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International Institute
for
Applied Systems Analysis

PROCEEDINGS
OF
IIASA PLANNING CONFERENCE
ON
AUTOMATED CONTROL OF INDUSTRIAL SYSTEMS

October 1 - 3, 1973

Schloss Laxenburg
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TABLE OF CONTENTS

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Preliminary Agenda for
IIASA Research Planning Symposium
on
Automated Control of Industrial Systems

October 1-3, 1973

Proposed by I. Lefkowitz, Co-Chairman

I. Problem Definition and System Structure

Define the nature of the problem of control of integrated industrial systems. Define system structures appropriate for the functions of data gathering, information processing, control, decision making, data management, etc. Outline hierarchical approaches for control of large scale systems. Discuss the role of the computer in real-time application.

II. Motivation--Application Areas

1. More Efficient Utilization of Resources. The ever-increasing demands of advanced technology for energy and raw materials are making more and more critical the need for their more efficient utilization. This reflects on the control problem in the sense that there is increased need to improve operating efficiencies of the production processes, to reduce scrap and waste, to adapt to varying properties and wualities of the raw materials used and the energy sources, to tighten the integration of the process units to improve thermal efficiencies, etc.

2. More Stringent Product Quality Requirements. The increasing impact of consumer legislation and public awareness will increase the need for automated product quality control. This leads to problems of automating product inspection, implementing feedback algorithms designed to maintain quality specifications, development of efficient large scale data systems for storage of relevant information, application of pattern recognition and related techniques for quality assessment, etc.

3. Impact of Environmental Constraints. The problems of air and water pollution and waste disposal are becoming increasingly important factors in the operation of industrial systems. This provides additional motivation to control of the system on an integrated basis where environmental interactions are included in the system model.

4. Economies of Scale. Trends toward ever-increasing sizes of production facilities tend to place increasing demands on the control system for more effective integration of plant variables, increased reliabilty and provisions for security/contingency control. As capacities increase, there may also develop increased demand for flexibility, e.g. ability of the control system to adapt to changes in load, product specifications, etc. Similar considerations apply to the implementation of new technologies which may be more critically dependent on integrated control for economic feasibility.

5. Extension to New Kinds of Industrial Systems. As our control capabilities improve, opportunities for realizing economic benefits of automation in other industries become more apparent. Possible candidates for consideration include construction and assembly processes, some aspects of food processing, etc.

III. Problem Areas--Theory and Methodology

1. Modelling of Complex Industrial Systems. Modelling techniques appropriate for large integrated systems, e.g. methods of model approximation and simplification, parameter identification, fast-time simulation and computer interactive design procedures.

2. Hierarchical Control Approaches. Multilevel structures in control of large scale systems, tradeoff considerations, bases for system decomposition, coordination of local controllers.

3. On-line Computer Control. Minicomputers in dedicated control applications, problems of data base management, communications between computers and man-machine interactions.

4. Security Control and System Reliabilty. Improved methods of designing for system reliability and adaptability to contingency occurrences. Detection of malfunctions and abnormalities and automated correction procedures.

5. Automation of Multi-Product Plants with Multipurpose Equipment. Nature of problem in application to batch processes, continuous processes, discrete manufacturing, multi-mode operations. Superposition of optimal scheduling/sequencing on process control functions.

6. Optimal Control/Decision Making in Large Dimensional Problems. Development of more powerful tools for on-line optimization in industrial control applications, including process optimization and scheduling under conditions of uncertainty, incomplete information and dynamic disturbances.

7. Incorporation of Robotry into Integrated Computer Control System. There are many questions that might be explored here regarding the advantages and limitations, potentials and directions of further development, etc. as related to the integration of large scale production systems.

IV. Non-technological Considerations.

Some discussion of the nature of societal problems emanating from increased automation of industrial systems may be appropriate, e.g. technological unemployment, educational needs for upgrading labor, other factors.

V. Summary and Conclusions.

Minutes of the Research Planning Conference on Automated Control of Industrial Systems*

Preliminaries

Mr. Raiffa, Director of IIASA, welcomed delegates to the eighth in a series of conferences convoked to generate suggestions for a meaningful, integrated research strategy for the Institute. He explained that IIASA would not lavish all its energies on one or two mammoth projects, but rather concentrate on a "menu of alternatives." Structurally, IIASA is unique, being supported by institutes with prestigious reputations in twelve nations. As a consequence, although IIASA has an annual budget in the neighborhood of three and one half million dollars and anticipates an eventual in-house scientific staff of approximately ninety scholars, the promise of available multilateral cooperation endows the Institute with virtually boundless project potential. At present IIASA conceives of partaking in four different sorts of activities:

1) A modest amount of original research.

2) Engineering tasks--the creation of software, gathering of data--in cooperation with organizations actively engaged in finding solutions to concrete problems. IIASA will draw on an extensive network of manpower sources. (WHO, for example, has requested IIASA's Medical Systems project to consider certain deeper philosophic implications of agency activities.)

3) Sophisticated clearinghouse activities--compilation, comparison and analysis of information in various fields. Publication of annotated bibliographies, handbooks, periodicals is a possibility. IIASA is fully as concerned with identifying problems as with formulating solutions. (The IIASA Energy Project has demonstrated the value of such information processing. Wondering whether it made an appreciable difference if heat sources enter into the atmosphere at different levels or in point rather than diffuse sources, researchers compared existing energy models exhaustively and found no model adequate to answer these important questions. Since heat pollution is a primary constraint on

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*These Minutes were prepared by D. Bloch.

unlimited supply of energy, the matter is of more than academic interest. In liaison with IIASA, various scientific groups informed of the issue are now hard at work.)

4) Conferences--not only conferences for the uninhibited exchange of ideas, but also gatherings directed towards well-defined topics of special interest for which elaborate preparation and paperwork will be carried out prior to meeting. Conferences on problems of inland seas or melting of polar ice caps are possible examples.

Four criteria determine IIASA's choice of specific projects. The research topic should:

- be important either globally or "universally" (occurring within many societies),
- be feasible for IIASA,
- not yet done elsewhere, and
- give promise of short, medium, or long term results which might compensate member nations for their investment in IIASA.

Mr. Cheliustkin, Co-Chairman of the conference, began his remarks to delegates by deploring that industry paid too much attention at present to technology and far too little to systems analysis. Problems of planning and scheduling production are becoming increasingly important. Operational control is the essential link between planning and technological control. He hoped IIASA would fill an essential gap in present knowledge by 1) helping to elaborate various structural problems of industrial systems, 2) helping to make clear the structure of decision making in systems, and 3) showing how to decompose complex problems into a number of local, interconnected problems. Another aspect of industrial systems which Mr. Cheliustkin thought worthy of study was learning how components of an integrated system which work in different time scales can be fitted into control procedures. A large problem is to establish a methodology for properly dividing the static and dynamic parts of industrial models; here, the cooperation of IIASA's project on optimization of large scale systems will be essential. Mr. Cheliustkin repeatedly emphasized the importance of building adaptable systems. A plant and a plan invariably diverge --not to accumulate data, to feed it back into design and to revise according to findings is to squander, among other valuable resources, time.

Mr. Cheliustkin concluded his introduction by wondering aloud about the usefulness of representatives from government institutes and universities conversing with private organizations. Was it realistic to expect sleeping proprietary interests to lie?

Mr. Raiffa responded by cautioning against prematurely ruling out the cooperation of private industrial companies. Firms are often surprisingly open--unless people begin to probe into detailed production decisions. Many major industries have in fact set up foundations expressly for research. There is nothing to prevent IIASA from obtaining cooperation in such instances. Another possibility, if the conference recommends a course of action which the Council adopts that focuses on a particular branch of industry as steel, for instance, is to approach a consortium of steel companies rather than one.

Mr. Lefkowitz, Co-Chairman of the conference, reported that his long experience working within an academic institute in intimate cooperation with industry confirmed the reciprocally profitable potential of research into large scale systems control which exists for IIASA and private companies. He expressed satisfaction at the broad spectrum of people with diverse backgrounds and orientations he saw represented at the conference. Mr. Lefkowitz then sketched the historical development of control of industrial systems from his perspective of experience in process control where "even before computers, planners realized the need for advanced procedures with information feedback loops."

The advent of commercial computing opened up previously impossible opportunities for control. The initial motivation was to realize savings of cost and equipment by multiplexing the control of many variables with a single machine. Early hopes were not realized--the machines proved expensive and reliability checks were a further difficulty. Optimization of key variables restricted to isolated functions evolved to consideration of restraints and of dynamic optimization. The ability of computers to process quantities of information quickly induced researchers to extend the boundary of their operations to consider aggregations and interactions, to attempt large, multivariable control procedures, and to integrate process units. Man-machine interfacing was a logical next area of consideration together with accompanying problems of reliability and security. Ultimately the design process itself was subjected to scrutiny, testifying to recognition that implementing control of large complex systems is related to software development, to modelling, to the reduction of decision headaches and to computing. Again, however, the cost of implementing ambitious systems was in excess of the cost of computer hardware and installation. The immediate consequence has been a flurry of activity considering appropriate languages. At present there is concern over user orientation of complex methodology and a high level of interest in computer design.

Mr. Lefkowitz then read to the conference a preliminary agenda including matters which he felt were germane to the conference interests. He mentioned topics which might invite research and exhorted the delegates to be on the lookout for ways that a project in the Automated Control of Industrial Systems might interact with other IIASA projects.

In response to the Co-Chairmen's introductions, a delegate inquired where the conference wished to concentrate its attention: on building new works, or on adjusting plants actually operating with given production requirements. He said that is not every day we have a chance to build a new plant. We should not deal exclusively with "green field" situations but keep practical applications constantly in mind.

Mr. Cheliustkin answered sympathetically that the optimization of existing systems is indeed limited. Such ongoing systems are relatively stable, insensitive. Control opportunities exist within a restricted context.

Mr. Raiffa took this opportunity to react to Mr. Lefkowitz's proposed areas of research one by one, citing relevant IIASA commitments in other programs:

1. IIASA here might well act as clearinghouse of what the present state of art is, with special attention to ascertaining research frontiers and bottlenecks.

2. The projects in Design and Management of Organizations and in Optimization of Large Scale Systems are also directly assaulting this topic. Problems of decomposition might yield to the pressure of a coalition seeking solutions.

3. Computer Systems Conference had been particularly interested in information processing, improvement of data base manipulation, user-oriented output.

4. This is of great concern to the Energy Project. The existence of nuclear reactors obliges consideration of reliability and security control. How can we do cost-benefit analyses involving risk to human life?

5. This has a logical tie-in with long range technological forecasting, a matter discussed at length in the Computer Systems conference. Research about breeder reactors and fusion plants is also relevant.

6. George Dantzig's project, Optimization of Large Scale Systems, could cooperate here.

7. The Computer Systems Conference favored investigation of automated design.

8. Externalities in terms of pollution is a concern of the Ecology, Water Resources, and Energy projects.

Presentation of National Research Activities

German Democratic Republic (Mr. Koziolek)

Activities in the GDR are mainly conducted by scientific institutes of the various branches of industry, as well as by the systems analysis and computing centers of large combines. This decentralized approach has established close working relationships with actual production. "Total systems" are no longer drawn up today. Instead partial solutions are sought which are suitable for being introduced progressively and for ultimately being integrated. A number of firms and combines of fundamental importance to the national economy have developed automated production control systems into one of the most consequential and effective fields of application of electronic data processing.

