these discussions has been that of a functional versus a geographical organization for the overall system.

The functional approach puts those functions which tend to be simple and those on a short time schedule at the lowest level nearest the process. Successively more complex and more detailed computations are in successively higher level computers which presumably are larger and faster and therefore more capable of handling the larger number of computations involved. This analysis is fine as long as the following conditions hold:

1. Simple computations are synonymous with fast time scales and complex computations with a more leisurely schedule.
2. There is a shortage of computational ability at the lowest levels of the system, i.e., small or inex-

pensive machines are of low capability.

3. A large amount of plant data is not needed for the complex calculations at the upper levels of the hierarchy. Otherwise the communications system must be very capable to assure that no overloads occur.

As mentioned earlier, the recent advent of very capable and inexpensive microcomputer systems has freed us from the restrictions of Item 2 above.

The second type of organization is based upon the geography of the plant. It is further based upon a translation over into computer hierarchy terms of the physical structure of the plant itself and the associated human operational structure which would have been necessary without the computer system. The following two propositions explain this concept further:

The first proposition to be used here is that the human organizations responsible for the operation of a particular facility, without the aid of automatic controls, will evolve gradually to the best hierarchical arrangement for the control of that operation if they are politically free to do so. We must be careful when considering plants which already have a significant amount of automatic control installed since this will tend to bias that organization to include the available automation capabilities.

We submit further that the hierarchical organization

evolved by this "free" human organization will be the correct one for the computer hierarchy we are considering here especially now that the microprocessor has released us from any computational restrictions on the form of these organizations.

As a second and further proposition, we would state that the physical layout of our plants has also evolved in a natural manner based upon the laws of economics and the operating principles of the operations involved. The distribution thus achieved tends to group the final control elements, valves, solenoids, switches, etc., into well recognized clusters throughout the plant, each cluster related to a particular mechanical, chemical, or other operation carried out upon the material being processed in the plant to produce its final product.

It must be noted here that these two propositions represent a significant retreat from the beliefs of those engaged in systems engineering studies in the early and mid 1960s. Then it was very commonly believed that the use of systems engineering principles and large computers would result in major changes in plant designs and management structures. This would be accomplished mainly through the tightening up of plant designs and the elimination of plant inventories and excessive layers of management structure. Time has shown that the risks of plant shutdowns and loss of production from process equipment or control system failure has simply been

too great to take advantage of what these systems engineering principles could have accomplished.

Let us first discuss the organization of a functional hierarchy. This method of analysis is due principally to Mesarovic and his associates (13-15, 20-23).

SYSTEMS CONTROL AND A MULTILAYER COMPUTATIONAL STRUCTURE

The multilayer control concept provides a convenient basis upon which to formulate a functional systems control approach to computer based control systems. First, we classify the variables associated with the controlled plant into three groups as follows:

- 1) disturbance inputs - these are inputs, independent of the control, that cause the system to deviate from its desired or predicted behavior and hence initiate a control action. In general, these disturbances represent the interactions of the plant with other plant units and with the environment, e.g., changes in composition of feed streams, changes in ambient temperatures, changes in throughput rates, etc. We also recognize a special class of disturbances called contingency occurrences. These refer to events that occur essentially at discrete points in time, e.g., a pump has failed, a feed supply tank has gone empty, a catalyst regeneration cycle is to be initiated. Often, a contingency

event signals that the system is no longer operating according to the assumptions implied by the current control model and that, as a result, it is necessary to modify the structure of the system, go into a new control mode or develop some other non-normal response. These are designated by the letter z in Figures 1-5.

- 2) controlled inputs - (also referred to as manipulated or decision variables) these are the results of the decision-making process carried out by the computer/controller. They are determined so as to compensate for the effects of disturbances by either directly or indirectly modifying the relationships among the plant variables, e.g., by changing the energy or material balance in the system. The compensation may be based on (a) measurement of the disturbance and prediction of its ultimate effect on the plant (feedforward action) or (b) measurement of the effect of the disturbance on the plant outputs directly (feedback action), or more generally, (c) a combination of both. These are designated by the symbol, m, in the first five figures.
- 3) outputs - these are variables of the plant which (a) are functionally dependent on the designated input variables, and (b) are relevant with respect to the performance measure on which control of the

(text continues on page

plant is based. These are symbolized by the letter y. The basic system is shown in Figure 1.

The multilayer structure of Figure 2 provides one possible procedure for resolving the control problem described above. In effect, the overall problem is replaced by a set of subproblems which are more amenable to resolution than the original problem.

The following explanatory remarks are in order:

1. The first-layer (direct control) function plays the role of implementing the decisions of the second-layer (optimizing). There are two useful consequences of this structure; (a) various disturbance inputs may be suppressed with respect to the second-layer problem, e.g., by specifying reactor temperature as the decision variable rather than, say, heat input rate, we remove the need for explicit consideration (in the optimization) of the many disturbance variables that may affect the thermal equilibrium and heat transfer relationships of the plant; and (b) the dynamic aspects of the control problem may be effectively "absorbed" at the first layer so that static models may be used at the higher layers to good approximation.
2. The dynamic and detailed plant model previously necessary is replaced by an approximate model. Note that this model characterizes the input-output