Projects for the utilization of APC systems have been implemented successfully in various spheres of metallurgy, the chemical industry, machine building and electrical engineering. A hierarchical model and computerized system is now operative, for example, in the oil refining industry. Certain problems associated with major technological processes--e.g. crude oil distillation, synthesis of ammonia, manufacture of terephthalic acid--have been solved. The problems solved include data logging, data correction, supervision of limit values, signalling of limit-value transgressions, computation of technical-economic index figures, and throughput integration. A central master computer to which process computers are linked handle such integrating problems as balance adjustment. In addition to the significant economic savings made possible through this process computer system, disruptions resulting from subjective errors in the operation of the installation have been reduced appreciably.

Efforts are being made in the metallurgical industry to rationalize and intensify the exceptionally complicated process of supplying the national economy with the complete and correct assortment of metallurgical products at the right time and place. Here, methods of operations research and electronic data processing are instrumental. Efforts include both measures to master the processes of long-term planning at the level of the national economy by the corresponding ministries, and measures to perfect control of production processes concerned in companies and combines. For this branch of industry, a so-called strategical planning model has been created which has made it possible to compute and evaluate--with auxiliary balancing and optimization methods--a large number of potential development variants for a period of fifteen years.

Experience with automated control underlines the importance of close contacts and mutual understanding of problems between the project designers of the system on the one hand and the personnel who will use the system on the other. Strong ties must be maintained throughout all stages--from preliminary studies of the problem and project planning activities until actual project implementation.

Considerable attention is being devoted to the difficulties of rationalizing technical production preparation. Work is being done on an Autevo system. The automation of technological production preparation consists of methods and processes for automated production of process documents and procedural instructions for the material production of products, assemblies and parts. Documents may include work plans, work instructions, punched tapes, and program cards. Electronic data processing is currently being used in technical production preparation for the design of printed circuits and wiring diagrams, for computation of the spatial arrangement of rod structures in building, and for computation of systems for the generation of the geometry of ship bodies.

Problems associated with the subject "Automated Production Control Systems" of special interest to IIASA can be summarized as follows:

1) Generalization of scientific design principles for such systems using the methods of systems analysis and drawing upon the most advanced lessons to be learned from experiences in other countries.

2) Combination of differing mathematical models of operations research in this system--close attention to model parameter adaptation.

3) Creation of effective computer hierarchies for such systems, including corresponding dialogue systems.

4) Integration of individual systems into a larger system.

5) Consequences of the alterations that result from implementation of such systems, and of alterations in company organization, in existing information systems, and in worker relations.

6) Control strategies for complicated machining and processing operations.

7) Principles of automated production control.

8) Establishment of program libraries.

Mr. Koziolek felt that IIASA should do its best to generalize experience gained in member countries and to mediate an exchange of understanding. A project of overwhelming interest would be the attempted generalization of construction principles of automated production control systems. Later on it would be possible to decide whether to specialize in the elaboration of sections of such systems that are of especial scientific interest or whether to participate in the elaboration of control systems for other IIASA projects which may have advanced sufficiently to profit from them.

As for IIASA's research program, practical experience acquired from relatively imperfect forms of systems analysis must not be overlooked. Practical management activity does not always or only include large-scale systems analysis backed by a computer. Forms of systems approach and applied systems analysis of the problems of industrial enterprises that have been comprehensively substantiated in theory but which employ simple methodology can surely be included in IIASA's methodological research with profit.

France (Mr. Estève)

Mr. Esteve presented a report on planar technology for economic control of silicon devices production (Document C). This is a concrete example of a three-level control system supported by a data bank. The series of questions which followed reflected the practical interests of delegates and identified a range of problems commonly encountered: How to define algorithms of coordination? How to introduce daily measurements into data bank? How to incorporate changing material costs into manufacturing system? How implement corrections when production drifts beyond quality control limits? How to increase responsiveness of system to accelerate decision making time? Is the model adequate? Is there any way to prove adequacy? Does model reflect the real life problem--can this be proven structurally?

Italy (Mr. Brioschi)

Mr. Brioschi proposed possible research into input-output relations in industry from point of view of material and energy conservation. He noted that problems of competition are more characteristic of industrial economics than problems of optimization. IIASA is in objective position. The example was cited of a newspaper article about an automobile that can run for twenty years--forgetting social implications, this annoucement is intriguing from the standpoint of economics.

Mr. Raiffa explained that this issue has an important role already in other projects. The Energy project is concerned with diminishing energy consumption. Recycling of materials is a theme in urban management program. Some delegates felt that while the topic is interesting, it is not directly relevant to discussion of control applications and is too broad. Others thought that it would be irresponsible to ignore the matter altogether.

Canada (Mr. Florian)

There is no "frontier" work; all efforts are standard and well-reported. Control of production flow of multi-product plants finds principal application in paper and paper products manufacturing. Linear program models for product mix are in use. Optimal scheduling problems are important--how to use most cost-effectively the machines which are capable of making a variety of products but not simultaneously. Transporting products also has challenging scheduling aspects. In attempting to make efficient use of barges and tugs, most successful methods employed are heuristic. Universities are especially interested in optimal scheduling and non-exact methods. Time today is an expensive commodity.

In describing finishing machines using automatic programs in the glass manufacturing industry Mr. Florian alluded to the success of the enterprise. He was asked what the meaning of success was. Increased production? Decreased wastage? A general lack of criteria for measuring "success" is a deficiency of major proportions in the field. Mr. Florian suggested that a system which people implemented and continued to use might be termed successful. Freeing manpower from tedious, time-absorbing tasks is also grounds for labelling a system successful.

Federal Republic of Germany (Mr. Eversheim)

A representative picture of mechanical engineering work in West Germany would agree substantially with that depicted by Mr. Hatvany in Hungary (Document I). Numerical control is of dominant interest. The Technical Universities of Berlin, Stuttgart, and Arnheim are all concentrating effort in that direction. The telescoping of innovation times and need for increased communication along production lines is contributing to NC orientation. A trend towards integrating design and production planning departments within industry, burgeoning attention to computer-aided design. Setting up data banks so all modules of a total system have access is a feature of present systems--when production is done by DNC, machines readily transfer data to shop floor. A final goal is achieving continuous information flow from design through assembly. Work in Mr. Eversheim's institute is conducted in cooperation with industry--not a green field situation. There is constant feedback whether proposed solutions for practical difficulties are in fact helpful. In general decomposition of large models and systems into transferable units must invariably characterize methodology of machine industries in the future as demand for increased production grows simultaneously with demand for production flexibility. Designing fundamental modules for industrial use is an expensive process--it is essential to build them to be used again and again. Mr. Eversheim expressed interest in totally robotic industrial systems.

<u>United Kingdom</u> (Mr. Rosenbrock)

There are two possible areas for IIASA. The first concerns the structural properties of systems. Despite intensive work in control theory many structural questions remain without answers. How, for example, do the properties of a system (controllability, observability, order, degree) depend upon the properties of subsystems? What are correct ways to define controllability and observability for non-linear systems? What is required is a "Hierarchical Theorem of Systems" instead of a "Theory of Hierarchical Systems." In effect "we're like a designer of diesel engines who is ignorant of thermodynamics." The importance of structural questions is that they define what can and cannot be accomplished. Answers are essentially independent of system size. Considerable progress is being made at present, partly with vector space methods and partly with algebraic methods. A relatively minor effort in the area by IIASA could usefully coordinate what is being done elsewhere and disseminate information about that work.

The second suggested research area is of pressing general concern: whereas automation in the process industries has acted to make the plant operator's job more demanding and more interesting, the opposite has occurred in manufacturing industries--jobs have been simplified and denuded of interest. A revolution in the technology of manufacture seems inevitable in the coming decades as computers and more advanced machine tools are introduced. IIASA might choose to anticipate grim reality by beginning now to consider and seeking to improve working conditions which technological progress creates. Improvements might occur naturally--as happened in process industries --but they more probably will require conscious thought and effort. The imposing difficulty is to make jobs more interesting while maintaining elevated standards of productivity and efficiency.

Mr. Raiffa commented that IIASA conferences on several occasions raised the issue of job satisfaction, and IIASA is investigating possible ways to pursue the topic.

Mr. Lefkowitz said that he agreed with Mr. Rosenbrock's assessment of the importance of studying structural properties of systems. Without generalizations about design, about what is and is not possible, every problem would be treated as new and distinct.

The Conference was informed that a IIASA project for the coming year was compiling a state of art handbook of systems analysis. Mr. Raiffa expressed his hope that "structural properties" would be included.

United Kingdom (Mr. Leslie)

Together with computer manufacturers and a scattering of university and government laboratories, the Manufacturing Systems Group at the National Engineering Laboratory is interested in the system engineering approach to batch production in the manufacturing industry--i.e. excluding both continuous production control and mass production on assembly lines. In the UK this leaves approximately thirty thousand companies employing batch production methods, some one thousand of which have production control computer programming aids. Few firms yet have a total production control system ranging from design, through planning, estimating, and inventory control, to production scheduling and computer controlled storage and dispatch. A survey a few years old indicated that complete modelling of every significant factor in a manufacturing unit necessitated complicated multi-dimensional networks which made manpower needs and cost too high to sustain hopes for economical modelling. As a consequence the Manufacturing Systems Group engaged in research to develop separately limited models which will yield economic returns for an industrial user, bearing in mind that such units must later fit together in an integrated manufacturing system.

Programs arising from this approach fall in the areas of computer aids for numerical control, production scheduling, production planning, estimating, and computer-aided design.

Experience jointly with the British Shipbuilding Research Association led to their "Britships" program which treats the design of the hull of a ship from initial lofting to the production of control tapes for the NC burning of nested plates. Similarly, there is experience with the Computer-Aided Design Center and the British Aircraft Corporation in exploring best interface possibilities between graphic design packages and NC computed programs. Experience with the Machine Tool Institute at Aachen since 1964 and with U.K. industry has accelerated progress towards superior ways to capture and make available to industry "cutting technology" or the provision of feeds, speeds, and sequences of tools for most efficient production of desired features--tapped holes, removal of metal, etc.--in engineering components. By regarding this as a small but important part of a manufacturing system, it became possible to develop a free-standing computer program for the planning engineer to use whenever cutting in a machine tool is involved. The same program however, automatically provides cutting information to be punched on numerical control tapes and also feeds back to the designer the cost of making proposed new components in various ways in his own workshop.

Computers are generally regarded as an aid to man, not a replacement. For example, the planning and estimating program uses a data bank of cutting information and supplies estimated costs and times for production of parts; should actual cost or time diverge significantly from estimates, this information is fed back to a chief planner who must ascertain why and, if he thinks it is necessary, must update relevant data in the data bank. The model of the workshop is therefore adaptive but exploits skilled manpower to control the adaptive process. This is a necessary expedient because even in the segment of the complete production system mentioned in this example, there are so many variables affecting cutting efficiency--over eighty--that to date it has proven impossible to control all or to account precisely for the effect of each. A data bank for the subset of materials, machine tools, and workpieces produced in a given workshop which will effectively reduce the number of variables appears preferable as a goal to any search for parameters and an algorithm that might be universally applicable.

Direct Numerical Control is particularly appealing because in a workshop such a system provides for the first time an opportunity to monitor in real time everything that goes on and therefore facilitates greatly the construction of a reliable data base. Too often data bases must reside on a foundation of hearsay, on information presented to the system by workshop staff who have their own reasons for filtering the data arising from their tasks and for adding "noise" to it as well.

In response to Mr. Leslie's report a delegate remarked that much ongoing research work reflected the hard fact that short term <u>results</u> are necessary to motivate industry to adopt control procedures. This is an additional advantage to a "step" approach towards total systems but an integrated strategy remains the ultimate goal.