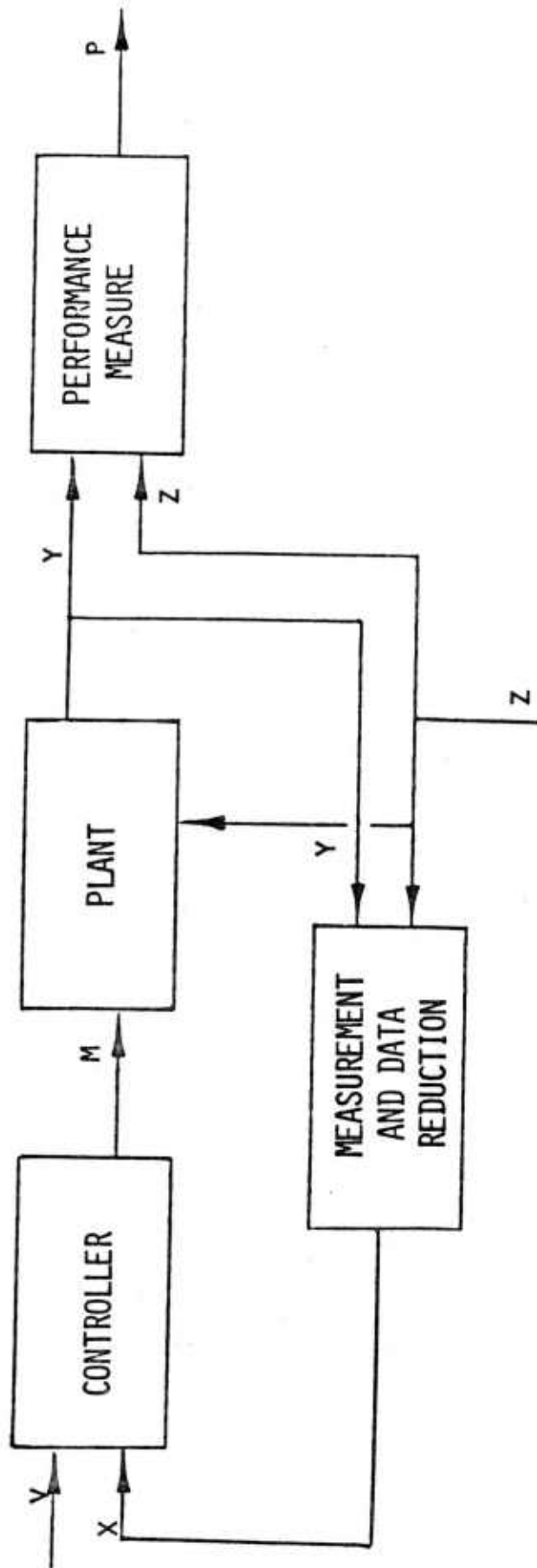


FIGURE 1
BLOCK DIAGRAM OF A BASIC CONTROL SYSTEM

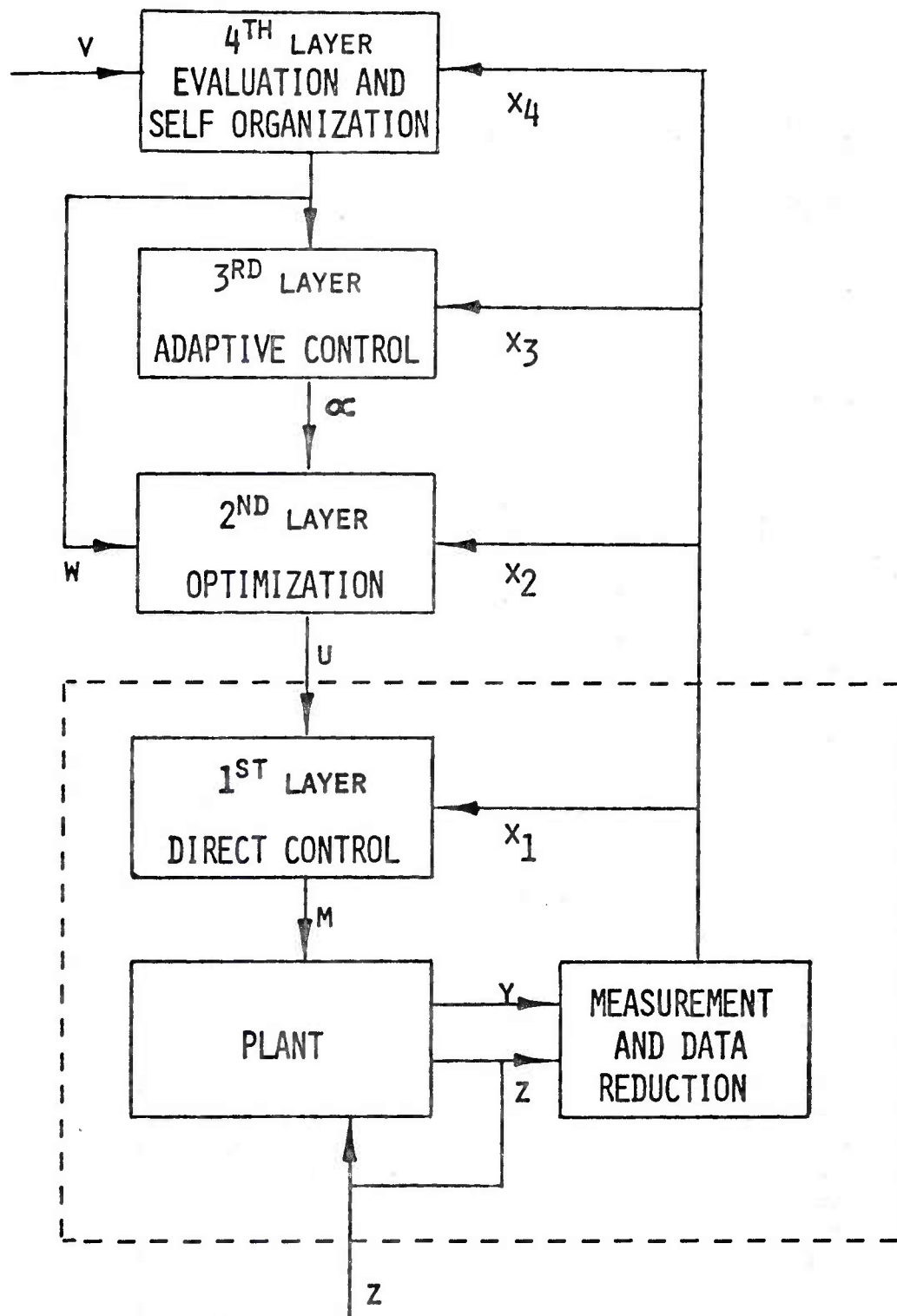


FIGURE 2
FUNCTIONAL MULTILAYER HIERARCHY-BLOCK DIAGRAM

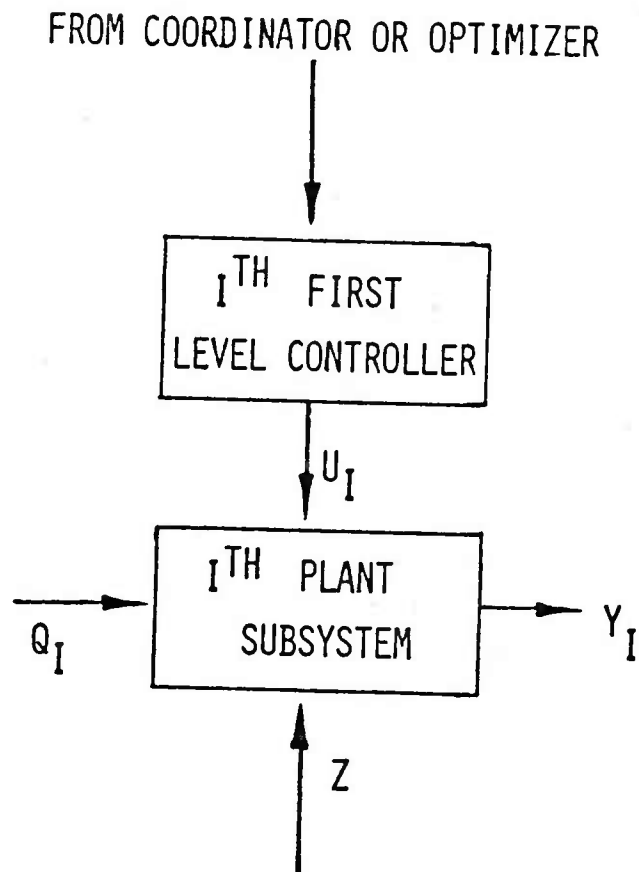


FIGURE 3
SUBSYSTEM OF MULTILEVEL DECOMPOSITION
OF THE HIERARCHY SYSTEM

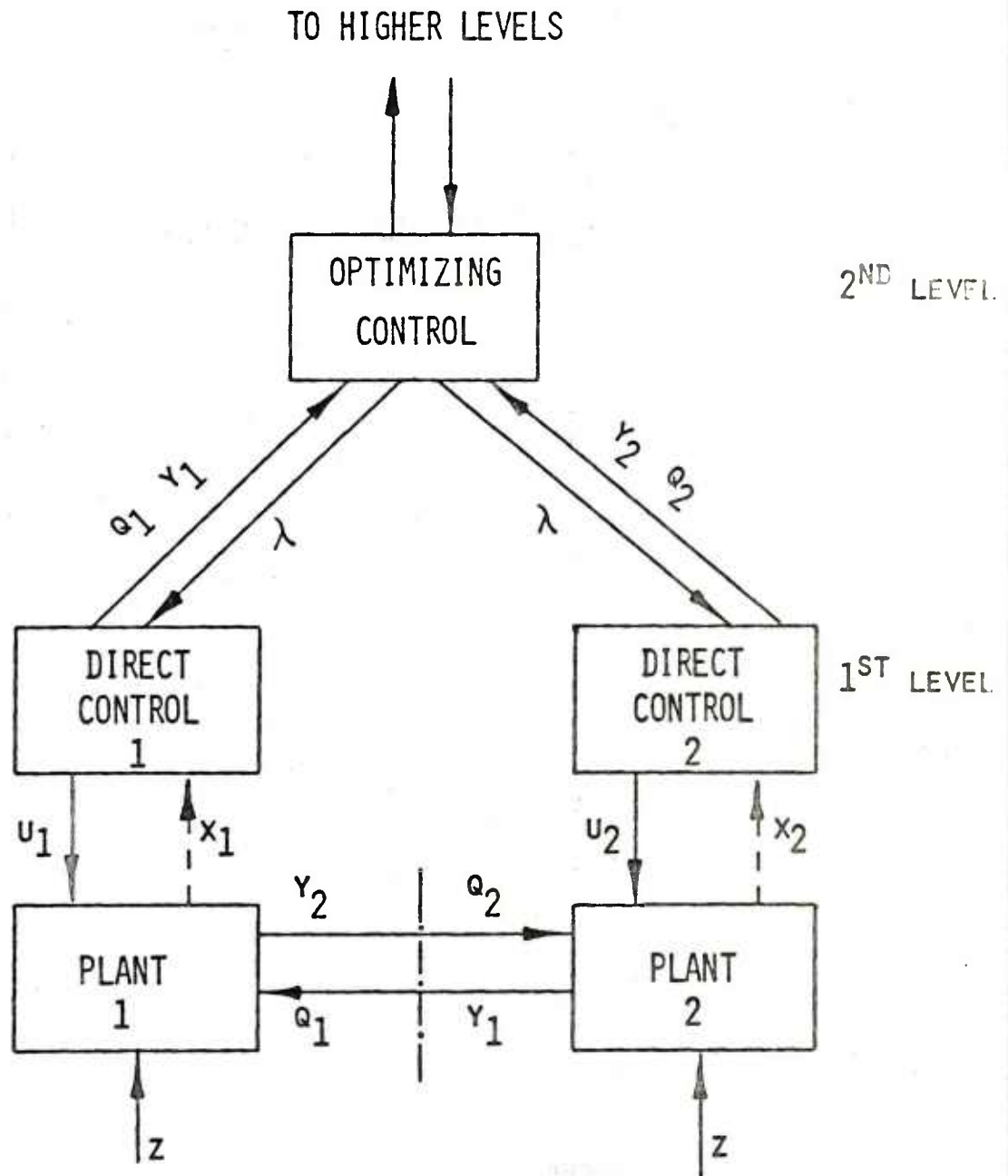


FIGURE 4
TWO LEVEL STRUCTURE ILLUSTRATING MODEL COORDINATION

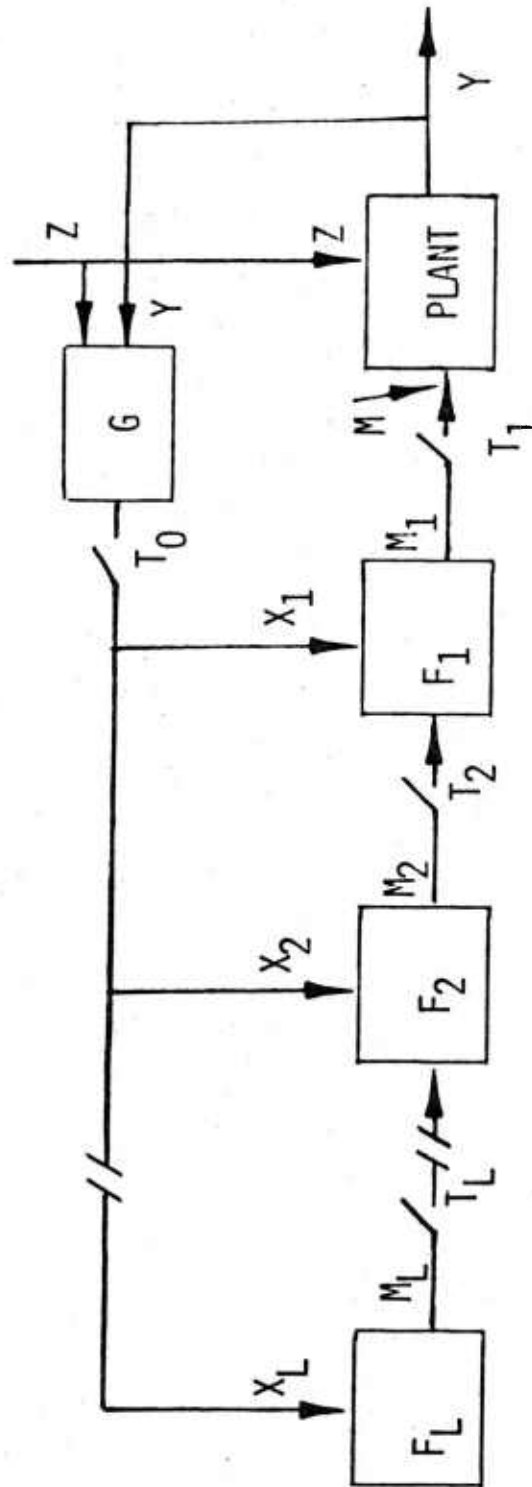


FIGURE 5

TEMPORAL MULTILAYER HIERARCHY

functional model of the combined system consisting of the plant, its direct controllers and its measuring elements as seen by the second layer (represented by the dotted block in Figure 2).

3. The model often includes, besides those constraints necessary to ensure a safe, feasible operation of the physical system, various other artificial constraints whose primary function is to maintain the physical credibility of the simplified model. An example of this is the placing of bounds on the temperature and rate of change of temperature of a furnace to ensure that deterioration of the refractory wall will be negligibly affected by the operating conditions to the extent that these factors can be ignored by the model.
4. The third-layer (adaptive) function provides for an updating of the parameters of the model in order to reflect current experience with the operating system. This means that we can eliminate from the problem formulation those factors which are not of primary significance, those which tend to vary slowly or those which tend to change infrequently (e.g., catalyst activity, fouling of a heat transfer surface, seasonal variations in cooling water temperature), since these factors (disturbances) may be compensated for through the adaptive function.

5. The external (economic) factors are now inputted to a fourth-layer (evaluation and self-organization) function and are transmitted to the second-layer model via the transmitted information, w. Changes in these factors may influence the weighting of terms in the lower models or some of the bounds used. More generally, the evaluation of plant performance may lead to modifications in the structure of the control system, e.g., in the definition of the constraints. Finally, we note that contingency events may also lead to changes in the system relationships or the objective functions, e.g., the shift from normal operation of a catalytic reactor to a catalyst regeneration cycle.
6. From the standpoint of plant performance, it is immaterial how the transformations from input information to output decisions/actions are carried out (i.e., whether by algebraic solution of a set of equations, hill climbing on a fast-time simulation, or simply through a table lookup operation) except as the method might affect the accuracy, the cost or the speed with which the controller outputs its results. By the same token, the control functions may be performed by man, by machine (computer) or by a combination of both.
7. Although, the multilayer hierarchy described here was

motivated by considerations of continuous process systems, the underlying principles apply equally well to control of batch processes, semicontinuous processes, etc. (21).

A case in point is the example of a batch reactor. The second layer function determines the optimal path of, say, reactor temperature (as the control input) and reactor composition (as the state vector) versus time such that the product yield of the reactor is maximized. The paths or trajectories may be computed prior to the start of each new batch, with inputs based on measured feed composition, estimated catalyst activity, etc. The first layer has the problem of implementation. There are a variety of disturbances that cause the actual trajectories to deviate from the computed optimal (reference) paths (e.g., changes in catalyst activity from that predicted, errors in the model used, etc.). One form which the first layer control may take (to compensate for the disturbances) in accordance with common control theory is to minimize a weighted mean square deviation of the actual trajectories from the reference values, applying the usual optimal control techniques of a linear model, quadratic criterion, etc. It is clear, in this application, that the third layer adaptive function may update the parameters of the (nonlinear) second layer model, as

well as perhaps the weighting coefficient of the quadratic criterion used at the first layer (assuming the coefficients for the linearized model are evaluated at the second layer along with the reference trajectories). The fourth layer functions will be concerned with a further modification of the control systems based upon its inputs. Some examples of application of the multilayer concept to systems involving discrete event decision processes (e.g., scheduling, contingency control) have also been described. (21).

8. There are a large variety of ancillary tasks which are normally carried out in conjunction with the control functions identified in the multilayer hierarchy. These might be looked upon as "enabling" functions that are deemed necessary or useful to the pursuit of the overall system goals. Indeed, the provision for such tasks is often a very significant factor in determining the hardware and software requirements in computer control applications. Among such ancillary functions we include (a) data gathering (filtering, smoothing, reduction), (b) record keeping (for plant operator, production control, management information, accounting, etc.), (c) inventory maintenance (e.g., keeping track of goods in process), (d) sequencing of operations (e.g.,

startup/shutdown operations). The essential feature of these functions is that they are routine, repetitive and open-loop, hence can be handled by stored programs and fixed hardware. Considerations of decision-making and control may come into the picture at the higher layers, however, with respect to modifying the procedures, operating sequences, etc., based on an evaluation of system performance or in response to contingency occurrences.

In the multilevel hierarchy, the subsystem problems are solved at the first level. These solutions have no meaning however, unless the constraints imposed by interactions between adjacent units are simultaneously satisfied. This is the coordination problem that is solved at the second level of the hierarchy as part of its optimization function.

There are a number of decomposition/coordination procedures that have been developed. Since there exists an extensive literature on the subject, (17, 22, 23, 29) we will not go into any detailed discussion here, but will only outline some of the basic ideas underlying the most common methods.

Some multilevel schemes for on-line application make use of feedback in their implementation. These schemes in effect incorporate parts of the physical plant into the models used in determining the local optima. This leads to simplifications in the mathematical model and, more important, reduced

sensitivity to model inaccuracies and to the effects of miscellaneous disturbances not included in the model (15).

In essence, the coordination schemes described above serve the purpose of initiating a set of iterative procedures for the solution of the mathematical problem of the optimization of an objective function subject to constraints.

Thus, the entire multilevel structure is internal to the computational block generating the optimum control. However, in the on-line application, the computation depends on the current values of z and these change with time. Thus, much of the advantage of decomposition may be lost if the iterative process of coordination has to be repeated with every change in the values of the disturbances.

If the system is divided in such a way that the interaction is at a minimum and if the coordination scheme is selected so that intermediate results are always plant feasible, then the multilevel structure provides the basis for a decentralized control wherein: (1) the first-level controllers compensate for local effects of the disturbances, e.g., maintain local performance close to the optimum while ensuring that local constraints are not violated; and, (2) the second-level controller compensates for the mean effect of changes in the interaction variables on overall performance. The desired result is a significant reduction in the cost of achieving control through reductions in the required frequency of second-level action and in data transmission requirements.

The minimum interaction occurs when the plant units selected are those usually designated as "unit operations" in the tradition of classical plant design. The interaction may be further weakened by such design factors as: (1) use of buffer storages between units, e.g., feed tanks and surge chambers; (2) decoupling control of key interaction variables, e.g., temperature control of feed stream; and, (3) output control of preceding unit, e.g., control of a distillation column which provides the feed to a subsequent unit. We remark that the measures taken to decouple the subsystems are not without cost (both capital and operating) and that there are economic tradeoffs to be exploited via the multilevel hierarchy, e.g., increasing the degrees of freedom by relaxing the coupling constraints - at the expense of more frequent coordination at the second level.

We make two final remarks: (1) the multilevel structure extends in an obvious fashion to a hierarchy of three or more levels with each upper level unit coordinating the actions of a group of lower level units according to the same principles as described above; and (2) there is a strong compatibility between the hierarchical control approach and the use of mini- and micro-computers in a coordinated system plant control.

TEMPORAL MULTILAYER HIERARCHY

In this formulation of the hierarchy, the layers are distinguished in terms of the relative frequency of control

action or decision-making. Three factors motivate this structure; (1) the basic response time or horizon for the underlying decision process; (2) the frequency characteristics of the disturbances instigating control action; and (3) a cost/benefit trade-off between the cost of carrying out a control action versus the performance degradation of the plant resulting from not exercising control (13).

The structure of the system is shown in Figure 5. The block G represents a measurement and data processing unit which transforms the raw input and output data into the needed information for the required control computations. There are several general features to be noted about the structure of Figure 5.

1. The controls are coupled. Thus the action at the i -th layer depends on the prior decision at the $(i+1)$ th layer. There is also interaction in the other direction. However, it is assumed that the coupling is so weak that the i -th layer decision-making may proceed on the basis of averaged properties of the lower layer actions (as communicated via x_i).
2. The decision-making horizon or time scale tends to increase progressively as we proceed up the hierarchy (i.e., toward the left). Thus, the structure accommodates very naturally the range of decision-making functions which are typical of production

systems, e.g., process control, operations control, daily schedule, weekly schedule, monthly plan, yearly plan, long range plan, etc.

3. The control functions of the multilevel and multilayer hierarchies previously described may also be encompassed by the temporal hierarchy in the sense that these functions are characteristically ordered with respect to time scale, frequency of action, degree of aggregation, and related attributes.
4. As we go from the i -th to the $(i+1)$ th layer, the model tends to get less detailed and more based upon the combined properties of the system. Thus, in general, the set of values, x_i , will consist of statistical parameters (mean, variance values) associated with elements of x_{i-1} averaged over the period T_{i-1} . By example, optimizing control of a reactor will be based on a technological model; production scheduling will be based on perhaps a regression model which relates mean product output of the reactor (under the assumed optimizing control) to predicted mean input conditions.

THE PHYSICAL STRUCTURE APPROACH TO THE HIERARCHY

Using the geographical approach mentioned above, Figure 6 lays out the physical structure for a six level hierarchy. Such a six level structure has been found necessary in the

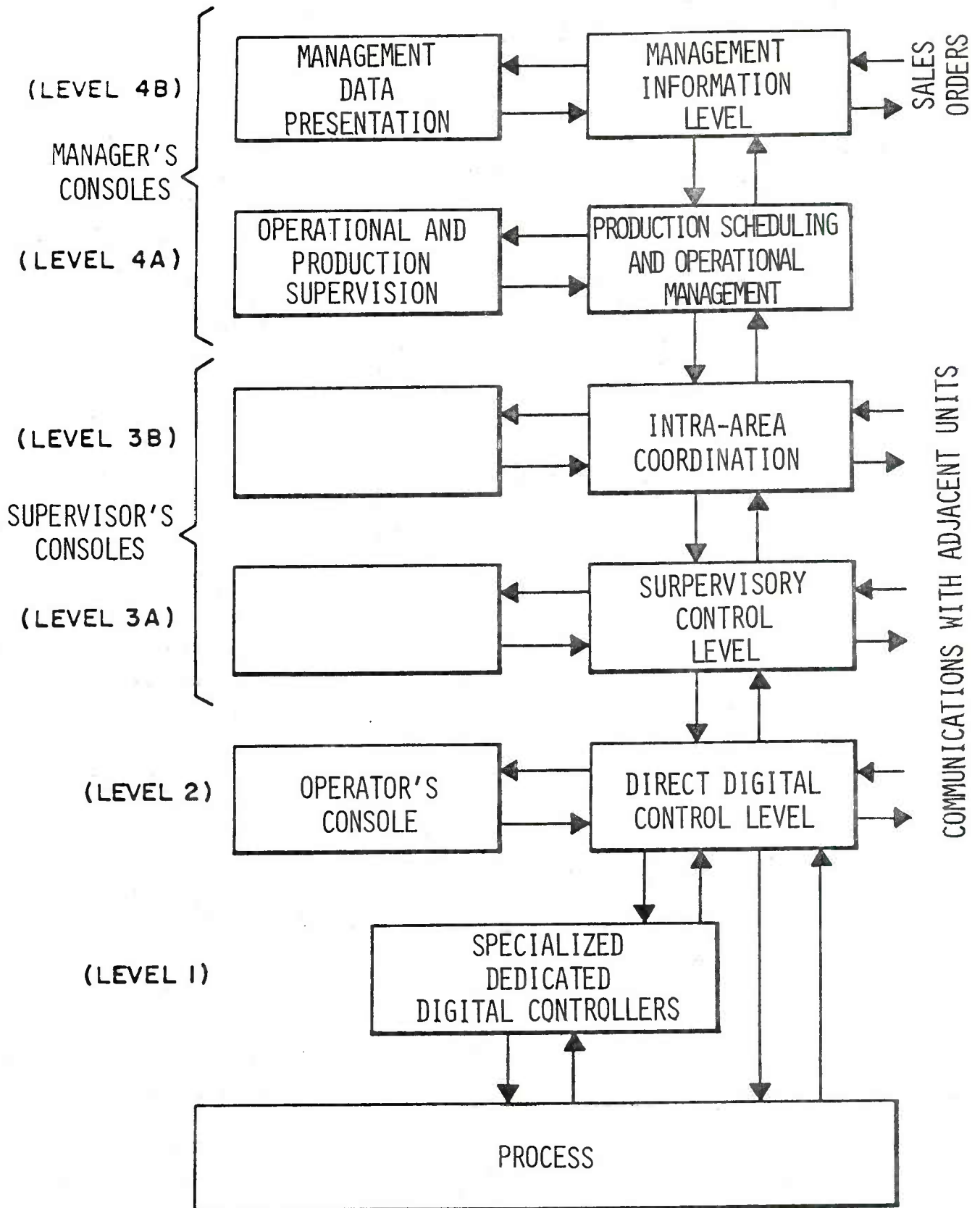


FIGURE 6
ASSUMED PHYSICAL HIERARCHY COMPUTER SYSTEM STRUCTURE
FOR A LARGE MANUFACTURING COMPLEX

work carried out at Purdue University on an overall hierarchy control system for a large steel mill (20, 32) in order to accommodate all of the tasks which such a system must carry out.

The dedicated digital controllers at this lowest level (Level 1) require no human intervention since their functional tasks are completely fixed by systems design and cannot be altered by operator action. The numbering system used here is a holdover from an original assumption of a four level hierarchy which proved inadequate.

It should be noted that these are operational levels and do not necessarily represent separate and distinct computer or hardware levels. In large systems this will be so but for small systems two or more of these operational levels might be collapsed into one computer level. The same statement applies to the functional level concept as well.

As we stated at the beginning of this paper, the physical hierarchy is proposed on the basis of a natural one to one relationship between the computer hierarchy and the management structure of the plant. Figure 7 and 8 show this relationship by comparison with Figure 6. Figure 9 presents typical time constants for the functions involved at each level (11).

Figures 10-14 show one arrangement by which this hierarchy might be implemented. Figure 15 shows the correspondence of the computing elements to the example strip steel