<u>United States</u> (Mr. Kriebel)

Mr. Kriebel presented his "Law of the Hammer": give a five year old child a hammer and he will apply it random and not believe you when you suggest there really are not many things in his environment that need hammering. Grown men in responsible places reacted similarly when computers were first put in their hands. Previously in the petroleum industry, before mathematical programming, the man who ran an installation was more likely than not an entrepreneur who applied the acid test of earnings to all production questions. Today, there are managers running models of wells and refineries every other day which cost more to run than potential savings accruing from their wisdom. In the paper industry, key decision variables remain today the province of a managerial artist. Mr. Kriebel advises not moving too fast to eliminate individuals from systems with the advent of advanced technology. IIASA might be well-advised to focus on management science implications of control problems. Hierarchical control structures featuring problems of scheduling and allocation are an excellent research area. The best way to integrate distributive data processing in such structures is another important area of study.

Mr. Kriebel remarked that he was aware of some two hundred various data base systems with various daily announcements of improvement. Invariably, however, a gap exists between claims of systems and their real results. Proliferation and success in languages for numerical control has led to formation of various committees to attempt some standardization, but such work proceeds principally in terms of periodic boasts of accomplishment but of not practical results.

The use of design prototypes and simulation techniques appeared to Mr. Kriebel to be laudable. There is always a danger that people (especially designers themselves) will consider a design to be The design and live as if the world never changes. Humble commitments to original designs usually have a positive effect when the product is at length operational.

Addressing the issue of transfer of technology, Mr. Kriebel thought that while standard languages on a program level have been to a resonable extent achieved, the same is not true on a data base level. How then is it possible to proceed? A delegate answered that although no ideal language may ever be found, something better is constantly coming along, and an argument solely founded on language difficulties would be insufficient to justify making no commitment towards transfer of technology. It is true that there are many bureaus, committees, workshops attempting standardization work. Perhaps from supranational angle IIASA can find out what actually has been done.

Mr. Lefkowitz added that until better standardization is achieved in the process industry an extraordinary amount of resources continue to be poured inefficiently into programming.

The waste of reduplicated effort is weighing on industry's mind.

United States (Mr. Feldman)

Mr. Feldman spoke with a triple persona--as computer scientist, as proponent of artificial intelligence work, and as delegate to the previous conference on Computer Systems. He commented first about standardization: he feels it is not yet possible in the foreseeable future either at the NC or the data base level. Deep intellectual problems remain. Standardization is part of professional worries of computer scientists. It was resolved at the Computer Systems conference to embark upon construction of a system with the ability to deal with variety of data representation. This would permit a user at a terminal to ask for information from a computer that knows where and in what form the information is kept and retrieves it in natural language without any visible intermediate step. This ambitious project has potentially great reward for all systems requiring accurate information flow. IIASA's initial commitment will probably be in form of study of semantics and representation within computers. Computer-aided design was also stressed in that conference; IIASA is likely to survey the area.

In AI the main application attempted currently is discrete manufacturing and assembly inspection. Some progress has been made. The preceding discussion was somewhat upsetting because it suggests disruption of communication between AI people and industry. AI has been busy tackling complicated decision processes beyond scope of rigorous techniques: How to capture rules of thumb humans use to make decisions? How to search spaces not limited by formal constraints and to apply these heuristic methods to management? There is a strong sense that AI has "abandoned" heuristic search linked with control theory because of the limit to complexity of problems that can formally be handled. AI can do certain things beautifully but these are seldom real. It is as if Industry is still flushed with optimism, elated by promises of ten years ago which as of now there are still no prospects of seeing fulfilled. For industrial people there is a clear need to synthesize the work of the last ten years in AI relevant to management decision making. The time lag is appalling. Management has a "tool-kit"--it must recognize the limits of what is already in the kit and shop for acquisitions of value.

For advanced automation systems, one can foresee in ten years devices with manipulation and perception to replace assembly workers, say, making motors. What to begin worrying about is can such robots convert to make a different motor? How can the robots be taught?

In conclusion, Mr. Feldman said that perhaps automated control of industrial systems is so big, so well-covered a field that IIASA should not enter in.

Poland (Mr. Kulikowski)

Mr. Kulikowski first described general methodological approaches and then cited certain applications to practical problems. The center of research is the Institute of Applied Cybernetics of Polish Academy of Sciences. There is ongoing work in identification and modelling of industrial systems, with close looks at the relationships between input and output of typical industrial processes--e.g. how can the relevant parameters be identified? Building an industrial model involves aggregating a number of processes with decisions. This would be a descriptive "common sense" model, but a non-active one. Researchers must incorporate administrative structure in any such model. An optimization study would be highly relevant in raising special scheduling problems. The goal is implementation of control by hybrid, analog, and digital computers.

Mr. Kulikowski then listed a number of industries employing partial automated control--e.g. glass and ammonia manufacture. There are concentrated efforts now in steel mills. Control of coal mining is a national speciality.

Mr. Raiffa thought IIASA might look at modelling for particular industry or plant and study how to model a specific plan for normative decision making. The choice of the industry or plant must involve overlap with other IIASA interests, methodologically and substantively. Coal is a possibility, for the Energy Project has at present a strong nuclear orientation but is looking for geo-thermal and solar topics. If IIASA were to explore modelling, transferability is likely to be one of major problems wrestled with.

Mr. Cheliustkin considered it imperative always to remember the need for adaptive models--not parameters alone, but structure as well. One must always think of application tasks.

Czechoslovakia (Mr. Mazel)

The Institute for Industrial Management Automation in Prague (INORGA) is one of the first research organizations to start applying computers and mathematical methods for management and control in practice. In CSSR at present, topics in applied systems analysis research include:

a) development of design and programming techniques and application of middle and large scale EDP for metallurgy and engineering,

b) design of automated control systems including utilization of mathematical computing techniques,

c) data processing and operational research consultation in the field of organization and management, and

d) cooperation with specialized engineering organizations to lay out preliminary projects for building up new production capacities, especially in metallurgy.

At present in satisfactory full operation with an automated control system are a SKODA car factory, and other plants with a complicated production structure, such as CUD in Prague and SKODA (job-shop and small series production) in Pilsen. Solutions to various metallurgical challenges include: a) construction of an automated control system for steelworks, b) production control of steel plants with electric arc furnaces, and open-hearth furnaces, c) pig iron production control, d) basic oxygen furnaces control, e) soaking pit control and blooming mill control, f) control systems for rolling mills and for metallurgic plants power systems, g) optimization of rolled material production, h) mathematical modelling of section mills, i) operative control of ingot stock, j) operative record keeping of finish mills, and k) production planning and scheduling by usage of adaptive models of LP and DP.

In the planning stage are the development of uniform methods of ACS solutions and project management, and the formulation of methodical principles and tasks for program blocks formation which will guarantee block universality and maximum adaptability under diverse conditions. Goals are "model conceptions and project solutions." A by-product of the approach will be the founding of a library of algorithms with mathematical description and recommended usage.

Czechoslovakia (Mr. Kacir)

The Institute of Applied Systems Analysis of Slovak Industry at Bratislava is concerned with applied research in the area of production management and production control systems for industrial enterprises. The research program has two parts: 1) Methodological problems, and 2) Problems of designing and developing concrete production management systems for concrete enterprises.

1) Basic research areas:

   a) Research into rational structuring of production management systems. Applying hierarchical concepts based on five levels of criteria, the organizational and functional structure of five chosen enterprises has been analyzed. Some uniformity, and therefore basis for standardization, exists in the structure. The degree of uniformity is a function of depth of structuralization, of the type of subsystem selected, and of similarity of technologies in use.

   b) Research into achieving some appropriate degree of unified description of systems and subsystems. Standardization of procedures and documentation in system work are an important result of this work.

   c) Research into problems of organization and control of systems work itself. Derivation of a system of control for major systems projects.

   d) Research into use of operations research models for special problem solution, e.g. applying linear programming for optimization of product mix in the textile industry, applying linear programming for optimization of wood allotment as raw material in the wood industry, applying inventory models in the wood industry.

2) Basic research areas:

   a) Subsystems for production control in machine building, textile, wood and chemical enterprises.

   b) Subsystems for sales management in the textile industry.

   c) Subsystem for labor force management in machine building.

   d) Subsystem for inventory management in the wood industry.

   e) Subsystem for equipment control in chemical enterprise.

   In designing these subsystems user requirements are a cardinal consideration. Methodology is tested and modified to conform to special conditions of different enterprises.

Mr. Kacir described the interest of the CSSR in Research areas 6.1-6.4. outlined in the IIASA Provisional Research Strategy.

Bulgaria (Mr. Gatev)

In Bulgaria, research and development in industrial systems adheres to a unitary Plan for social and economic development--a five year plan for perfection, modernization, and automation of industry. Certain elements of the plan would interest IIASA: development of technology (devices, materials, hardware); development of software (SOS, POS, etc.); systems studies and design (automated systems in chemical, petrochemical, cement, metallurgical, mechanical, paper, and other industries); education of specialists. Mr. Gatev proposed that IIASA's research program include 1) Modelling and 2) Automated Design of Automated Control Systems:

1) Modelling (identification) should be oriented to technological (zero) level, operational control and high level of control system.
2) Automated Design of Automated Control Systems research might seek out automatic generation of mathematical models and control algorithms. A concommitant venture would be the derivation of algorithmic problem-oriented languages to design control systems.

Close cooperation with IIASA groups in computer systems, artificial intelligence, and optimization is essential.

Mr. Gatev was asked what sort of model for design purposes he envisioned--steady state or dynamic? His answer was that although there are at present effective dynamic models for control reserve tasks operative in existing plants, any realistic project must initially aim for a steady state model. The delegate who raised the question said he was aware of much research done by chemical and oil companies in the dynamic models area. There is reason to believe any modelling exercise--to be complete--would take from six to ten years. Mr. Gatev thought IIASA could best concentrate in-house resources towards development of software and control strategies. Collection of widely scattered, often abstruse material would be a valuable service.

Japan (Mr. Nomoto)

Until the advent of IIASA, systems studies have proceeded in a generally unsystematic way in Japan. Japanese participation in IIASA has led to internal organization of systems work. Planning is in progress now for a national institute for applied systems analysis. Mr. Nomoto described automated control research and development in process industry steel, mechanical and shipbuilding industries. Inspiration for the steel industry derived from the Spenser Steel works in the UK which a full ten years ago used a computer to control an oxygen furnace. In 1968 an integrated system for a whole plant was first implemented when Japan Steel Works opened a new plant 100 kilometers south of Tokyo. That plant now produces fifteen million tons annually. For planning plants of such size computers are indispensable. Since 1968 all six major steel companies have built new plants, the largest of which will when it fulfills production potential, have an annual output of sixteen million tons. All new plants have a total online system with online control linked to management control. Implementing hierarchical systems inevitably entailed problems--human, not technological problems. In 1972, 276 computers functioning in steel plants were supplemented by 90 used for managerial purposes. Automation is desirable to boost production, to stabilize quality level, to save money, to insure accuracy of data management, and to achieve standardization of operational works. Japan is at present providing consultation services for the People's Republic of China in construction of a steel plant to produce four million tons annually.

International stimulus has prodded Japanese naval architecture. Seven or eight major companies are seeking an automated, integrated system for shipbuilding. At a conference in Tokyo last August three hundred and fifty representatives from all countries gathered to discuss computer applications to shipbuilding. Reasons for applying systems study and computers include shortage of skilled labor, need to abridge production duration, to lower prices and, again, to achieve standardization in operational works.

Mr. Nomoto's personal suggestions for IIASA are:

a) conduct productivity studies of integrated industrial systems;

b) attempt a meaningful assessment of human factors involved in such systems; and

c) initiate comparative studies of the structuring of integrated systems.

Austria (Mr. Fleissner)

Advanced projects are just beginning in various Austrian technical universities. Automated control is applied in nationalized steel industry. Mr. Fleissner called conference's attention to a previously slighted aspect of automated control--the implications of such technology for work. He expressed concern for quality of life. From the standpoint of workers there should be numerous indicators in industrial models of successful production which are usually omitted: health conditions, organizational pressure, leisure opportunities, income. A firm is basically not a harmonic system; optimization must recognize different interests in conflict.

Young workers are currently interested in experimental work being done in this area. This is a potential asset for labor unions.

A delegate remarked upon similar modelling employed by BEA during wage bargaining over past few years.

Hungary (Non-Member Country. Presentation by Mr. Hatvany)

Mr. Hatvany described efforts to achieve technology transfer through total manufacturing systems in the mechanical engineering industry. IIASA is well-placed to attempt to breach the technology gap separating the developed and developing worlds. Others are engaged in research to develop total systems but without transferability in mind. IIASA may perhaps have to contend with proprietary interests and with nationalistic problems, i.e. rigidly defined development policies. Experience strongly suggests the value of a modular system integrating numerical control, direct numerical control and computer-aided design both for production and for educational purposes in a backward environment. In a pilot plant near Budapest, such a system is in use to turn out machine tools--this might be an area for international experimentation (Appendix I). The total visibility of such a system is a marked virtue. A technical problem which remains is the functioning of a complex data base--diagrams in terms of simple feedback loops invariably understate complex information relationships (Document I). Mr. Hatvany concluded his report with suggestion that IIASA first study the feasibility of transferable systems and, if convinced of their potential, proceed to initiate a project to determine guidelines for setting up such systems.

Delegates referred to ongoing projects in various industries for achieving total manufacturing systems. The British Aircraft Corporation is involved in developing a complicated process manufacturing system to produce thousands of parts. Should IIASA duplicate such work? Mr. Hatvany reported that he was in close contact with British Aircraft Corporation and twenty other firms experimenting with similar systems. What he hoped IIASA might achieve was a reduction of the "nothing is too expensive" approach to a form that existing engineering plants in the developing world can use--a communication of know-how and skill that does not interest major companies.

Since no two systems ever are alike, one delegate challenged the notion that transferability is a practical goal. Mr. Hatvany countered that within limits there is room for remarkable achievement. Data processing systems in primitive societies have, for example, raised significantly the level of environment. The catalytic effect of an advanced technological enclave together with skillful management is potentially profound.

The costliness of numerical control was held up as an argument against widespread implementation of such systems. Mr. Hatvany explained that nearly all mechanical engineering at present is going in the direction of NC which may be expensive originally but is adaptable. Mass manufacture of a single product is chiefly an anachronistic phenomenon--market fashions, consumer demand, and technology are all changing rapidly. Meaningful contemporary mass production requires adaptable equipment. Small batch production is of increasing prominence.

Delegates asked what approaches are adopted to scheduling problems and to the feedback of information on line into the design. Mr. Hatvany replied the collaboration of systems analysis specialists assures consideration of these problems. He agreed that maximum feedback is essential to such systems.

Mr. Cheliustkin remarked that the work described was surely very interesting for IIASA.

IIASA and Technical Policies

Mr. Letov formulated questions related to development of Technical Policy. He first told of an old fable about a donkey, a goat, a monkey, and a bird who wished to form an orchestra. They sat down to play and produced noise. Why noise, they asked? Are we sitting in wrong order? Mr. Letov asked analogously whether any discussion of automated control of industrial systems which ignored administrative decision making could be valuable. What are possible roles of director's hierarchy? Consider automobiles, for example. What kind of technical policy should be related to production--cars should transport people, should be safe at high speeds, should be durable. But where should the limits be drawn? In the aircraft industry should planes be subsonic or supersonic? Are there externalities which ought to be considered? Surely there are recognizable limits to desirable development--not necessarily limits that human beings realizing their full potential can reach but common sense limits as well. From a social point of view should we take not only our own requirements and demands into consideration but those of coming generations as well? Should IIASA engage in scientific activity to achieve optimal structures for shoddy philosophies?

Mr. Letov believes that the project of which he is director, Water Resources, has an intimate connection with the field of automated control of industrial systems. The technical policy of the Water Resources Project advises that every industrial plant should have water treatment facilities to avoid polluting nature. Despite firm paper measures in many nations, at least three-quarters of operative industrial enterprises continue pollution.

Mr. Lefkowitz thanked Mr. Letov for his pertinent remarks. The general problem of depleting resource and energy sources should not to be forgotten either.

Mr. Cheliustkin, demurring, thought industrial control should not concern itself with what is produced--that is an upper level decision. When faced with building a bridge and figuring out how best to build it, we do not distract ourselves by wondering whether to put the bridge across or alongside a river.

Mr. Lefkowitz offered his opinion that planning problems necessarily include medium and long range decisions of what to produce and how to distribute.

A delegate mused whether an abstract study of how to construct a bridge might not end up dictating that the bridge stretch alongside the river. At this point, some delegates felt that the conference was "getting beyond reality," and asked if we must take everything in the world into account before doing anything. Perhaps one should forget optimization of what should be made and concentrate on making factories more efficient.

If it is possible to consider mankind's energy needs in the future globally, a delegate postulated, why is there antipathy to seeing industry with similar perspective?

Opinions were segregated into two entrenched camps:

1) Industrialists have "stuff to make," there is "technology around," how to produce best is the question of primary urgency; or

2) IIASA is not in "that business," but rather is dedicated to weighing externalities.

One delegate regarded the split as "real and reasonable," and as grounds to conjecture that IIASA is not a suitable domain for any project of the first variety.

Mr. Raiffa described a somewhat similar schism which developed during Urban and Regional Development conference. A representative of the New York City Rand Institute talked about fire-fighting and optimal distribution of firehouses and scheduling of shifts, etc. He was worried basically about management implications. Some delegates considered the talk directly relevant and valuable. Others thought the speaker had missed the point--that it is foolish to plan to fight fires when similar energy expended to improve housing and garbage collection could prevent fires. Difficulties arise when, discussing an "axiomatic structure," certain parties to the discussion reject the structure. Compromise in orderly fashion is necessary for dialogue to continue. Perhaps it is best to separate the issues raised. From a narrow point of view how can we best design and develop an industrial system? What are the interfaces of such design and development activity with other IIASA projects? From a broader point of view--call it idealistic--what are the price and the implications of environmental issues, quality control, and monitoring for technology and for industry?

Brief Overviews of Three Ongoing IIASA Projects

Water Resources Project

1) General modelling activity under the direction of Mr. Letov. Continuation of work begun at the Institute of Control Sciences in Moscow. Interfaces with projects in energy, urban and regional systems and, optimization of large scale systems.

2) Initial survey of the state of the art: three major studies recently completed (Trent, Vistula, Delaware Rivers). Gather principles from these studies, determine what methodological, political, legal lessons they have to teach. Issue open invitations to those with experience to come discuss high level strategic problems.

3) A modest project seen through from beginning to end with a rigorous systems analysis approach: perhaps an ecological project to cooperate on study of Alpine Lakes, an undertaking immediately useful for the surrounding countries and valuable as a pilot project for work now agreed upon between USA and USSR--the study of Lake Tahoe and Lake Baikal.

4) Analysis of the infrastructure of a large river system from a management point of view. Perhaps investigation of various commissions controlling transport, power, and recreation along the Danube. Join work with project in Design and Management of Organizations to assess organizational and legal aspects of commission interaction.

5) Periodic conferences on well-defined topics, e.g. oil spills.

Energy Project

1) Systems perspective throughout.
2) In-house study of demand and supply of resources. Substitutability of one energy source for another.
3) Concern with technological uncertainties--breeder reactors, fusion, solar, and geothermal energy.
4) Interest in developing forecasting procedures utilizing expert opinion, a subject discussed at computer conference. If current usage of energy continues and if the developing countries in turn assert claims to energy sources, what will total demand be like? In the long run there is probably enough energy but waste is the problem. Scenario writing.
5) Thermal pollution is the most ominous problem--incremental rainfall, melting of polar ice caps. Collaboration with meteorological centers to study climate.
6) Concern with quality of life has motivated project to investigate setting up of environmental standards.
7) Problems of evaluating risk in decision making. Proliferation of nuclear know-how necessitates procedure for control, accountability, and monitoring of nuclear materials.

Ecology Project

1) Concentrating efforts on study of equilibrium and resilience. Direct attempts to involve decision makers in modelling.
2) Plan "to get hands dirty on concrete level" analyzing Alpine Lakes.
3) Monitoring of environmental standards is approached with the idea of influencing data collection agencies to collect relevant data--information useful for systems analyses on global level.
4) Project to compare existing global model packages interested in both methodology and structures.

Mr. Raiffa expressed his hope that the summary presentations might suggest to delegates the spirit of IIASA's planning, the thrust towards combining and interweaving programs.

Discussion

1. One delegate wished to emphasize the importance of IIASA's engaging only in important, feasible activities which would otherwise not get done. At present an adequate fund of knowledge exists about how to use computers in industry in many ways. In retrospect, much time and energy has been wasted; anyone starting fresh should be spared floundering. Three areas are poorly considered at present:

A) What are the real, practical needs of a particular production environment. How can we predict or calculate benefits of using a computer system. In the past there was an evangelical attitude towards automation. Can IIASA develop techniques for such an evaluation? ("The fact that there is no practice-proven method for a well-founded selection of the fields of application of process computer techniques and for the determination of the required level of automation...should therefore be the motive for analyzing and generalizing corresponding international experience. A method that is applicable in practice could be created in this way." Document M).

B) Frequently gathering sufficient data to put in formulas for regression analysis, etc. is a problem. Measuring a key variable is often a great challenge. Can IIASA develop techniques to determine what data is needed to support a particular system?

C) The Conference has talked considerably about systems capable of doing operations previously performed by humans, about machinery to relieve humans of complex decision-making loads. For long days to come industry will still have employees. Far too little attention to date is paid to how employees interact with machines. (Cf. "Another problem that has not yet been satisfactorily solved concerns the manner of transmission of the controlling functions of the computer to the object....Of major scientific and practical interest in this connection is the question which assignments should be transferred to the computer and which jobs should be allocated to the man in the process of production control. In this connection it is necessary to investigate the interaction of man and machine in such processes, and how effective dialogue systems should be devised for control systems." Document M)

2. In the course of the conference there was lengthy discussion of the art of modelling. Certain themes asserted themselves recurrently.

A) How to decide what degree of detail to include in a given model? Once the idea was widespread that a model should be as inclusive as possible. Experience now suggests otherwise. "To build a model which adequately represents a process at any time it is necessary to increase the number of variables (many of them impossible to measure) thus making the model very complicated, or even nonfeasible. To overcome these obstacles the adaptation of the models is used so that the model having only few variables and adjustable parameters is close enough to the simulated plant for a short duration of time." (Document A) Delegates recognized the contradiction which exists between the desire to create a model of a system which is to be controlled that is as accurate as possible and the need to keep at a minimum the expenditures to formulate and solve the model equation. The sources of information from a given system--what data is obtainable, measurable--must further limit the complexity of any model which will be practical. With fuzzy data it is possible to employ a crude model, but then one must be more sophisticated in interpreting it. Generally there is a trade-off of the sensitivity of model, the accuracy of results in performance, and the ability of model to be updated.

B) Many people speak of models, but do they use them? What nature models are used most often--not merely reported as in use but actually helping decision makers? Rand Corporation did an inventory of models in actual use and discovered that most of these were arithmetic. Another researcher uncovered the fact that in NASA in the USA many management models purportedly in use were not, and that the more complicated and elaborate the model was, the more likely it was idle. IIASA should approach modelling with the goal of involving implementers in the process.