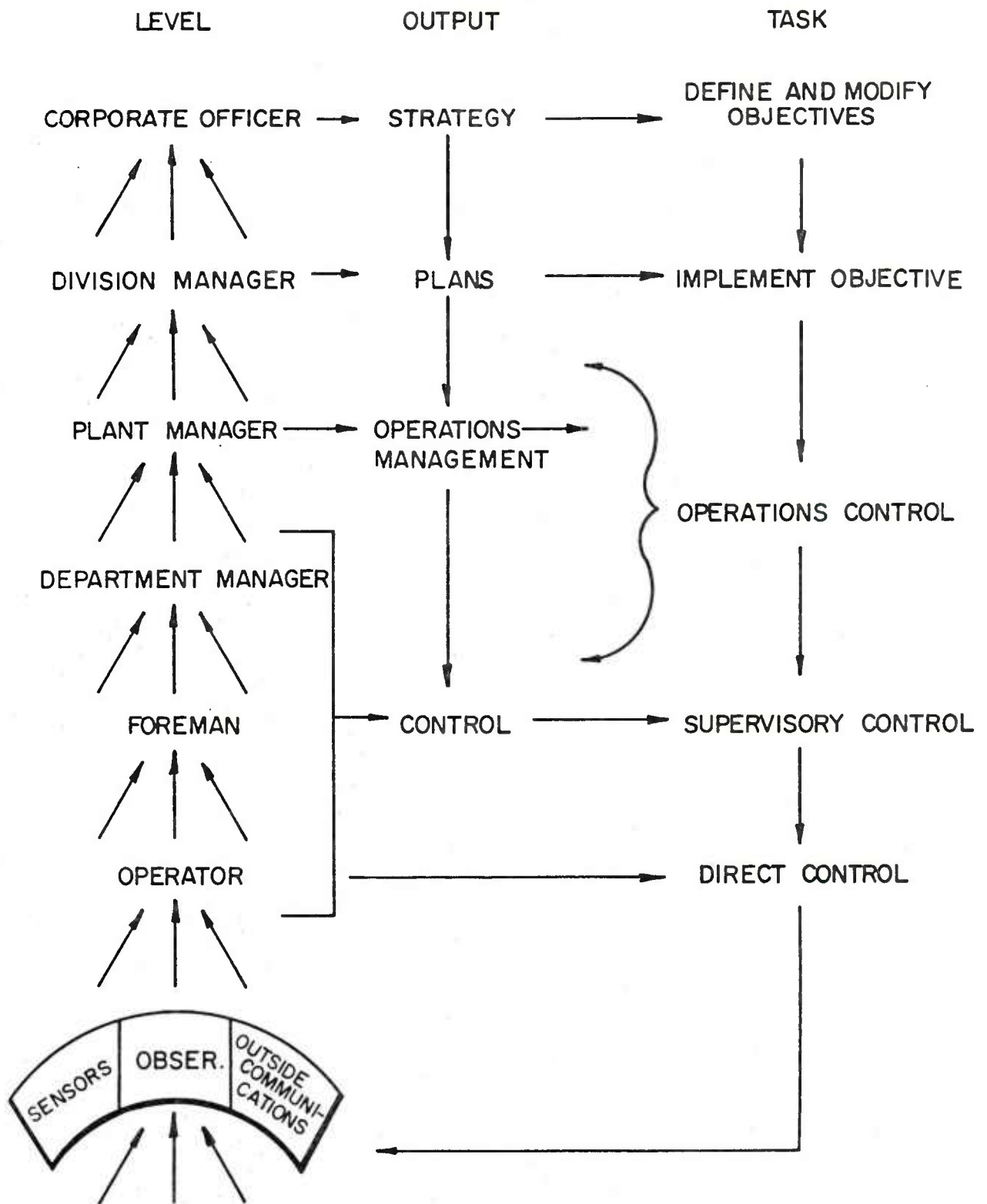


FIGURE 7
PERSONNEL TASK HIERARCHY IN A LARGE
MANUFACTURING PLANT

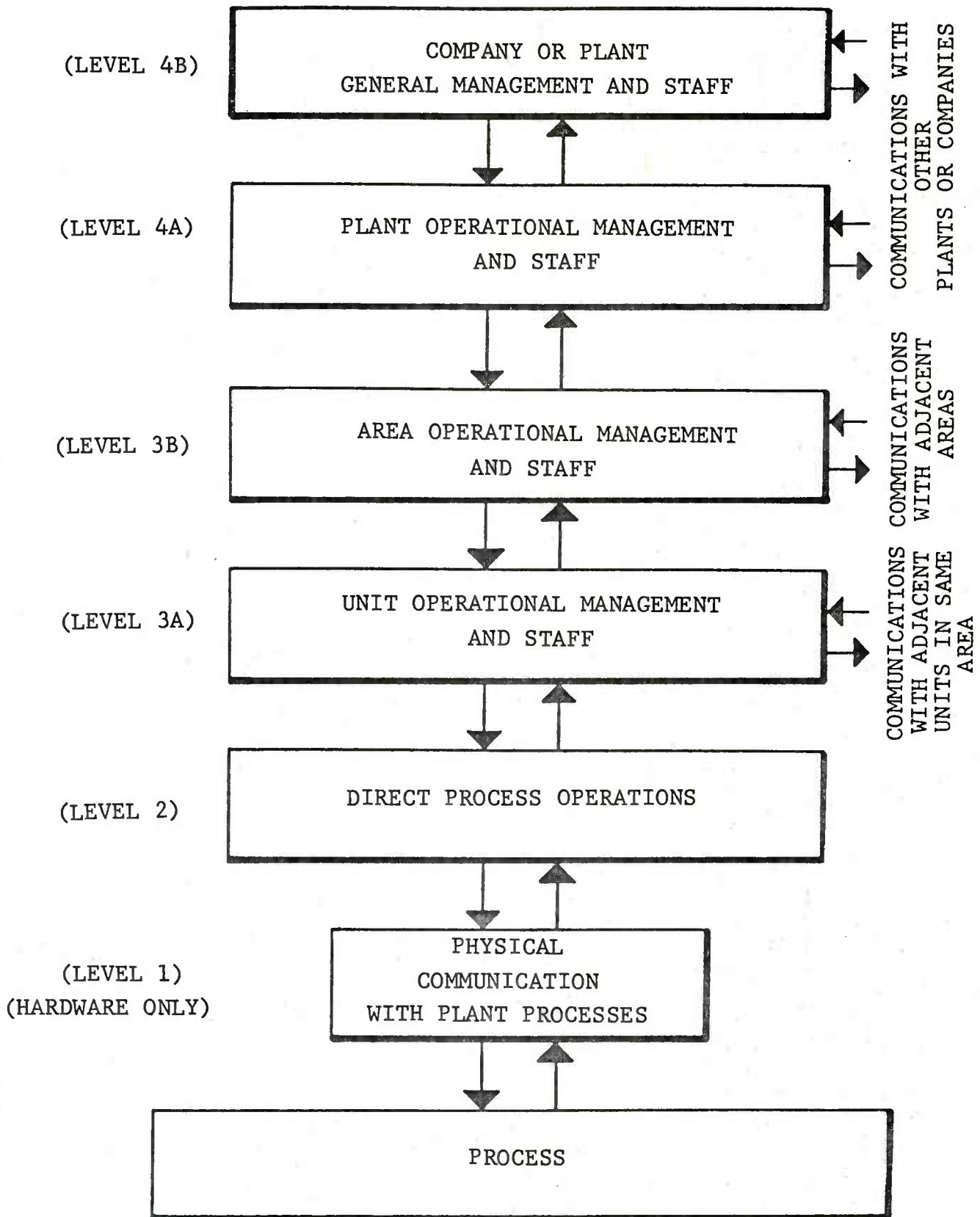


FIGURE 8
PLANT OPERATIONAL MANAGEMENT HIERARCHY STRUCTURE
TO MATCH THE COMPUTER HIFRARCHY OF FIGURE 6

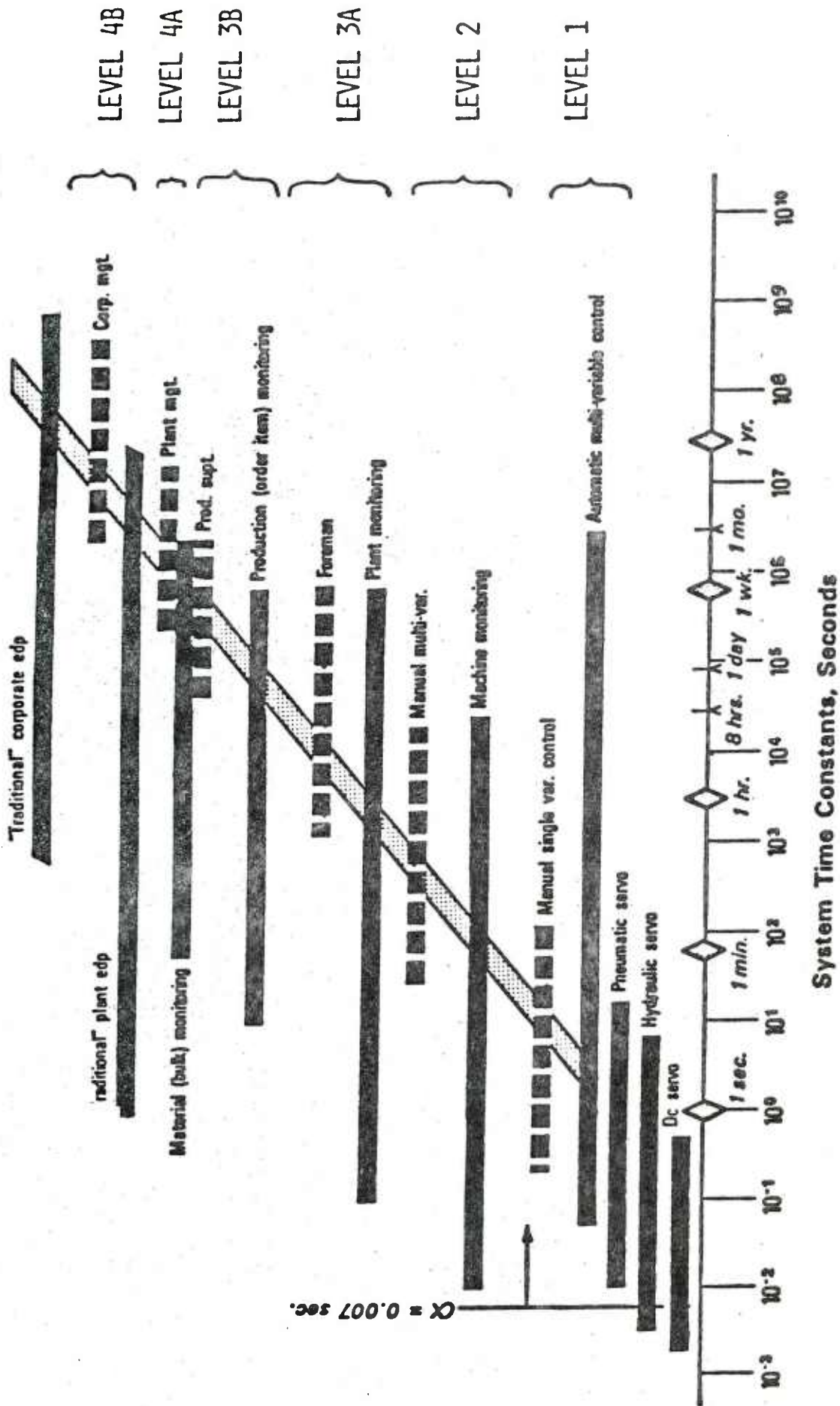


FIGURE 9
THE DYNAMICS OF HUMAN & MACHINE ORGANIZATIONS
IN MANUFACTURING PLANNING & CONTROL

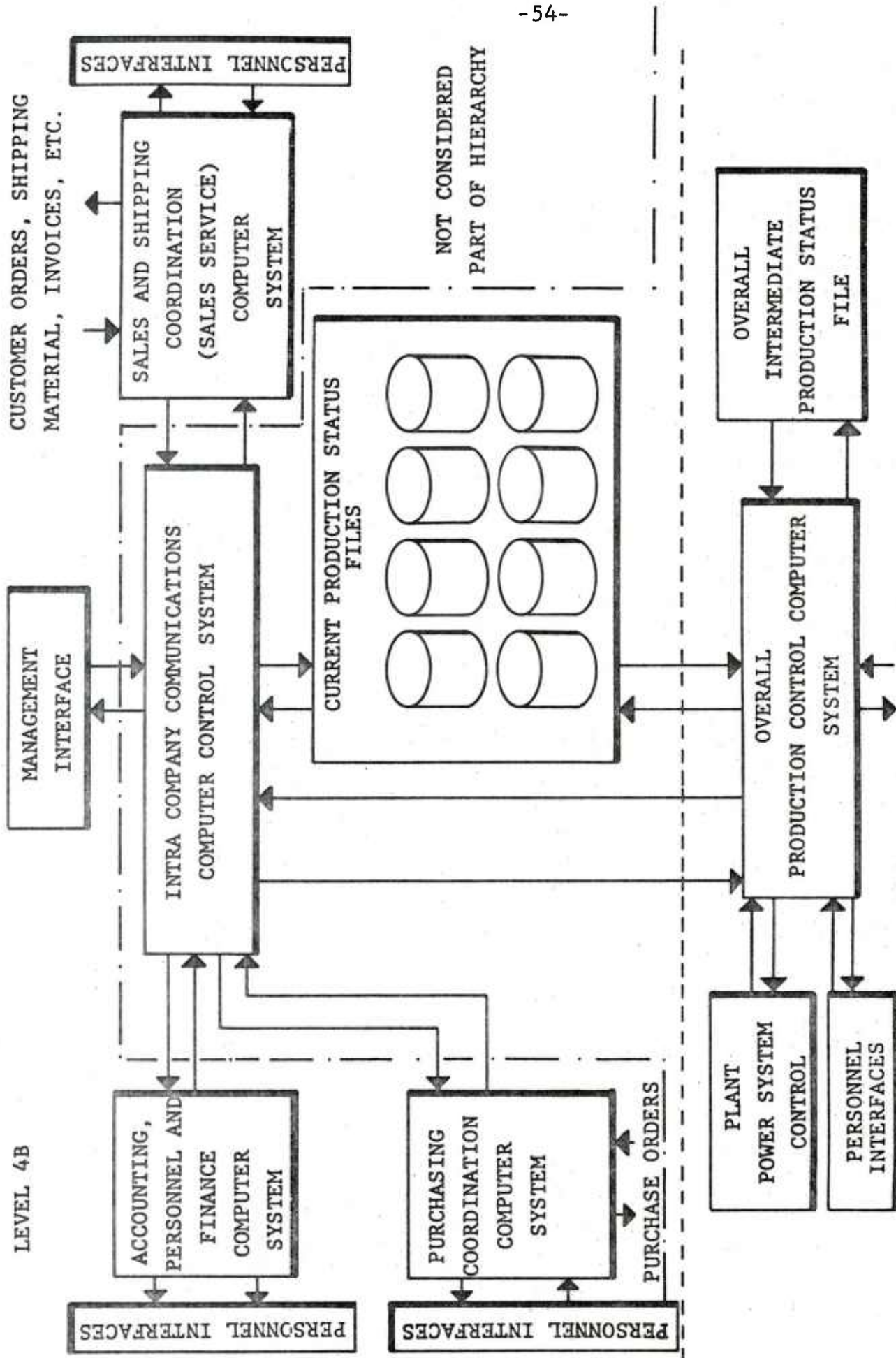


FIGURE 10

OVERALL PLANT PRODUCTION CONTROL SYSTEM

LEVEL 4A

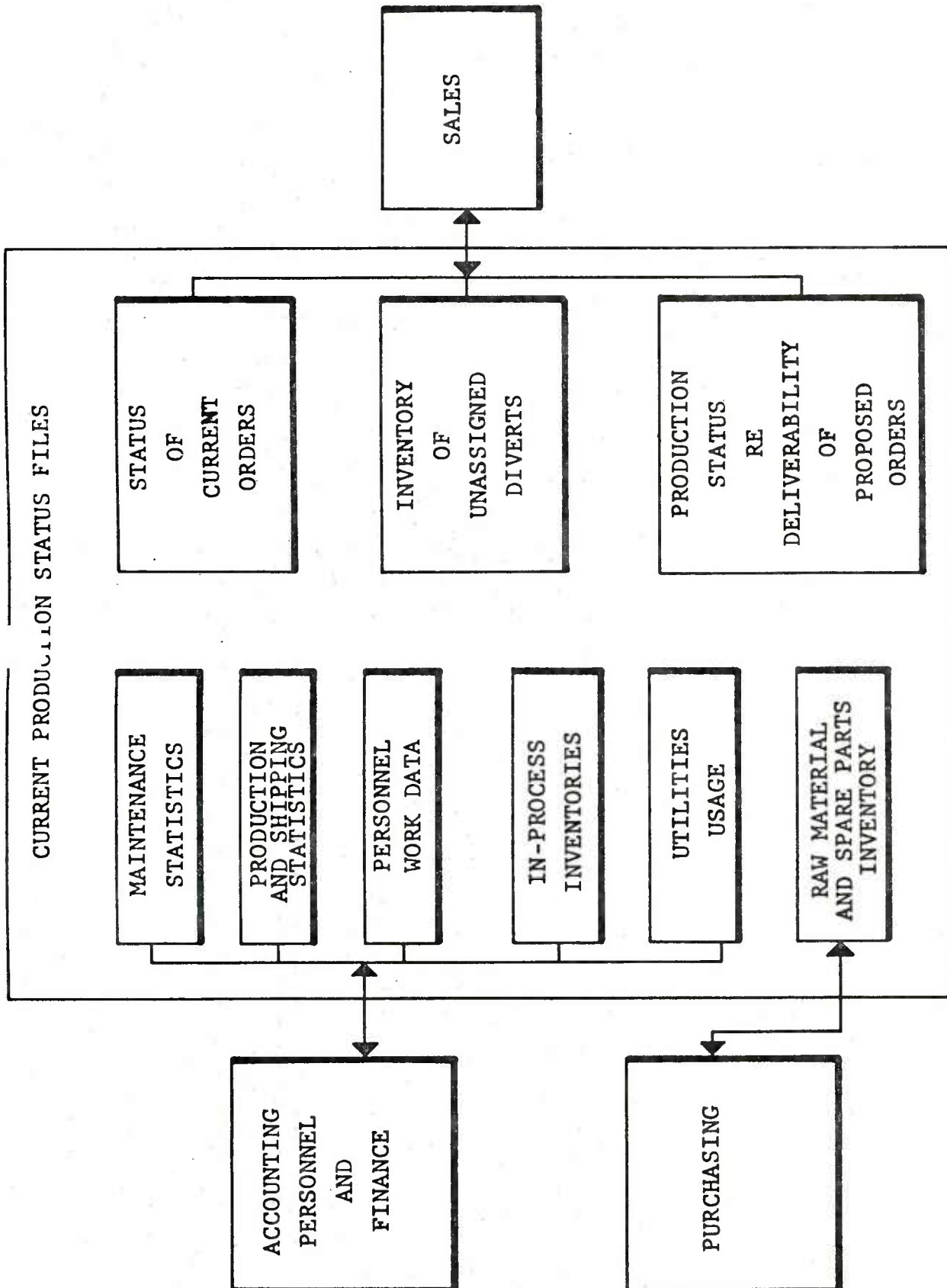


FIGURE 11
NON-OPERATIONAL CONTACT WITH HIERARCHY
COMPUTER CONTROL SYSTEM (LEVEL 4B)