The importance of online computing with graphic display was stressed. The participants also felt that designers of models generally needed more experience in situations where models were to be applied. Shortly after it was reported that British Steel is now using more models than ever before, but simpler ones (no linear program in last five years), voices rose to say that models which are too simple are no improvement over too complex models. Talk returned to point (A) above: Can IIASA develop a methodology for picking the optimum degree of complexity for a model in a given situation?

C) Can IIASA develop a methodology of modelling in general? Is it possible to derive guidelines to accelerate the process from looking at various kinds of models to determine common features and to discover a means of formalizing these features mathematically? Recent work in decomposition of complex models can be regarded as tentative steps in this direction. A number of delegates remained skeptical about the possibility of any such venture or the value of any "general theory" of modelling. Worrying over a particular set of details is the essence of model building which, some thought, precludes transferability. Mr. Raiffa recounted experience within a mathematical group concerned with problems of management. In the area of "Theory of Firm and Management" complicated models exist. When actual cases arise for deliberation the models never seem quite to fit. Several models often illustrate different aspects of the same decision making problem. Still, in case after case, certain sub-problems recur. Solving certain analytical problems saves time later. A spirit, a technique is acquired with which to approach problems. Certainly a respectable activity for applied systems analysis trying to cope with real problems is to survey experiences of good modelling, to abstract whatever is possible, and at the same time to perceive artistic accomplishments, and to endeavor to communicate them. At this point a delegate clarified the fact that models of continuous and semi-batch operations are different from mechanical engineering and electronics models which include not only the process of manufacture but the nature of the product also in the model. Nonetheless, despite intrinsic differences in kinds of modelling, it may well be possible to identify correspondences and aspects with universal validity. (A discussion along similar lines about Automated Design occurred in the Computer Systems Conference.)

3. "Lines of Research in Development Automatic Production Line Control Systems" (Document B) was distributed to delegates. This is a list of twelve possible IIASA research areas compiled by Mr. Cheliustkin in an attempt to represent the variety of interests expressed by delegates during national presentations.

Mr. Cheliustkin subsequently addressed the conference about control systems currently employed in USSR for batch processing in metallurgy. The aspect of his description of steel works which evoked most response was a special version of the "travelling salesman" problem, scheduling difficulties arising while dividing ingots among pits with cranes. Mr. Dantzig, Director of IIASA's Optimization of Large Scale Systems project, referred to a body of literature dealing with related problems.

There was enthusiastic discussion of scheduling as suitable for in-house research ("Planning, Scheduling and Flow Control," Document E, an elaboration by Mr. Florian of points eleven and twelve on Mr. Cheliustkin's list). To begin with, IIASA must locate experts to conduct in-depth study of the current state of the art. Six experts might then proceed to correlate acquired material and to compose an expository paper, subsequently convening a conference to discuss their work. After monitoring the proceedings of this conference --revising and updating findings within a year--the publication of a book would be a possible concrete goal.

Mr. Raiffa asked the delegates to think of other topics suitable for similar treatment and to submit them to IIASA. Because IIASA aspires to establish maximum cooperation with other groups (universities, committees, agencies), Mr. Raiffa asked the delegates to suggest names of such groups and scholars active in the field of automated control of industrial systems.

4. Film. To impress upon the conference the potential of artificial intelligence to contribute to discrete manufacturing, Mr. Feldman ran a short film. The film depicted a mechanical arm constructing and testing a water pump. The process involved computer vision. The ultimate ideal is a minicomputer, "like DNC" hook up to large computer doing scheduling and planning.

5. Mr. Lefkowitz offered the conference general thoughts distilled from the discussions relevant to the selection of potential research projects:

a) Control of Industrial Systems refers to techniques applicable to a broad class of activities. We should avoid bogging down in particular problems, and should seek "portable, generalizable, universal" ideas.

b) Direct attention to applications to industry and not development of theory. Call on other IIASA groups to service this project with theoretical and mathematical investigations and repay them with feedback on the limits of the analytical tools when plugged into industry.

c) Examine current practice in diverse systems to discover commonalities. Perhaps review success stories in the field. Compile a State of Art publication.

d) Focus on an industrial system both representative and accessible--and try to decide how to evaluate it.

e) Remaining conscious of limited resources (few scientists), attempt to maximize intersection with other IIASA groups and increase critical size of activities by proposals which admit decentralized attack. Keep in mind that IIASA will have an integrable slate of programs.

Relevant to Mr. Lefkowitz's fourth point, Mr. Eversheim presented to the conference a "Thinking Model" (Figure 1).

Delegates expressed satisfaction with the model as "A good step in how to analyze a system." Feeling remained, however, that the what and why for analysis remained to be decided.

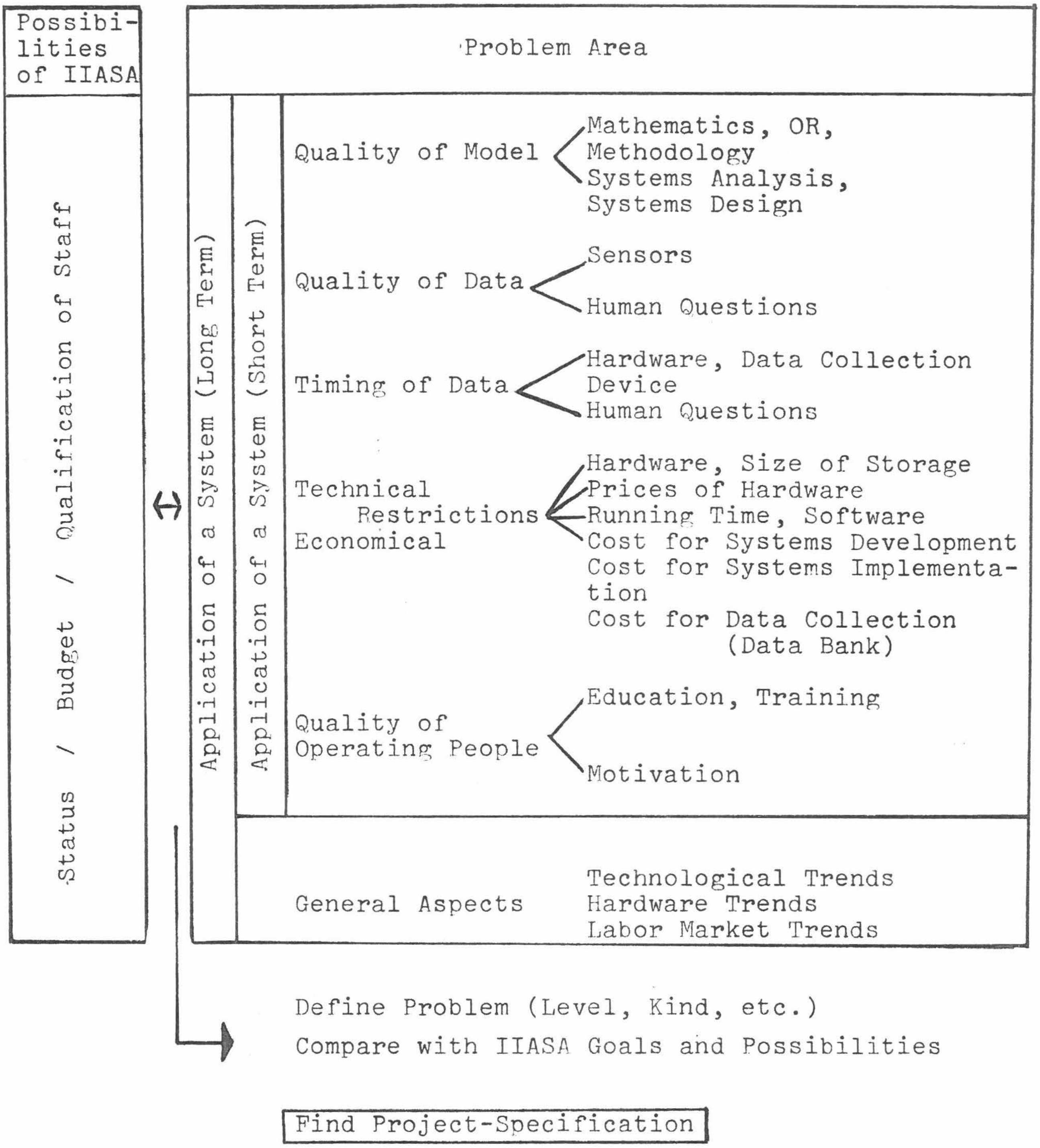


Figure 1. Thinking Model (Eversheim)

A delegate pointed out that a non-functioning system presents certain problems which experience and specialist consultations might solve. But when a system works, only not so well as it might, when improvement is possible, the detection of weakness is a far trickier proposition. A radio that emits no sound is often easier to repair than one which performs fitfully.

Doubt was enunciated that anyone with a disaster on his hands, a system that won't run, would call attention to the fiasco by inviting analysis of the wreckage.

Mr. Raiffa explained that at a previous conference a delegate recommended IIASA study not Artificial Intelligence but Natural Stupidity. Major disasters where control is sadly lacking from obviously dangerous situations still occur. Why? The issue was also discussed at length in the Design and Management of Organizations conference. Sadly the topic is too hot politically to handle. Human nature shuns exposing failures to critical analysis. Successful applications can withstand constructive criticism in a context of praise.

A modification of the Thinking Model was proposed by a delegate who thought forecasting of developments must somehow be incorporated into the scheme.

The prediction was made that analysis of systems with the Thinking Model would be most likely to reveal failures coming from bad planning and non-realistic goals. The emphasis of scrutiny should bear not on mathematical models but on organization. Perhaps the conference is too heavily academically oriented without enough delegates experienced enough in industry to realize the essential importance of the man who must open the gate to let the new computer in. It is possible to err by setting goals on the safe side, too. A realistic goal may be one you can't quite achieve.

6. Mr. Hatvany presented to the conference his attempts to begin synthesizing the emerging concerns of delegates in terms of concrete proposals. He thought it helpful to imagine a matrix, the horizontal lines of which were Mr. Cheliustkin's twelve points and the columns of which might be typical application areas. As an example of one column he made a concrete proposal of a mechanical engineering project. (Document I).

In Mr. Hatvany's proposal the commissioning of reports occasioned the comment by Mr. Raiffa that under the terms of its charter IIASA was not a funding organization. He thought, however, there was nothing to oppose paying for contributions to a IIASA state-of-the-art publication. Perhaps a periodical was a better idea than a handbook, considering the speed of innovation and discovery in automated control at present and diversity of interests. Contributions might be solicited on frontier topics, read by referees as part of standard procedure, and periodically published.

One aspect of the project involved the use in member countries of pilot plant facilities to test transferable modules. In answer to questions, Mr. Raiffa then explained that IIASA will have an excellent computer support service capable of carrying out extensive computer tasks: At present IIASA has four interactive terminals (two Hazeltine, two Honeywell-Bull) attached by cable to Frankfurt and by satellite to Cleveland. CDC remote batch equipment is possessed as well. A hook-up with the Cyber 73-74 in Vienna at the beginning of next year will provide a massive number crunching facility. We will be acquiring a minicomputer to facilitate "intelligent conversation with computer networks." A project in the computer area on networking--how to achieve computability of great variety of software, how to exchange files and programs--is contemplated.