INTRA-COMPANY COMMUNICATIONS

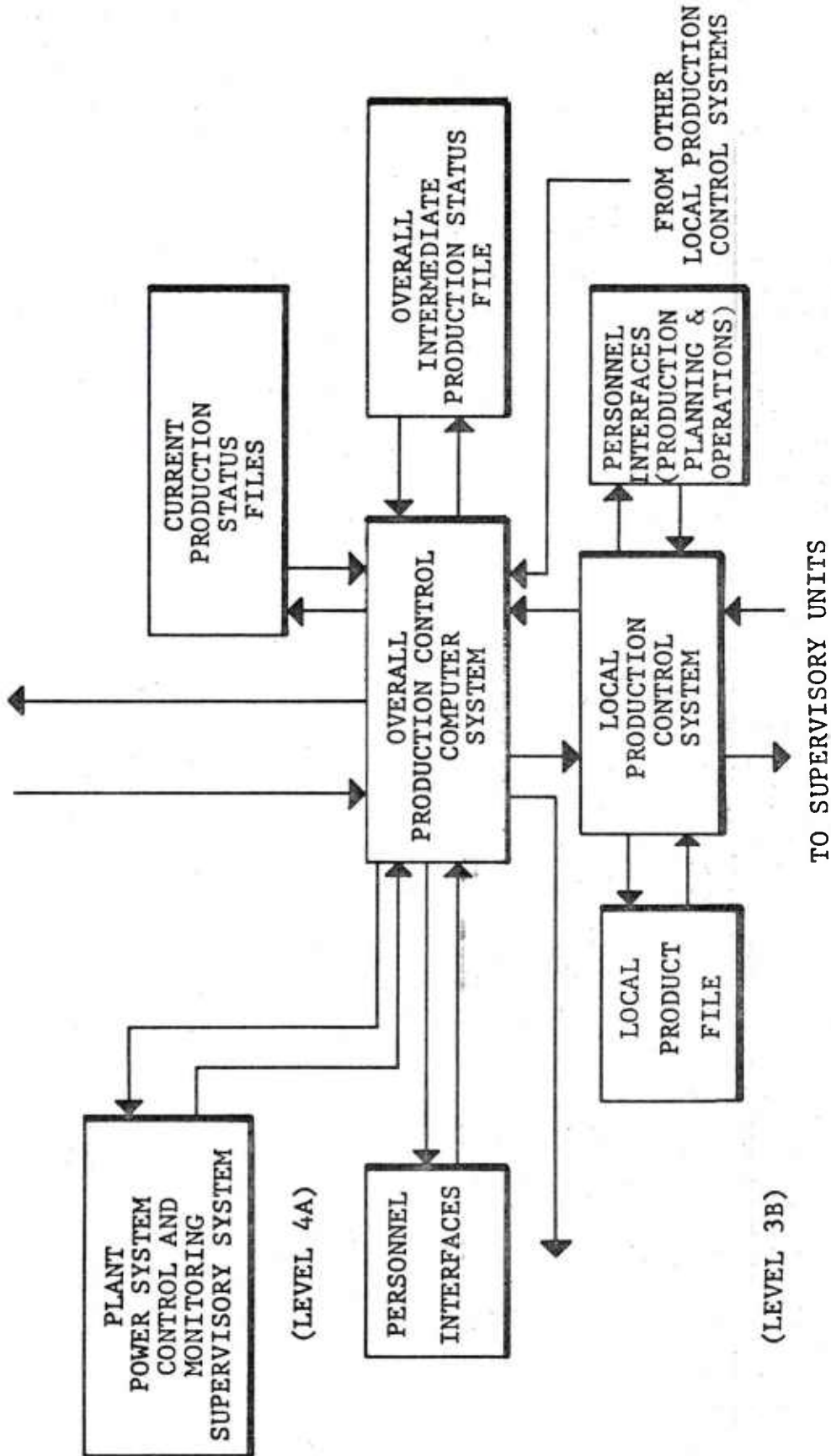


FIGURE 12
RELATIONSHIP OF OVERALL PRODUCTION CONTROL AND
LOCAL PRODUCTION CONTROL IN THE HIERARCHICAL COMPUTER
CONTROL SYSTEM

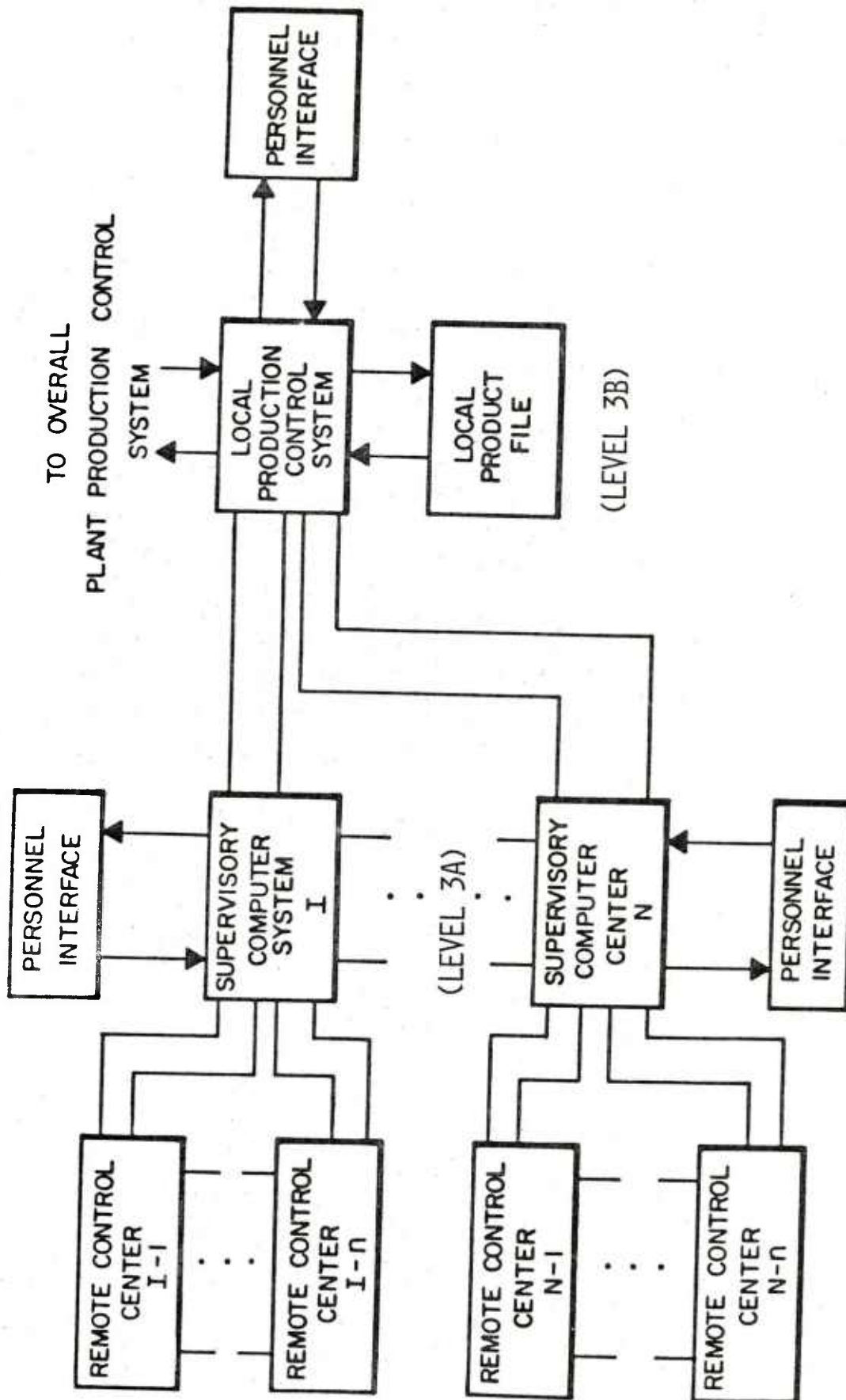


FIGURE 13
SKETCH OF THE SUPERVISORY CONTROL UNITS FOR A
SET OF PARALLEL AND ALTERNATIVE PROCESSING UNITS

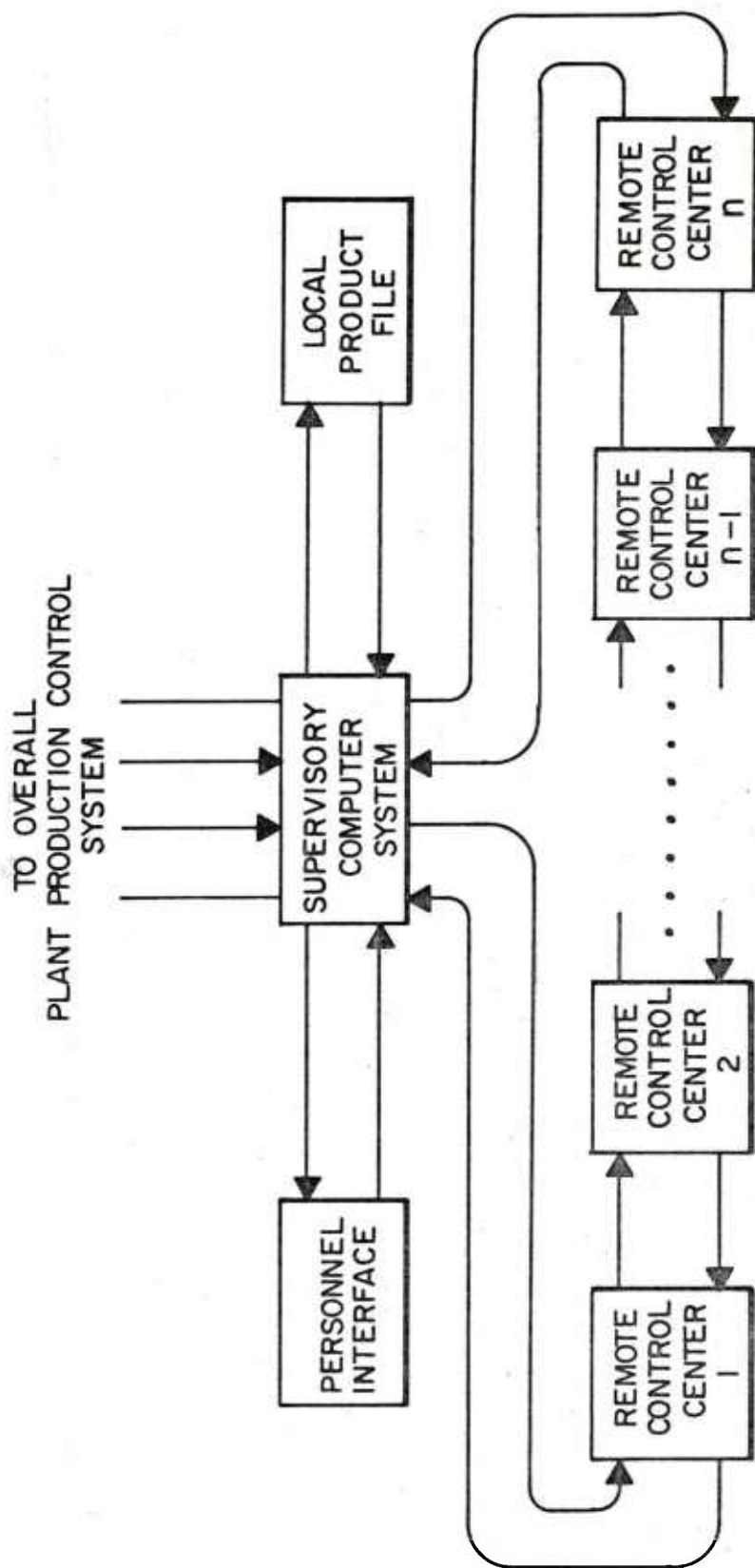


FIGURE 14
SKETCH OF THE RELATIONSHIP OF THE LOWER LEVEL CONTROL FOR
ANY SPECIFIC PROCESSING AREA

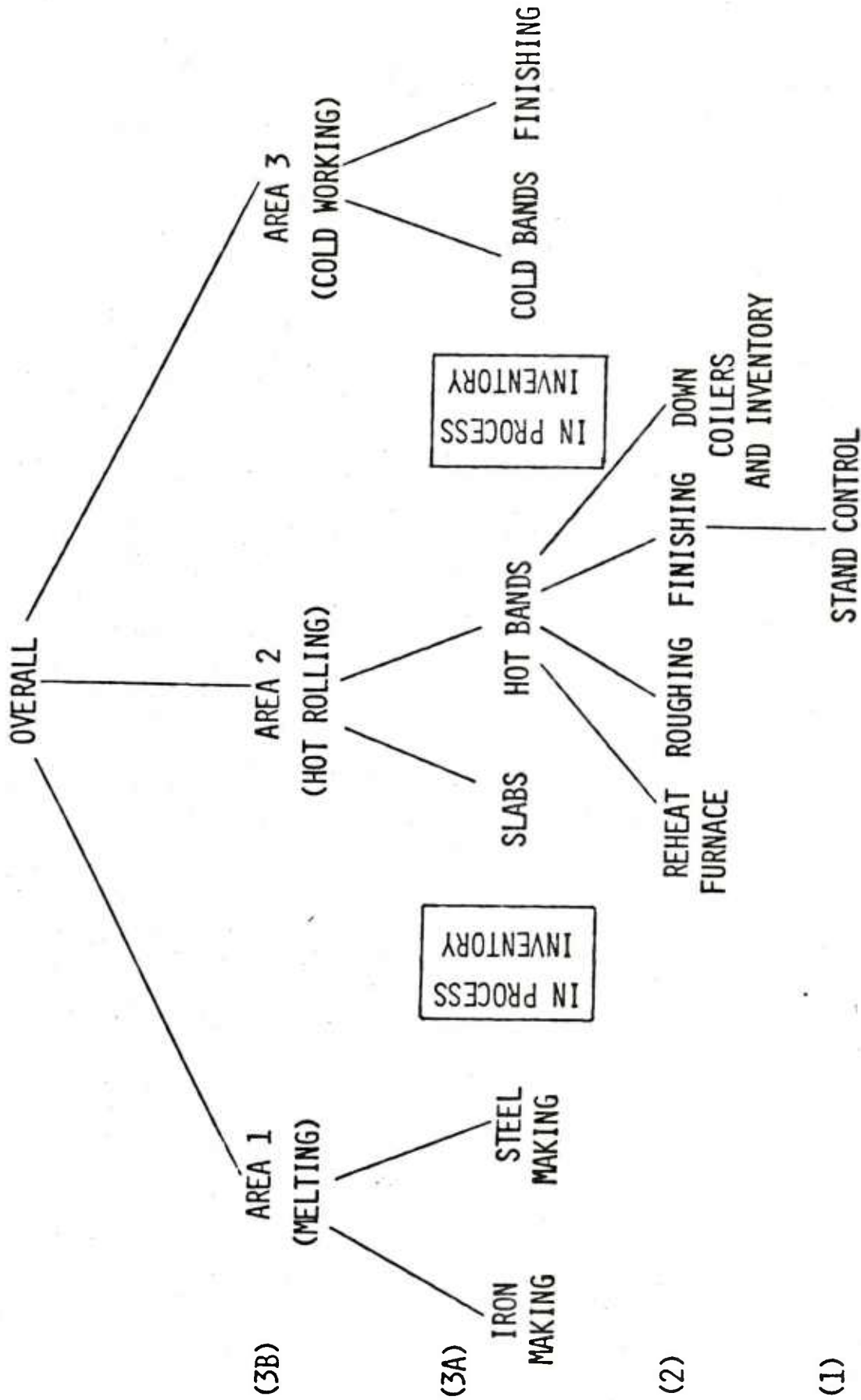


FIGURE 15

HIERARCHY ARRANGEMENT OF THE STEEL PLANT CONTROL
TO SHOW RELATIONSHIP OF HIERARCHY TO PLANT STRUCTURE

production plant being studied in the project at Purdue University, However, by renaming the elements this diagram could apply to any large industrial plant. In Figure 15 examples only are presented for Levels 1 and 2 due to the complexity of the diagram if all elements at these levels were included. Due to the space available in this report, complete details of the example system mentioned here must of necessity be presented elsewhere (26).

It should be called to the attention of the reader that it is the existence of the in-process inventories in Figure 15 which makes possible the separation of the plant into three distinct coordination areas and allows the three area controllers. These again are natural occurrences in very large manufacturing plants due to the economic risk involved in a straight-through, no inventory design.

Tasks of Each of the Levels of the Hierarchy

In the context of a large industrial plant, or of a complete industrial company based in one location, the tasks which would be carried out at each level of the hierarchy would be as described in Tables I to V. As was mentioned above, it is this author's contention that these Tables outline the tasks which must be carried out in any industrial plant, particularly at the upper levels of the hierarchy. Details of the operations as actually carried out may vary drastically, particularly at the lowest levels, because of

(text continues on page 66)

TABLE I

REQUIRED TASKS OF THE
INTRA COMPANY COMMUNICATIONS CONTROL SYSTEM
(LEVEL 4B OF FIGURE 6)

1. Maintain Interfaces with
 - (a) Plant and Company Management.
 - (b) Sales Personnel.
 - (c) Accounting and Purchasing Departments.
 - (d) Production Scheduling Level (Level 4A).
2. Supply Production and Status Information as Needed to
 - (a) Plant and Company Management.
 - (b) Sales Personnel.
 - (c) Accounting and Purchasing Departments.
 - (d) This Information Will be Supplied in the Form of
 - (1) Regular Production and Status Reports.
 - (2) On-Line Inquiries.
3. Supply Order Status Information as Needed to Sales Personnel.
4. Perform Self Check and Diagnostic Checks on Itself.

TABLE II

DUTIES OF THE PRODUCTION SCHEDULING
AND OPERATIONAL MANAGEMENT LEVEL (LEVEL 4A)

1. Establish Basic Production Schedule
2. Modify the Production Schedule for All Units Per Order Stream Received.
3. Determine the Optimum Inventory Level of Goods in Process at Each Storage Point. The Criteria to be Used Will be the Trade-Off Between Customer Service (i.e., Short Delivery Time) Versus the Capital Cost of the Inventory Itself. As Well as the Trade-Offs in Operating Costs Versus Costs of Carrying the Inventory Level. (This is an Off-Line Function).
4. Modify Production Schedule as Necessary Whenever Major Production Interruptions Occur in Downstream Units, Where Such Interruptions Will Affect Prior or Succeeding Units.
5. Maintain Raw Material Use and Availability Inventory and Provide Data to Purchasing for Raw Material Order Entry.
6. Collect and Maintain Overall Energy Use and Transfer to Accounting.
7. Maintain Interfaces with Management Interface Level Function and With Area Level Systems.
8. Run Self Check and Diagnostic Routines on Self and Lower Level Machines.

TABLE III

DUTIES OF THE AREA LEVEL (LEVEL 3B)

1. Establish the Immediate Production Schedule for Its Own Area Including Transportation Needs.
2. Optimize the Costs for Its Individual Production Area While Carrying Out the Production Schedule Established by the Production Control Computer System (Level 4A) (i.e., Minimize Energy Usage or Maximize Production for Example).
3. Make Area Production Reports.
4. Collect and Maintain Area Files for Production, Inventory, Raw Materials Usage and Energy Usage.
5. Maintain Communications with Higher and Lower Levels of the Hierarchy.
6. Operations Data Collection & Off Line Analysis as Required by Engineering Functions.
7. Service the Man/Machine Interface for the Area.
8. Carry Out Needed Personnel Functions Such as:
 - (a) Vacation Schedule.
 - (b) Work Force Schedules.
 - (c) Union Line of Progression.
9. Diagnostics of Self and Lower Level Functions.

TABLE IV

DUTIES OF THE SUPERVISORY LEVEL (LEVEL 3A)

1. Complete Detailed Production Schedule Based on Instructions From Higher Levels and Modified as Necessary by Any Plant Interruptions or Emergencies Which May Occur.
2. Respond to Any Emergency Condition Which May Exist in Its Region of Plant Cognizance.
3. Collect and Maintain Files of Production, Inventory, and Raw Material and Energy Usage for the Units Under Its Control.
4. Optimize the Operation of Units Under Its Control Within Limits of Established Production Schedule. Carry Out All Established Process Operational Schemes or Operating Practices in Connection With These Processes.
5. Service the Man/Machine Interfaces for the Units Involved.
6. Perform Diagnostics on Itself and Lower Level Machines.
7. Maintain Communications With Higher and Lower Levels.
8. Update All Standby Systems.

TABLE V

DUTIES OF THE CONTROL LEVELS (LEVELS 1-2)

1. Maintain Direct Control of the Plant Units Under Its Cognizance.
2. Detect and Respond to Any Emergency Condition Which May Exist in These Plant Units.
3. Collect Information on Unit Production, Raw Material and Energy Use and Transmit to Higher Levels.
4. Service the Operators Man/Machine Interface.
5. Perform Diagnostics on Itself.
6. Update Any Standby Systems.

the nature of the actual process being controlled. However, it would seem to us that there is a tremendous amount of commonality, particularly at the higher levels. Thus general techniques could be developed which could be translated to a wide variety of plants not only in the same segment of industry but throughout all industry.

Other than the physical relationship between plant structure, management structure, and computer system brought out above, the major differences between this physical or geographical hierarchy and the functional hierarchy presented earlier are as follows:

1. Because of the tremendously increasing availability of computing power at low costs now becoming available, all aspects of the dynamic control of a manufacturing unit can be concentrated at the lowest levels of control (i.e., at Levels 1 and 2). Thus the direct control (Layer 1), the dynamic adaptive control (Layer 3), and any dynamic optimization tasks (Layer 2) from the functional hierarchy will be carried out by the first level physical controller. The result will be a great reduction in the necessary data transmission in the hierarchy and a significant modularization and simplifying of the overall programming necessary.
2. The learning aspects given as Layer 4 of the functional hierarchy have been greatly downplayed since

no recent developments have materialized to show their practicality for presently conceived industrial control systems. The adaptive control functions actually used will also be much less sophisticated than originally thought (34).

Therefore outlining the basic control system which we have in mind, we will use the current concept of a widely distributed set of isolated functions carried out by small and relatively inexpensive computer systems. These systems will be highly redundant to preserve the integrity of the control system in the face of the possible failure of any one unit. Their work will be coordinated by a set of successively higher level, and probably larger, computers connected together and connected to the distributed remote control computers by an extensive plant communications system.

The lower levels of the hierarchy as proposed here will be based on the recent developments in the large scale integration of electronic circuits which has produced computer models with a very high capability and low cost in comparison to other present day systems. At the same time, communications research has produced very high-speed, serial data systems which are similarly reducing the costs of multicomputer system communications. From these components, very reliable multicomputer control systems should be able to be developed to automate most of the functions of a modern industrial plant.

The requirements for a specific large industrial plant will thus result in a system architecture that incorporates several small computers to perform control and monitoring functions within each functional area and a set of supervisory minicomputers controlling the overall system and performing the necessary calculations and interrogation functions to support and maintain suitable control performance as mentioned above. Finally the supervisory level systems are controlled by higher level area systems and an overall production scheduling system.

Any plant which we may use as an example can be readily divided into several different areas of activity chiefly centered about the separate manufacturing processes and their related raw material and product inventories and their utility suppliers. Because of the physical size of these processes in large plants and the required space for the related inventories, these process areas are often separated by considerable distances. For these reasons essentially the same distinction should be maintained in the design of the related control system, at least for the lower level members of the hierarchy involved. Thus the actual architecture of the distributed computer control system and the physical location of the members of the computer hierarchy will be fixed by the actual layout of the industrial plant itself rather than by any questions of actual control functions carried out on a particular computer system or of the capabilities of the computer

models in question. This is due to the difference in specific process control requirements between different processes and the physical distance separating one plant production unit from another as just mentioned above.

CHAPTER V

A CRITIQUE OF SOME PRESENT OFFERINGS OF DIGITALLY BASED CONTROL SYSTEMS

Several of the instrumentation and control systems suppliers are now developing new product lines designed to take advantage of the increased capabilities, higher reliability, and potential lower costs which appear to arise from the many recent developments in digital electronics and communications devices and concepts. These include but are not limited to the following:

1. Microprocessors
2. Serial data transmission
3. The concepts of distributed processing and hierarchical computer control.

At the time of the initiation of a new product line, especially one involving many entirely new concepts and using a technology with the potential for an almost unlimited future development and cost reduction, the opportunity exists for studying the potential of introducing several items of a customer service nature in the design such as:

1. Redundant components and other fail-safe techniques (or the optional capability for their use) to greatly increase unit reliability.
2. The use of industry standard interface techniques (for both hardware and personnel) wherever they

exist and the promotion of the development and the acceptance of these in areas where such do not as yet exist.