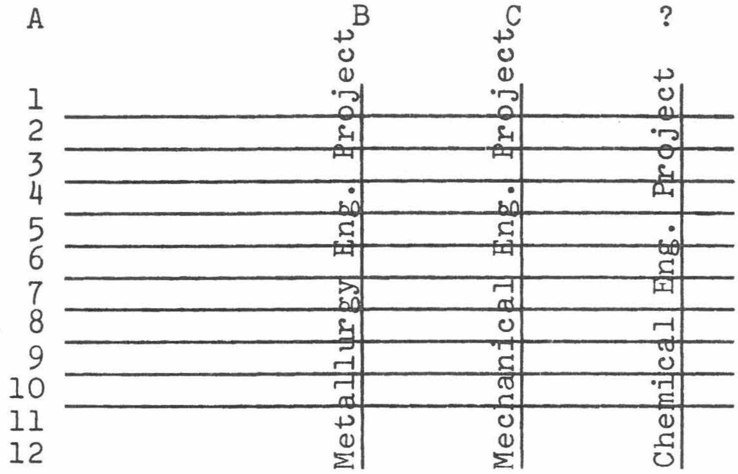
As a consequence of this newly perceived information, Mr. Hatvany appended to his proposal a suggestion that IIASA engage in in-house modelling of a direct numerical control system, or more specifically, in the expansion of an integrated mathematical model already prepared--under the constraint of limited facilities--for a CDC 3300. Testing of control schemes and information flow programs in Laxenburg would be an important sophisticated clearinghouse function for IIASA - "A first go proving ground for programs. Not a substitute for a pilot plant but an initial step."

Concluding Discussion

The conference decided to ask a committee of self-selected delegates to prepare, with the cooperation of the co-chairmen, a summary of the previous days' activities and to make ready the constituent ingredients of a possible IIASA research strategy in Automated Control of Industrial Systems. This committee met, deliberated, and reported back to the conference at large.

Mr. Lefkowitz formulated the general sentiments of the group. AC of IS must be practical in orientation and not indulge in academic exercises. It must restrict the scope of study to realizable proportions and to realizable goals. It should stress methodology--the structure of systems, the ways of handling control integration--rather than particular problems. It should achieve maximal interaction with other IIASA projects. This consensual overview is presented in Document G of these Proceedings.

Mr. Hatvany's matrix concept was reintroduced in fuller detail:



A. Twelve Areas of Investigation into the Development of Automatic Production Line Control Systems (Document B)

B. Memorandum: Integrated Control System For Large Scale Production Process (Document A)

C. Outline and Justification for Mechanical Engineering Project at IIASA (Document H)

Procedure for B and C:

1. Collation of available data (one year)

2. Synthesis (testing, checking of modules)

   a. Use of national institute pilot plant resources

   b. Use of hierarchical systems modelling tool developed along lines suggested by Mr. Lefkowitz's in-house research proposal: Proposal for IIASA Research Project on Theme of Control of Integrated Industrial Systems (Document O)

3. Preparation of report and guidelines for comparable systems

The various column-projects would have an estimated three year duration. One possible IIASA manpower allotment is:

	1974	1977
Metallurgy	1	4
Mechanical Engineering	1	4
Chemical Engineering	1	4
Hierarchical Modelling Tool	3	3

A more elaborate version of the above information is presented in Document G of these proceedings.

Attention was re-directed to the conference's resolve to pursue scheduling and flow control problems. Mr. Kelly provided a prologue to Mr. Lefkowitz's Hierarchical Structure proposal to clarify the thoroughly pragmatic orientation of conference interest:

1. IIASA must act where and when others do not or cannot.

2. IIASA should tackle real problems. It is not sufficient to identify and specify the limits of problems. Criteria for judging the success of systems must be determined.

3. A pressing need exists for methodology to divulge the payoff in a given environment of attempted automation: considering the age of equipment, availability of data, models, computers, sensors, and attitude of management--should automation be implemented? What to do further with human cogs in the system?

A possible goal for IIASA is the preparation of guidelines for organizations seeking automation and integration which will answer the questions, "Why put in a control system?" and "Is a control system viable for us?"

Mr. Lefkowitz said that, realizing the limits of time, he hoped the foregoing condensation was at least representative of the variety of interests and approaches mentioned in the course of the conference. Some sentiment was expressed that a working group should be constituted as speedily as possible to make ready a more specific set of proposals and to draw up a timetable based upon recommendations of the conference.

Mr. Raiffa remarked that such a work group was standard procedure once leadership of projects was ratified. He realized that a basic level of agreement must be achieved before convening any sizable group to prepare for implementation. The present conference is not intended to be a symposium, is not designed to be informative only for those attending but also to make possible more sophisticated conversations among IIASA staff afterwards. Out of chaos may come--if not exactly order--at least galaxies of ideas not previously charted. The free exchange of half-baked ideas is highly useful. Mr. Raiffa solicited written contributions, even "vehement minority reports." Lines of interest without majority support sometimes prove exciting and feasible as research projects interfacing with other programs. Often ideas come later--conferences sensitize, delegates to many issues but they must in the privacy of their institute offices debrief themselves. The minutes of the conference will be submitted to the chairmen for their comments and then distributed to all delegates together with documents accumulated during the conference. The process ought not to end there. Please react.

Profiting from its hectic experiences in the past months, IIASA hopes to study the organization of international conferences. Suggestions for improvements were requested from the delegates. Mr. Raiffa thanked delegates and the chairmen for their contributions and extended an invitation to those with stamina to attend the recently begun conference on Optimization of Large Scale Systems.

Mr. Lefkowitz and Mr. Cheliustkin thanked each other, their fellow delegates, Mr. Raiffa, and the IIASA staff for helpful cooperation.

Summary of Research Planning Conference on Automated Control of Industrial Systems

I. Lefkowitz, Co-chairman

It was difficult to prepare a simple, compact, generally acceptable summary statement of results and conclusions for this conference because of the many different ideas and points of view brought out in the oral and written statements and the discussions generated by the conference. These led to a variety of proposals and recommendations regarding the proper role to be played by IIASA in the area of control of industrial systems, and more particularly, regarding the nature of research to be carried out by the Institute. The differences reflect, to a large degree, the broad range of backgrounds, experiences and orientations represented among the participants. For example, there seem to be some basic differences in approach and in the definitions of problem areas as expressed by those participants oriented toward continuous process systems versus those who were primarily concerned with mechanical or production operation systems. Nevertheless, despite the differences, there were a number of problem areas which appeared to be of common interest in the sense that they were cited by various participants, or that there was expressed agreement on their importance and relevance.

There was considerable discussion regarding the role IIASA should play in the area of industrial systems. Some of the points of controversy are summarized as follows:

1) Should IIASA try to set up research projects in this area or confine itself to serve as a "clearing house," i.e. cataloging relevant information on available models, computer programs, analytical techniques; assessing "state of the art" with respect to various industrial applications; identifying new problem areas and priorities for research. The main arguments against trying to do a research project was that a) it would be impossible to define a meaningful problem and to obtain useful results within the severe constraints of limited time, limited laboratory facilities and limited funds available to IIASA, and b) various research groups among the member nations are in a better position to carry on work of this sort than a newly formed IIASA team. The counter arguments seem to center on the position a) that there were indeed research activities appropriate to IIASA, and b) that a clearing house function would tend to be somewhat sterile and unattractive

to the kind of outstanding person who we might want to attract to IIASA. The concensus seemed to be against the clearing house function, although it was felt that an initial phase (and a by-product) of any study would necessarily encompass an assessment of the latest developments and state of the art relative to the field of study.

2) Should the research project be directed to an application of applied systems analysis to a specific industrial system, or should it be concerned with the development of methodology and approach? The argument for the specific application was that, in order to get useful and meaningful results, it is necessary to focus on a specific and well-defined problem, and that attempts to generalize tend to lead to results of only academic interest. The argument in favor of general methodology rested on the premise that such results would have very much broader applicability and be more in keeping with the spirit of an international research institute. This latter position seemed to carry more support among the participants; however, the feeling was expressed that the generalizations must proceed from experiences with real systems applications.

3) Should the research objectives include societal considerations in addition to the normal technological factors in designing the system? This was perhaps the most warmly debated issue with those in favor arguing that such considerations were very germane to a "systems" view and to the broad goals of the IIASA program. Those in opposition contended that the inclusion of societal factors would only serve to further dilute the research effort and lessen the opportunities for achieving definitive results within the constraints envisioned. Again the balance seemed to be with the latter position, with the possibility of including within the scope of the control objective, some active consideration of environmental factors, energy resource constraints and the like.

Notwithstanding the differences mentioned above, there were many points in common in the citing of problem areas and directions for research cited by the participants. These are summarized as follows:

Design methodology. Existing methodology and analytical tools for design of integrated control of large scale systems are inadequate. The development of such methodology, particularly if it has broad applicability, would greatly extend our capabilities in the area of systems automation and intergrated control. In order that the results have maximum "portability," it was stressed that there be explicit efforts at standardization. The major approach advanced for structuring and control of large-scale systems was that based on the multilevel hierarchy. The development of computer-aided design techniques for design of large-scale systems was also cited as an area where useful contributions to the resolution of the problem may be made. The importance of incorporating scheduling and planning functions into the integrated industrial control system was pointed out with some frequency.

Modelling. There was general agreement that the development of adequate models was an essential prerequisite to the achieving of effective system integration and controller design. There were some proposals that IIASA effort be directed to developing models of various industrial subsystems so that these may be catalogued for general use in systems design, but it was pointed out that this kind of activity might require very large investments of time and manpower, with perhaps very limited useful output. Again the hierarchical approach was advanced as a rational basis for structuring large scale systems and for developing overall models as organization of interacting subsystems. The notion that the form, accuracy, and completeness of the model must relate to how it is to be used was stressed. In particular, it seemed that models should be designed for on-line parameter identification and adaptation to permit the effective use of simpler, less exact models.

Software. The software needs were also generally stressed, including standardized packages for direct numerical control functions, real-time data processing, data base management, optimization, scheduling and related algorithms required in applications of computer process control, production control and management information systems. Development of commonly accepted user-oriented and process oriented languages for computer simulation and real-time control applications was also proposed as an objective of IIASA effort.

Applications. There was the strong feeling that any research undertaken by IIASA ought to relate to real systems and real problems. Although some of the work can be based on computer simulations, access to an experimental facility was considered necessary as a source of data and as a basis of reference and evaluation. Thus, it was recommended that the research project be selected with some consideration given to collaboration with an on-going research activity where there is an experimental facility available and where there is extensive background in the system selected for the study (e.g. knowledge of the requisite models). As far as choice of system to serve as the vehicle for the IIASA project, there seemed to be strong support for consideration of a metallurgical system (e.g. steel making) and a mechanical system (e.g. automated machine tools). An important aspect of the study, it was pointed out, is the evaluation of the economic tradeoffs in implementing automation, and a realistic measure of how well the overall (economic) goals of the system are realized.

Cooperative efforts: There was virtually universal agreement that cooperative efforts with other groups both within and outside IIASA be strongly encouraged as a means of achieving maximum effectiveness within the constraint of limited resources. Thus, the research teams on Energy Systems and on Water Resources provide sources of competence and background knowledge on questions in the industrial area pertaining to energy or to water resources. (Similarly, the team working on industrial control may provide a reference source in the area of information processing and control to the research groups on energy and water resources). Perhaps even more pertinent are the intersecting interests with other groups and research teams, to be set up within IIASA, concerned with methodology, organization, etc. (e.g. Optimization and Control of Complex Dynamic Systems; Organizational Design; Computer Systems; Artificial Intelligence). Further, as pointed out earlier, it was felt that the IIASA team should work closely with laboratories and research groups among national organizations, industry, professional societies, etc., that identify common objectives.