3. Development and use of fault tolerant, error correction, automated fault analysis, and automated calibration techniques wherever possible. The state of the art will probably not allow many of these techniques to be incorporated into early models of the new line of equipment. However, whenever possible, designs should be made with the conscious precaution of not eliminating the adoption of such techniques when developed in the future.
4. Modular designs to achieve as much commonality as possible across the line to minimize spare parts inventories and to simplify maintenance practices. Fortunately digital products lend themselves to such practices. Such techniques will also help promote the functions discussed in Item 3 above.
5. The concept of the use of the units of the presently proposed line of hardware as potential building blocks in what may eventually become an overall plant hierarchical control system. Special attention to Item 2 above will go far to help assure this.

As a comment on Item 2 above it is the sincere belief of this writer that there is a much greater desire on the

part of the user companies for industry-wide standards than vendors care to believe. The introduction of a new line of equipment (as mentioned above) gives a unique opportunity to reassess this question. It would be a shame to let this opportunity pass by without consideration. This writer readily admits his own bias in this area because of his own leadership in these activities. He wishes to call the attention of the reader to an equally strong negative bias in the part of the vendor because of perceived commercial advantages.

THE SINGLE LOOP CONTROLLER

The Place of the Single Loop Controller

A large amount of the work devoted to developing the new product lines mentioned above has been used for the digital equivalent of the single loop analog electronic or pneumatic controller. This has been done because of a perceived desire on the part of the manufacturer that the user wishes to maintain the application techniques with which he is familiar, i.e., single input-single output type uses.

In discussing the single loop controller it must be recognized at the outset that this writer has a definite bias toward the use of advanced control concepts such as feed-forward control; multivariable, noninteracting control; adaptive control; dynamic optimization, where practicable; automatic sequencing control; and the development and use for

control purposes of inferred and indirect process operating variables such as yield, quality, profit, safety, etc. Such concepts require access to several input variables; a high degree of computational capability; and a very high degree of reliability or better, availability.

The single loop controller by its single input, single-output, nature violates the first of the above requirements and thus, to a large extent, relegates itself to the same type of tasks as those carried out by conventional analog electronic and pneumatic controllers today. The proposed digital device can, of course, capitalize on the increased computational ability of the microprocessor and any potential reliability techniques. The point of controversy, therefore, resolves itself very simply to a determination of the potential buyers' adherence to the familiar, the single loop concept, versus his desire to take advantage of advanced control concepts, etc.

SOME OTHER SHORTCOMINGS OF PRESENT EQUIPMENT AND PROPOSED ADDITIONAL CAPABILITIES

It is difficult for any controls manufacturer to provide a system which meets the control needs of every type of industrial process. However, many of the control requirements are shared by a broad range of processes. Thus, identifying and satisfying these control requirements with one manufacturer's product line would probably lead to a much more wide-

spread use of that product line. It might also lead to a wider application of the advanced control methods described herein.

Some of the shortcomings of present equipment now on the market or planned for early sale can be listed as follows:

1. There is no present capability in these equipments for the programming of a sequence of operations, such as for the start-up and shut-down of the distillation column or reactor.
2. There is no method for direct communication between the supervisory computer and the operator stations. This may limit the effective use of these in hierarchical control systems. Since the operator stations are designed to be the main operator interface, they should provide a communication link between the process control and supervisory levels of the hierarchy.
3. There is no method of communication between multi-controller units. This forces the user to find relatively small groupings of process variables. Therefore if a process variable is needed in more than one controller computation, the user must provide an additional sensor input or use a computation output as the input for the second controller unit.
4. The capability of the new systems for generating multiple cascade, i.e., multiple input control loops and for performing algebraic calculations is

severely limited by the availability of inputs in a single controller block unit. For example, six computations are required for performing a multiple cascade made up of three secondary and one primary control loop. Also, to perform the heat exchange calculation (30):

$$F_s = F_f K_f (T_f - T_o) - BKb(T_1 - T_2),$$

the present system requires three summer computations and two multiplier computations, thus using more than half the available computational ability of presently available equipment for this single calculation.

5. At present, there is no provision for simulating a dead time in the process, although the digital nature of the equipment should make this easy to implement. The same applies to the ramp function often described in the feedforward algorithm (30). The feedforward algorithm presently available in some models consists of a simple lead/lag delay with no provision for dead time, or for modification of the gain, time delay, and speed of the response based on the type of external upset imposed on the process. This is necessary for the type of feedforward and multivariable control proposed.
6. As the systems are presently designed, the operator

must enter separate proposed control system configurations manually, or load the entire configuration by some automatic means such as from a cassette. This limits the operator's ability to load various combinations of control strategies (or, to build a control package).

7. There is no present capability for user modification or addition to present controller algorithms or operator station functions. This feature would make a generalized control system much easier for the engineer to implement.

Some Proposed Additional Capabilities

Since the functions performed by most of these systems are determined primarily by software, it should be possible to add the additional capabilities mentioned with programming modifications in the operation of the operators stations and controller block units. The central functions, such as sequencing and control package programming, might be performed in the operator stations themselves. The control algorithms, such as multiple cascade and feedforward, might be implemented directly in the controller block units. If possible, all the vital control functions should be performed at the controller level to improve the security of the control system.

CHAPTER VI

THE CURRENT WORK OF THE INTERNATIONAL PURDUE WORKSHOP ON INDUSTRIAL COMPUTER SYSTEMS TO PROMOTE THE FIELD OF INDUSTRIAL COMPUTER APPLICATIONS

INTRODUCTION

The International Purdue Workshop on Industrial Computer Systems is described in detail in Report Number 77 of the Purdue Laboratory for Applied Industrial Control (37). The work accomplished by the Workshop prior to the date of that publication (September 1976) is summarized in a group of six reports prepared for the United States Navy at that time (38-43). In addition a subject and name index was also prepared. This was Report Number 88 of the Laboratory (44). Because of the existence of the above reports only a brief description and update of the program of the Workshop will be given here.

The generation of guidelines and standards is necessarily slow and tedious work, due in part to the necessity of obtaining a consensus on carefully worded and exact documents. Many trade-offs are involved. To be meaningful the choices must be made by individuals who are highly knowledgeable in the technology by virtue of their normal work. This means that it must mostly be done by volunteers who are willing to contribute their spare time, energy and knowledge more for the benefit of others, than for themselves.

The International Purdue Workshop on Industrial Computer Systems has earned an enviable world-wide reputation for the development of guidelines and standards in their field. Originally the workshops began as a software activity with sponsorship from the Instrument Society of America (ISA), but activity is now strong in the hardware area as well. The world-wide influence of the workshops has expanded, particularly because of the formation in 1974 of the European Region of the International Purdue Workshop (IPW), and the Japanese Region. Like the American Regional division, these groups and their many Technical Committees meet regularly in addition to meeting at the combined International Workshop which is held at Purdue University in Lafayette, Indiana each October.

Activities of the European division are recognized by the Commission of European Communities (CEC). Activities of the division in Japan are closely tied to the Japan Electronic Industry Development Association (JEIDA), and Canada has become a formal sponsor through the National Research Council Associate Committee on Automatic Control (NRC-ACAC).

At any given point in time each workshop committee may have many documents in progress. These are in the form of working papers, draft guidelines or requirements, partial or complete standards and so forth, up to and including widely distributed guidelines or standards. This can include those distributed by the ISA, the American National Standards Institute (ANSI), or eventually the International Organization

for Standardization (ISO). Thus the Purdue Workshops contribute significantly to many standards or extensions to which they may not necessarily be the sole authors.

ORGANIZATION OF THE INTERNATIONAL PURDUE WORKSHOP

A formal organization for the Workshop, complete with by-laws and officers, provides a stable base for the development of formal industry-wide standards proposals, even though most workshop activities do not require this. Officers include a Workshop General Chairman, a Vice-Chairman for Standards Coordination, a Vice-Chairman for Planning, Regional and Organizational Representatives, and Technical Committee Chairmen. (See Table VI).

European, Japanese, and American regional organizations, each with their own complement of technical committees, aid in the world-wide pursuit of solutions to common problems. Each regional organization provides a representative to the Workshop Executive Committee. Regional meetings are held each spring, and a combined international meeting is held each fall at Purdue. Technical committees, and their subcommittees, also meet as needed between the main workshop meetings. The Regional Organizations are given in Tables VII - IX and Figures 16 and 17.

Attendees represent many industries, both users and vendors of industrial computer systems and components, universities and research institutions, with a wide range of

experience in the industrial application of digital systems. Each workshop meeting features tutorial presentations on systems engineering topics by recognized leaders in the field. Results of the workshop are published in the Minutes of each meeting, in technical papers and trade magazine articles by workshop participants, or as more formal books and proposed standards. Formal standardization is accomplished through recognized standards-issuing organizations such as the ISA, trade associations, and national standards bodies.

The Workshop is divided into ten separate Technical Committees, most of which also have branches in each Region. The Committees are:

1. Industrial Real-Time FORTRAN Committee
2. Industrial Real-Time BASIC Committee
3. Long Term Procedural Language Committee or LTPL Committee
4. Problem Oriented Languages Committee, or POL Committee
5. Interfaces and Data Transmission Committee (IDTC)
6. Man/Machine Communications Committee
7. Systems Reliability, Safety and Security Committee
8. Operating Systems Committee
9. Glossary Committee
10. Microcomputer Committee

Each of the Committees is discussed briefly below with a description of their latest results and/or projects.

TABLE VI

EXECUTIVE COMMITTEE

INTERNATIONAL PURDUE WORKSHOP

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TABLE VI (Cont.)

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TABLE VII (Cont.)

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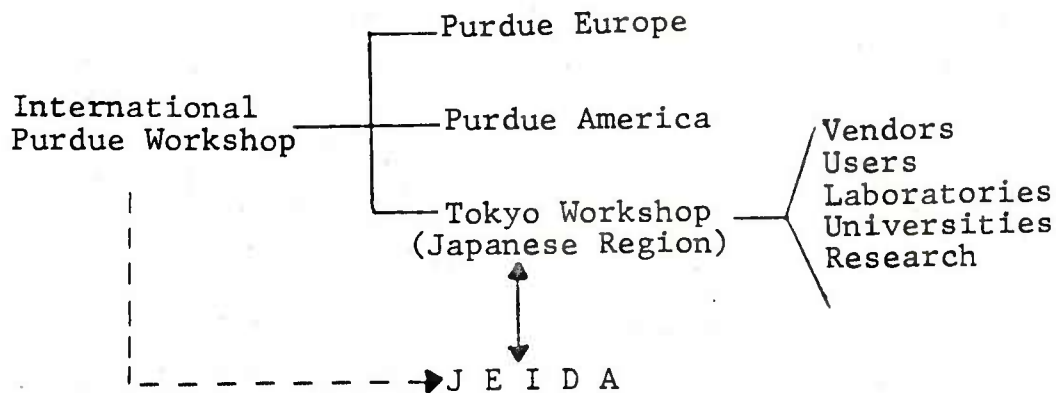
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FIGURE 16
RELATIONSHIP BETWEEN PURDUE JAPAN
AND JEIDA

JEIDA (Japan Electronic Industry Development Association)

-Policy Board on Systems

- Steering Committee of Industrial Computer Systems-
Chairman; Prof. M. Terao
- Committee for Coordination of Industrial Computer Systems-
Chairman; Mr. W. Yamanaka
- Committee for Technology of Industrial Computer Systems-
Chairman; Dr. K. Sato
 - Subcommittee for System of Industrial Computer Systems-
Chairman; Dr. Y. Matsumoto
 - Subcommittee for Hardware of Industrial Computer Systems-
Chairman; Mr. H. Tamura
 - Subcommittee for Software of Industrial Computer Systems-
Chairman; Dr. M. Sudo
 - Subcommittee for Safety and Security of Industrial
Computer Systems
Chairman; Mr. I. Ido
- Committee for Standardization of Industrial Computer Systems-
Chairman; Prof. M. Terao; Secretariat; Mr. T. Tohyama
 - WG 1 (ISO/TC97/SC13/WG1); Chairman; Mr. T. Tohyama
 - WG 2 (IEC/TC65/SC65A/WG6); Chairman; Mr. K. Oguro
 - WG 3 (ESO/TC97/SC5/WG1); Chairman; Mr. K. Mori
 - WG 4 (Man-Machine Interface (IPW); Chairman;
Mr. T. Tohyama

FIGURE 17

JEIDA'S ORGANIZATION FOR INDUSTRIAL COMPUTER SYSTEMS

THE INDUSTRIAL REAL-TIME FORTRAN COMMITTEE

The Industrial Real-Time FORTRAN Committee, TC-1, was originally organized, as one of the first standing committees of the workshop, as the Short Term Procedural Languages Committee in contrast to the Long Term Procedural Languages Committee or LTPL Committee organized at the same time. However, the long term nature of the achievement of its goals of the standardization of the necessary extension to the FORTRAN language to make it a good industrial computer systems language were soon recognized. At that time its name was changed to the FORTRAN Committee and subsequently to the Industrial Real-Time FORTRAN Committee, popularly still called the FORTRAN Committee.