Several specific proposals for IIASA research projects were presented by participants (Cheliustkin, Lefkowitz, Hatvany, and others), and these were discussed to a limited extent. The group tended to feel that many aspects of these proposals were compatible and, perhaps, could be combined to form a single final project proposal; however, such further efforts required much more time to consider and to work out the details than was available at the present conference. This led to a formal recommendation that: a) a project on the theme of automated control of industrial systems be included in the research program of IIASA, b) the proposals by Professors Cheliustkin, Lefkowitz, and Hatvany be considered as the basis for preparation of a single research proposal for the project, and c) working group be organized to prepare the final proposal with details on time schedule, participation in the project by member countries, scope and objectives of the research, and relevant state of the art background. A suggestion was also made that a seminar be organized at some later date where the project may be discussed, and relevant experiences and state of the art communicated.

PAPERS, PROPOSALS, AND COMMENTS

Document A

Memorandum:

Integrated Control Systems for Large Scale Production Processes

A. Cheliustkin

The existing methodology for production control system design lacks a systems approach. Thus, control systems for technological processes and transport operation are designed without much consideration of the problems for planning information and dispatcher systems. This situation can be explained by the inherent complexity of the problems to be solved and by the lack of general conceptions and methods.

Another by no means unimportant factor is the high specialisation of systems designers. To solve the control problems for technological processes profound knowledge of the technology itself is necessary, and usually such control systems are supplied by manufacturers of the technological equipment. In designing the production control system for a plant, specialists in management, economics, and planning who are acquainted with the specific features of a particular plant should take very important part. Usually these specialists belong to the staff of the plant to be automated.

This lack of coordination leads to the exclusion from consideration of one important problem: operational control. The operational control system should act as a link between control systems for technological processes and the planning system.

On the basis of the environment economics analyses and the knowledge of the production ability of the plant, the planning system develops an overall production plan. The realisation of this plan by the organisation of the production process and by the control of its fulfillment is the function of the operational control system. The organization of the process included operational planning and scheduling, selecting the technological path, and resetting the equipment of the selected path according to the requirement of the technological process. It is obvious that the largest gain can be obtained if all these three types of systems are designed as one unit. These systems are formed in three levels of the hierarchy, working in different scales of time.

Due to the considerable time spent for analysis of the stochastic environment the planning system can perform its function for a period of time much greater than the duration of the production cycle. In the meantime the operational control problems should be solved within the production pace by predicting the future readjustment of the process according to the production plan specified by the upper level of the hierarchy. The technological control systems are working on-line in a real scale of time.

Because of the considerable time differences, we may consider the solution of the planning problems as the "outside supplement" in Stafford Beer's terminology. Consequently, with the inputs to the operational control system regarded as the outside supplement, we may omit the planning system from our studies. To solve the operational planning problems a set of possible production process versions should be examined, and an optimal one chosen.

The number of possible versions is greatly increased if the production process can be organized by different technological paths. In this case the planning problem includes selection of the path.

Each of the production process versions must be regarded as a dynamic process incorporating all production and transport operations, since the realization of the plan to be selected is also a dynamic process. Thus the operational plan should have a form of schedules for all part of the technological routes and cover the entire planning period.

Due to the extreme difficulties in composing such schedules with high number of variables and random disturbances present during the realisation of the selected schedule, the operational planning problem is divided in two parts. The first part is working out a detailed production plan divided into time intervals; the second is composing schedules for these intervals, considering the situation at the end of the preceeding interval.

This decomposition of the problem into static and dynamic parts principally reduces the optimality of the problem solution since the first part is based on the mean production ability. As the optimality of the solution is higher for longer intervals, they should be made as long as possible. But with increasing length of the intervals the probability of the divergence between the real production process and its plan also increases.

Apart from internal disturbances, caused by the drift of the technological equipment characteristics, there are external disturbances from the outside supplement such as new urgent orders, cancellation of old ones, shortage of materials, and so on. All these disturbances cause divergence between predicted and real production processes. This divergence increases with time in proportion to the complexity of the technological processes and the number of orders to be satisfied.

Analysis of the existing production processes may give us the relations between the divergence rate and technological and organizational complexities. Thus by setting the admissible divergence value (as a time shift or integrated value of the production) we may find for a particular set of orders the maximum schedule time intervals. Since the production plan includes different orders with many items it is first necessary to arrange all orders according to types of products and delivery times. This reduces the organizational complexity thus permitting longer schedule time intervals.

Since the outside supplement partly changes by its random nature there is some uncertainty in the composing of the schedule. To eliminate this uncertainty all changes which occur during the preceeding interval are accounted for at the beginning of the next interval.

So long as increasing the schedule time interval increases the optimality of the production process, it is advisable to employ a gliding planning horizon in order to compose the schedule for periods larger than the selected intervals. But once this time interval ends, the new schedule is composed for the newly selected time interval with allowance for changes in the outside supplement.

The schedule is composed for the technological path selected at the first step of the operational planning. However, during the composing of the schedule the selected path may lead to overspending the resources. Therefore both parts of the operational planning can be iterative.

Solution of the second part of the operational planning is one of most difficult and complicated problems. Its tools are: overall production plan, technological paths, and mathematical models of the divisions of the paths. Mathematical models permit predicting the course of the process by its simulation; coordinated production and transport operations can then be selected. It is obvious that there is less divergence between real and predicted processes if the model is adequate for the simulated process. But to build the model which adequately represents the process at any time, it is necessary to increase the number of variables (many of them impossible to measure) thus making the model very complicated, or even infeasible. To overcome these obstacles the adaptation of the models is used so that the model having only a few variables and adjustable parameters is close enough to the simulated plant for a short duration of time. The adaptation is performed in the course of the real process, and is based on the statistical comparison of the model and real plant outputs. The duration of the adaptation depends on the frequency spectrum of the disturbances and on dynamic response of the plant.

To reduce the adaptation time, and thus to reduce the divergence between real and predicted processes, one plant is simulated by several models. Several models can be used if the disturbances have different frequencies. For instance, to control the steel melting process in an oxygen convertor two models are used: 1) a static model, which considers low frequency disturbances, like the wear of refractory lining, and 2) a dynamic model which considers the behaviour change of the convertor in the course of each heating. Depending on the adaptation and schedule time interval relations, the verified model is used both for obtaining control action to reduce the divergence between the predicted and real processes, and for composing the new schedule.

The selected schedule is, in some sense, the decomposed general control problem in the set of local multiconnected control problems.

Simultaneously with the production schedule, the material and power supply schedule is composed. To realize the production schedule the organization of the process along the technological path should be performed: the instructions for resetting the technological units (by means of automatic controller resetting and shop service team instruction) and for appropriate transportation mechanisms. The organizational problems are solved by the models which relate the selected technological path to quantitative and qualitative characteristics of the production operations (without considering the internal behaviour of the process itself). Since the technological units can act in different regimes depending on the type of the manufactured product, the models used for the organization problem solving are built with adjustable parameters. All control actions and instructions are realized in accordance with material flows, which are controlled by a special system equipped with automatic sensors and manual information panels.

The course of technological processes is controlled by means of technological unit instruments and compared with the predicted course as specified by the schedule composition. Such comparison reveals the divergence in advance and permits use of the feedforward type control. If the divergences detected are caused by the characteristic drift of a single technological unit, the control actions are generated by the adapted models of this unit. In the case of the divergences caused by outside disturbances, the control actions are generated by the model of the production division and directed to coordinate technological regimes of different units. As can be seen from the above, control problems are solved by several models with different adaptation times. Thus the proper control actions can be composed of different time intervals, corresponding to the adaptation times of the models. Having different time intervals for composition of different control actions the problem of their strimling (sic.) as the problem of hierarchy in time.* In designing the control system it is necessary to estimate the number of models by finding the adaptation time. This estimation can be performed by investigation of information flow dynamic characteristics.

Control actions aimed at eliminating the divergence of the actual and planned processes course might fail and the divergence would then reach the point of the maximal permissable value before the interval ended. In this case correction of the schedule is required because the internal control resources have been exhausted. This correction is carried out by the manager who has received a draft of schedule alterations from the system. In some cases this alteration results in changes of the sequence of some operations with no alteration of the overall production. In general, however, alteration of a schedule entails alterations of both the overall production and the nomenclature of final products. For example, in the steel industry a wrong grade of steel may be melt. In such cases, the heat of the expected steel grade should be replaced in the production list by a new one, and appropriate changes introduced into the list of orders and the schedule, because the processing routine for an order with the resultant steel grade may be different.

Management acts in the same way when the uncompensated deviations from the schedule are caused by a breakage or shortage of materials.

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*Editor's note: The meaning of the translation here is unclear. It may perhaps be re-written as: "Having different time intervals for composition of different control actions, the problem of their streamlining can be taken as the problem of hierarchy in time."

The first integrated control systems were developed in England for the steel plant (Spencer Works). With its continuous and discrete technological processes, with fixed technological paths and frequent alteration of final products, a steel plant is a very suitable object for integrated control system application.

In the chemical and petrochemical industries, where fixed technological paths also exist, characteristic final product changes are very rare, and therefore operative organization and production planning are not so urgent.

In engineering and instrumentation plants, the development of integrated control systems is much more complicated due to the wide range of possible technological paths and a great number of prefabricated and final products. Only at the enterprises specializaing in mass production of a limited number of articles and equipped with automatic and semi-automatic lines, are organizing and production planning conditions similar to those at chemical enterprises. All this makes the iron and steel industry the primary object of studies. A vast body of knowledge has been accumulated in this field, the analysis of which enables us to formulate the principal concepts of integrated control system structure and to develop their design engineering methods.

The above discussion has left aside certain problems of technical consideration such as the choice of the system hardware structure, the numbers and types of computers, communication links, data, and software, and a number of other factors affecting cost-effectiveness and reliability. These choices cannot be made unless adaptive models for control problems have been defined, and discrete control actions quantified in time have been coordinated.

Criteria and aim of definition have also not been mentioned since they are largely a function of social factors.

Document B

Lines of Research in Development of Automatic Production Line Control Systems (APLCS)

A. Cheliustkin

1. Definition of the goal and criteria for the APLCS.

2. Definition of the optimal functional structure of the APLCS.

3. Methods of the APLCS subsystems formation.

4. Investigation of information flow characteristics and their relation to the dynamic characteristics of the material flow in the production lines.

5. Methods for creating the subsystems mathematical models and their dynamic interaction.

6. Decomposition methods of the control problems in hierarchical systems as decision making problems.

7. Adaption principles for mathematical models of the subsystems and time quantification of the decision making problems.

8. Definition of the APLCS functional reliability.

9. Investigations of the relation between the functional reliability, the hardware reliability, and the information excess.

10. The methods for the definition of the APLCS and the structural hierarchy of the subsystems hardware.

11. Methods and algorithms for solution of the APLCS control problems (planning, scheduling, and flow control).

12. The APLCS software development (as a functional and hardware hierarchical system with human participation in the solution of decision making problems).

Document C

Integrated Automatization of a Semiconductors Components Production Line

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Fifteen years of intensive studies have contributed to the implementation and the enormous development of the "planar" technology for silicon devices production.

The modern requirements of cost, efficiency, and very severe adaptation of the product to the demands of the market necessitate the use in the production line management of the most efficient Automatic Control techniques.

This process is a system involving a great number of different types of variables (determinist, random logic, discrete...) and is included in the class of incompletely specified complex systems. In view of an integrated management of this process, we must use a wide variety of techniques and methods necessitating the collaboration of engineers and research workers with complementary competences.

In such a production line, two parts have to be distinguished. The first, the physical part of the line, includes all operations from the reception of silicon bars to obtaining electrical components on the wafers. The electrical properties of the components can be measured at this level. The second part, assembling and screening, concerns the transformation of these components into their commercial form. Each step of the procedure is separated by stocks.