The committee has carried out its work through the Instrument Society of America (ISA). Early in its work, ISA organized a committee labelled SP61, Industrial FORTRAN, under its Standards and Practices Board. The members of this Committee serve as a Working Group of the FORTRAN Committee to interface with ISA and assure that standardization rules are carried out in the committee's deliberations. For some time now Dr. Matthew R. Gordon-Clark of the Scott Paper Company has served as Chairman of ISA SP61 and as the FORTRAN Committee Chairman.

The work of the committee has been broken up into three areas:

1. S61.1 - Industrial Computer System FORTRAN Procedures for Executive Functions, Process Input/Output, and Bit Manipulation.

2. S61.2 - Industrial Computer System FORTRAN Procedures for File Access and the Control of File Contention.
3. S61.3 - Industrial Computer System FORTRAN Procedures for Management of Parallel Activities.

ISA issued S61.1 as a standard in September 1972. Some technical difficulties were discovered in this version so a revised and updated version was published by ISA in September 1976. S61.2 was approved by the Standards and Practices Board in the fall of 1977. Both Standards have been submitted to the American National Standards Institute (ANSI) for approval as nationwide standards. A draft of the proposed S61.3 has been developed and is now under review.

The International Standards Organization (ISO) has recently initiated work in the area of process control or industrial control languages. It has been formally instituted as ISO/TC 97/SC 5/WG 1 entitled Programming Languages for the Control of Industrial Processes. The American Region of the Workshop has been designated to serve as the United States Technical Advisory Group (USTAG) for this work. ISA S61.1 has been submitted to this group for International Standardization.

The TC-1 Committee of Purdue Europe is also working on the standardization of industrial process control extensions to the FORTRAN language. Because of the VDI/VDE origins of this latter committee the initial version of FORTRAN being studied is different from the American version in several respects, particularly in the areas of S61.2 and S61.3. Extensive liaison work is now underway to resolve these differences.

INDUSTRIAL REAL-TIME BASIC COMMITTEE

The Industrial Real-Time BASIC Committee was organized to carry out for the BASIC Language essentially the same tasks as were being carried out for the FORTRAN Language by the FORTRAN Committee. That is, convert a language which was designed for batch, scientific computing into a worthwhile industrial computer system language through the addition of the necessary extensions to accomplish this.

In carrying out this work the Committee has established a very close working relationship with corresponding committees in ANSI, ECMA (European Computer Manufacturers Association) and the ESONE Group (European Standards on Nuclear Equipments). Work here is proceeding admirably and its final proposal for an Industrial Real-Time BASIC should be presented to the sponsor organization by the fall of 1978.

The Industrial Real-Time BASIC Committee (TC-2) of Purdue Europe has carried the majority of the work in this area in recent months.

THE LONG TERM PROCEDURAL LANGUAGES COMMITTEE

GENERAL

As mentioned earlier, the Long Term Procedural Languages Committee (LTPL-C) was established at the same time as the FORTRAN Committee to investigate the possibility of an industrial computer systems language which might eventually

replace FORTRAN as the most important procedural language for such use.

The Department of Defense of the United States has been involved in the process of developing a "common language" for U.S. service use popularly called DOD-1. The several LTPL groups have been actively engaged in reviewing the preliminary specifications (STRAWMAN, TINMAN AND IRONMAN) for this language as developed by the HOL Working Group of the Department of Defense and in reviewing the preliminary proposals for this language. Further, the ISO/TC 97/SC 5/WG 1 work mentioned under the FORTRAN committee will also be considering languages of the LTPL type and active cooperation is anticipated here.

THE PROBLEM ORIENTED LANGUAGES COMMITTEE

GENERAL

A definition of the term Problem Oriented Languages was given at the 1971 Fall-meeting of the International Purdue Workshop on Industrial Computer Systems (IPW):

"POL's are user-oriented languages, where the user is not a programmer. The POL should allow both 'Fill-in-the-blanks' type programs and 'sentence' type."

As an amendment to this definition the following statement of the International TC on Problem Oriented Languages was given during the 1974 Fall-meeting:

"The Problem Oriented Languages Committee is charged with

the responsibility for definition of software based interfaces between humans and industrial computer systems, and with methods of their implementation. These interfaces are to be of a higher level than the long term procedural language."

There is no realistic possibility for the POL-Committee to propose standards for Problem Oriented Languages for all of the special applications for which such a standard might be of interest. Therefore it has been agreed that a comparable aim may be achieved by the development of standards for the tools and the methods for the definition and automated implementation of problem oriented languages for special applications whatever they may be.

GOALS OF THE SUBCOMMITTEES

The American, TC-4, POL-A, is surveying vendors and software users of microprocessors and special purpose languages looking toward the possible use of STAGE 2 to implement already defined Problem Oriented Languages or subsets of them in this language.

The Japanese TC-4, POL-J, is mainly working on PROCOS (Process Control Oriented Software System). PROCOS utilizes a fill-in-the-blanks description with a simplified procedural language and data file structure.

The POL-E group is involved mainly in aiding the other two groups to complete these above mentioned goals.

INTERFACES AND DATA TRANSMISSION COMMITTEE

It was early agreed in the Workshop that work looking toward a standardized industrial computer main frame would be unrewarding because of the vendors needs for innovation in this area and because the field was probably not yet fully mature.

It was however also agreed that a major area of difficulty in using mixed systems of machines from different vendors was the incompatibility of the interfaces between them. This area of the field was considered sufficiently mature so that profitable work could be carried out looking toward standards or guidelines in this area. The Interfaces and Data Transmission Committee was therefore formed. The main committee and its regional branches are heavily engaged in the development of standards for serial data highways for high speed data transmission between field units and computers and between the different computers of a plant computer hierarchy. All three groups have made proposals in this area which are now being resolved by the International Committee.

The American Regional Subcommittee, IDTC-A, has been designed as ISA SP72, "Industrial Computer Interfaces and Data Transmission Techniques" in much the same manner as the FORTRAN Committee's designations as ISA SP61. As such they have been designated as the USTAG for IEC/SC65A/WG6, entitled, "Description of Interface Between Process Computing System and Technical Process".

MAN-MACHINE COMMUNICATIONS COMMITTEE

GENERAL

The work of this committee has been mainly directed toward the production and a considerable revision and updating of a document entitled, Guidelines for the Design of Man/Machine Interfaces for Process Control. This work was initially completed at the Fall-1975 Meeting of the International Purdue Workshop on Industrial Computer Systems but has been extensively expanded in subsequent work by the committee.

SYSTEM RELIABILITY, SAFETY AND SECURITY COMMITTEE

COMMITTEE DEFINITION

The Committee on Systems Availability and Safety is concerned with providing protection against dangers to human well-being, environment, and property, arising from internal failures in computer controlled systems. This type of protection can be defined by the term "safety".

The Committee is also concerned with providing protection against dangers from outside a plant or installation, arising accidentally or from deliberate actions, both inside or outside a plant. This protection can be defined by the term "security".

COMMITTEE DOCUMENTS

Guidelines are being developed on methods

- to design and develop computer systems with specified safety and security requirements.
- to establish safe software systems.
- to establish a documentation according to safety and security requirements.
- to verify safe computer system performance.

These guidelines will be presented to national and international professional groups and standardization bodies to be developed into standards. Thus, the Committee could become a "clearing house" for national and international standardization committees.

INTERACTION WITH OTHER ORGANIZATIONS

In the pursuit of its objectives, the Committee closely cooperates with

- other technical committees of the Purdue Workshop, e. g., with TC's on language development to make sure that reliability, safety and security requirements are considered.
 - other technical organizations working in the field of safety systems, e. g., Office for Research and Experiments of the International Union of Railways (ORE).
-

-national and international professional groups (e. g., VDE - GMR in Germany).

REAL-TIME OPERATING SYSTEMS COMMITTEE

The Real-Time Operating Systems Committee was initially organized as part of Purdue Europe and has since expanded to the other Regions and the International Workshop itself.

In Europe the Committee is organized into two working groups entitled, Operating System Interface and Kernal Definition working groups. The Committee is particularly concerned with the following topics:

1. Development of a proposal for an operating system interface which is real machine (i.e., hardware) independent to help solve the problem of transportability of applications programs from one machine to another.
2. Modularity of operating systems.
3. Distribution of tasks between operating systems and higher level languages.
4. Error handling techniques in operating systems.
5. Functional requirements for a minimum kernal operating system.

GLOSSARY COMMITTEE

The Glossary Committee published a Dictionary of Industrial Digital Computer Terminology through the Instrument

Society of America in September 1972 as a hard-bound book. Work is now proceeding to develop a Second Edition of the above book by 1979.

MICROCOMPUTERS COMMITTEE

The rapidly developing importance of the microcomputer and the microprocessor to industrial systems led the International Purdue Workshop in 1977 to organize an Ad Hoc Committee on Microcomputers. This group was to study the field and report back at the 1978 Fall International Meeting on a proposed scope and program of work for these systems. This is now in progress and it is expected that a Microprocessors Committee, or a similar titled group, will be organized on a permanent basis this fall.

CHAPTER VII

SOME TRENDS AND PREDICTIONS OF FUTURE PROGRESS

SOME PREDICTIONS

It has been stated that all of us who have attempted to predict the course of development of future technology have continually made two grave errors:

1. We have badly overestimated the progress which can be expected in the short term (less than 5-10 years).
2. We have just as badly underestimated the progress which can be made in the long run (more than 15-20 years).

Who of us, enamored with the publicity which DDC received in the mid 1960's and the popularity and success of the several DDC Workshops held at that time would have predicted the very bad press and disillusionment which the same topic would receive in the late 1960's after several companies had had experiences similar to that of the Chocolate Bayou detergents plant and after prices showed no immediate trend of decreasing as predicted. In fact, prices increased greatly because of the addition of the DDC Set-Point Station to give an analog backup capability.

At the same time, which of us would have predicted the

microcomputer and the tremendous effect it has already had on, at least, the potential future of all of our applications.

With this caveat let us now attempt to gaze into the crystal ball, cloudy as it may be.

1. Multiple redundant computer systems for reliability purposes have been strenuously resisted by industrial applications engineers even though they have been enthusiastically embraced for military systems. This has been due to several factors:

- a) An instinctive dislike for "wasting" the computing capability of the second machine while it sits there idling along waiting for the first to fail.
- b) The price of the second mainframe in the past was an obvious point for cost saving even though an analog backup system was often more expensive.
- c) A reluctance to sever oneself completely from the analog "umbilical cord" of familiarity and consequent trust.

Nevertheless, I predict that we will see an ever increasing trend to multiple redundant computer backup systems replacing the present analog backup. I do not see an elimination of back up per se - it is too cheap an insurance for that to happen. These standby redundant machines will not be given secondary

tasks to do while in standby status. This is because of:

- a) The software complexity involved and the lack of trained personnel to carry out the work required, and
 - b) The fear of interaction between the primary and secondary tasks at the moment of switching and subsequent failure of the standby system to take over the primary task.
2. I believe a programming system, such as that which was listed earlier under the set of tenets, will be developed. Unfortunately there are tremendous proprietary, commercial advantage, company pride, and even national political problems standing in the way of its successful development and acceptance. Therefore, unless we get a breakthrough soon in the standards area, which I don't foresee, I believe this will be 10 years and more in coming, and even then, may not be universally accepted because of the reasons just given.
3. Electronic techniques today have the potential, so far unexploited, of drastically reducing the costs of our industrial control systems. I predict that this will not come to pass. The system offered us will continue to carry similar prices to those of the past for equivalent functions. We are used to

paying a certain relatively small percentage of total project cost for instrumentation and control. A drastic change in this amount would thus have little relative effect upon total project cost.

Therefore, the lowered unit electronic component costs will be compensated for, by the vendor, with a greater complexity, hopefully all useful. This complexity can comprise redundancy or other fail-safe techniques, self-contained diagnostics, packaging for easy maintenance by large unit replacement, etc. Where it does indeed do this, it is to be applauded.

4. I believe we will have an acceleration in the research and development of on-line diagnostic techniques and self-diagnostic systems for easy maintenance. This is a very complex subject so I do not expect much progress for some time, perhaps five years. It must come, however, driven probably by the needs of military systems for such a capability.
5. Distributed systems are the wave of the future. As we have said, they are driven by the relatively low cost and low capability of the microcomputer as presently perceived. At the same time, they have promoted a modularization and simplification of systems programming which we would not like

to lose. This combined with the obvious reliability gain makes it easy to predict that relatively soon all of our systems will be distributed rather than centralized.

6. Much as I hate to admit it, I don't see our universities doing much specific to solve the personnel problems which we have emphasized earlier. Important as our needs are, they are still a relatively small proportion of the total requirement for engineers and technicians in industry today. Thus it appears to me that our universities, mine included, will continue to turn out the discipline-oriented generalist and depend upon industry to produce the specialist by on-the-job training or short courses.

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