The technical management of the physical part of the line, which can be defined in terms of actions to be taken from technical criteria, is one of the important goals of this project.

At the present time, this step of the procedure is rather poorly mastered due, for example, to:

- the imperfections of the regulations carried out manually or automatically,
- the intervention of insufficiently characterized products because of economic constraints or a lack of knowledge of appropriate methods,

- the existence of ageing and various wearing effects, and
- the presence of spatial heterogeneities in the treatment of the wafers and the batches.

The technical management must realize two objectives:

1) the first is the regulation of the process around previously set points; then we must be able to identify and master the incidents and deviations appearing during the operations in order to avoid the production's quality drift with time.

2) The second objective concerns the rapid adaptation of the products to new specifications. To do this, we must determine the set points to be used all along the production line.

Naturally, this production line is situated in an economic context which introduces additional constraints and production criteria:

- cost of the equipment required by technical management
- decision problems related to the continuation or stopping of the production of devices when, in line, hope of success and cost are taken into account
- criteria of adjustment of stock levels taking into account the random character of the production.

Setting up a global control of this kind of process imperatively passes through a structural, qualitative, then quantitative analysis of the process. Even if the system of integrated automation can be outlined without a detailed study of the systems to be controlled, its definitive realization depends, on the contrary, on the results of the above-mentioned analysis.

However, imperatives of production and operation of the production line led us in a first step to carry out studies on punctual controls problems which are later integrated in the planned global control.

Parallel to a well-defined methodology, the automatic management of this process also necessitates powerful computer support composed of a network of computers whose essential function is to acquire and treat the numerous measurements qualifying the production line.

First we define more precisely the process and propose a graphic representation. The principal functions of diagnosis, supervision, and control are then introduced into a hierarchical structure. Finally, some methods relative to these different functions are developed. Secondly, we describe briefly the research undertaken toward the integration of technical and economic management.

Some examples will illustrate the different methods presently studied.

Structural Analysis

Description of the Process

The physical part of the production line is composed of operations carried out principally in series. Some products can be reworked after control of their quality at certain steps.

Since the manufacture of an electronic component consists mainly of depositing and diffusing elements on an epitaxial layer, operations of the same type are encountered several times (photoengraving, deposit, diffusion). The production unit is a set of several wafers, containing several hundred or thousand components. The production time for one set is of the order of several weeks. The presence of human operators for the execution and control of certain operations, particularly cleanings, introduces a random factor in the process. Finally, the process is presently very sensitive to uncontrolled disturbances or to disturbances which are difficult to reveal and control; this gives it a very large variability which is translated by notable and random changes in the output.

Modeling of the Process

Qualitative Analysis. After having recorded all the operations of the line, we have described these operations in terms of systems (identification of the input, output--measurable or not--and control and disturbance variables).

For this, we supposed that an electronic component can be characterized at any instant of its manufacture by a set of elementary properties (dimension, impurity levels, distribution of these levels, etc.) During an operation, certain physical properties are modified, others are introduced; this leads to the following representation of an operation:

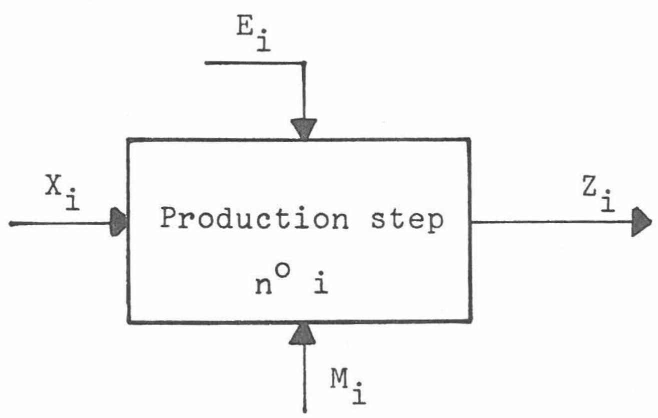

Figure 1. A Production Step Scheme

In this figure:

X_i are the physical properties of the component which are modified during operation n° i;

Z_i are the physical properties of the component at the end of operation n° i;

E_i are the physical properties of the component which are implied in the elaboration or modification of other physical properties but which are not modified during operation n° i; and

M_i are the parameters of operation n° i. These are, at the same time, parameters of the operation model n° i and variables of the control.

The properties are measured on line either a) directly (thickness of the epitaxial layer, for example), or b) indirectly through the intermediary of variables depending on several physical properties (case of all the electric properties of a component).

By examining the way in which the physical properties and the qualitative relations between physical and electrical properties of the component are successively elaborated and modified, we define a graph of the production line illustrated in Figure 1.

Quantitative Analysis. The modelling is done either from observations on test patterns, or from global variables which are representative of the considered set of samples; in this case, the first step is to characterize them. We shall describe here the characterization of the distribution of the manufactured components.

The N components of the batch are sorted in k compartments according to their electric characteristics.

Let P_i be the probability that an element taken at random is classified in compartment i.

The probability of having a certain distribution of components (n_i in compartment i) follows a multinominal law

$$P(n_1, n_2, \ldots, n_k) = \frac{N\,!}{n_1\,!\; n_2\,! \ldots n_k\,!} P_1^{\,n_1} P_2^{\,n_2} \ldots P_k^{\,n_k} ,$$

where $\sum_{i=1}^{i=k} n_i = N$.

Let us suppose, moreover, that the P_i's depend on a certain number of coefficients which we shall indicate as μ_j and which we wish to estimate.

We shall use the maximum likelihood estimator

$$\text{Log } P = \text{Log } \frac{N\,!}{\prod_{i=1}^{i=k} n_i!} + \sum_{i=1}^{i=k} n_i \text{ Log } P_i$$

$$\frac{\partial \text{Log } 1}{\partial \mu_j} = \sum_{i=1}^{i=k} \frac{n_i}{P_i} \frac{\partial P_i}{\partial \mu_j} = 0$$

$$I\,I_{jl} = N \sum_{i=1}^{i=k} \frac{1}{P_i} \frac{\partial P_i}{\partial \mu_j} \frac{P_i}{\partial \mu_l} \,.$$

For the solution, we can use the algorithm

$$\tilde{\mu}_n = \tilde{\mu}_{n-1} + \frac{\partial \text{Log } L(\mu_{n-1})}{\partial \mu} \,.\, I\,I^{-1}\,(\mu_{n-1}) \quad .$$

Function of Supervision and Control

We mentioned, in an initial definition of the study, that one of the control tasks is the regulation of the process around specific set points. Since presently the operation of the production is not well known and an identification must be carried out at the same time as the control, the supervision of the process is an important function to be realized. We shall define supervision as the set of actions which, after detecting a deviation of a measurement compared to a reference, tries to identify the cause or causes of this deviation. We find this supervision function in other complex systems [4]. It can be followed by a correction action which makes up the regulation.

It is necessary to distinguish between the supervision of the manufacturing process and the supervision of the quality and quantity of the manufactured product [5]. A complex process consists of numerous operations which the product or products undergo and which interact in a complex way so that satisfactory functioning of the operations does not guarantee a satisfactory behaviour of the global process. Thus, for the production line, if all the operations were well regulated, it is not certain that the component would be of good quality if the identification of the process is too incomplete. However, reciprocally, a necessary condition for a component to have the desired electric characteristics at the end of the physical part is for all the operations to be correctly carried out.

This distinction, already introduced on the lines, thus defines two levels for the supervision function if we have two sources of different information. The first level is operations monitoring. The result of an operation is controlled by measurements made on a control group of test pattern, which undergoes only this operation. The second level is monitoring of a group of operations, thus monitoring of the evolution of component quality. The result of several operations is controlled by measurements made on test patterns having undergone all these operations.

To set up this hierarchical supervision (with two levels) the graphic representation of the process is of obvious interest since it describes precisely the interaction between operations.

Having shown the monitoring levels, we shall define and clarify in the following paragraphs the possible monitoring modes which are essentially functions of the information of which we dispose, the means implemented to treat it, and the corrective actions which can be undertaken. This determines the structure of the monitoring and control system (Figure 2).

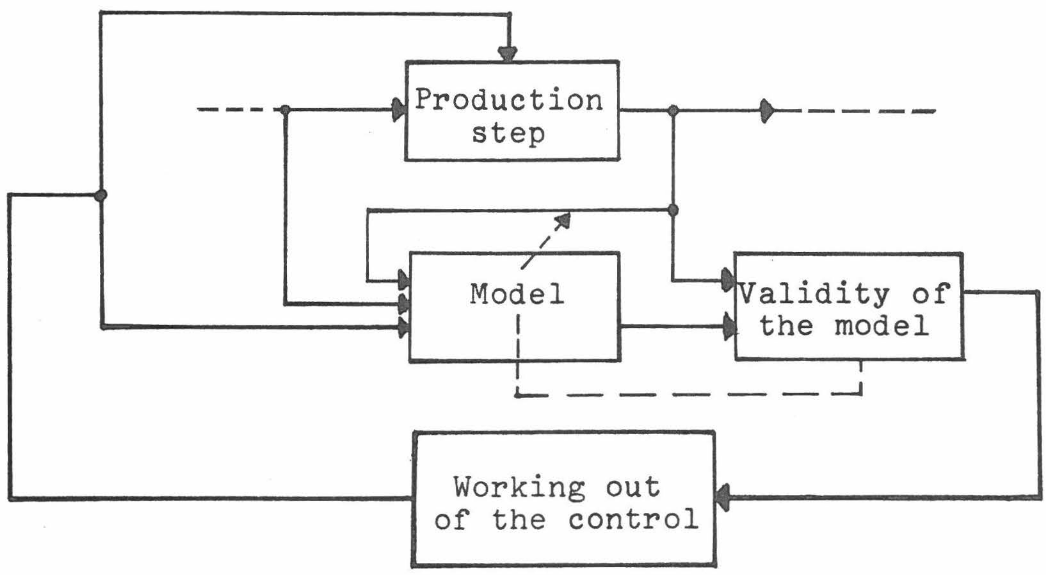

Figure 2. Modelling and Adaptive Control

Monitoring and Automatic Control

Here we are concerned with one of the most classic aspects of systems control, that is, regulation. Disposing of measurements on the variables of which we wish to supervise the evolution and of a quite exact model of the system generating these variables, we put regulation loops in place. The system is then controlled in closed loop which allows an automatic compensation of disturbances.

The control algorithms can be realized either analogically (cabled regulation) or numerically (programmed regulation).

The monitoring function is, in this case, accompanied by an on-line automatic control function.

The role of this function is double:

- to regulate the mean value of the principal characteristics of the finished products;
- to contribute to reducing the line variability.

For this, the study led to the development of algorithms permitting the elaboration of a control from a simplified model of physical or electric property transformations undergone by a set of components during an operation.

Taking into account, on one hand fluctuations in the characteristics of the basic materials and, on the other hand, slow deviations of the machines of the line, we are led to consider an adaptive modelization and control (Figure 3).

Static Model and Control. We suppose, in a first approximation, that the operation can be modelled by a linear equation

$$\underset{(1,1)}{Y_K} = \underset{(1,MX)}{\underline{\Theta}^t} \cdot \underset{(MX,1)}{\underline{X}_K} + \underset{(1,1)}{\varepsilon_K} ,$$

where

Y_K is the output variable or the variable to be controlled,

$\underline{X}_K$ is the explicative variable vector (the control variable is one of its components),

$\underline{\Theta}^t$ is the transposed vector of the parameters to be estimated, and

ε_K is a random variable taking into account the modelling error and disturbances which act upon this operation, and it is such that

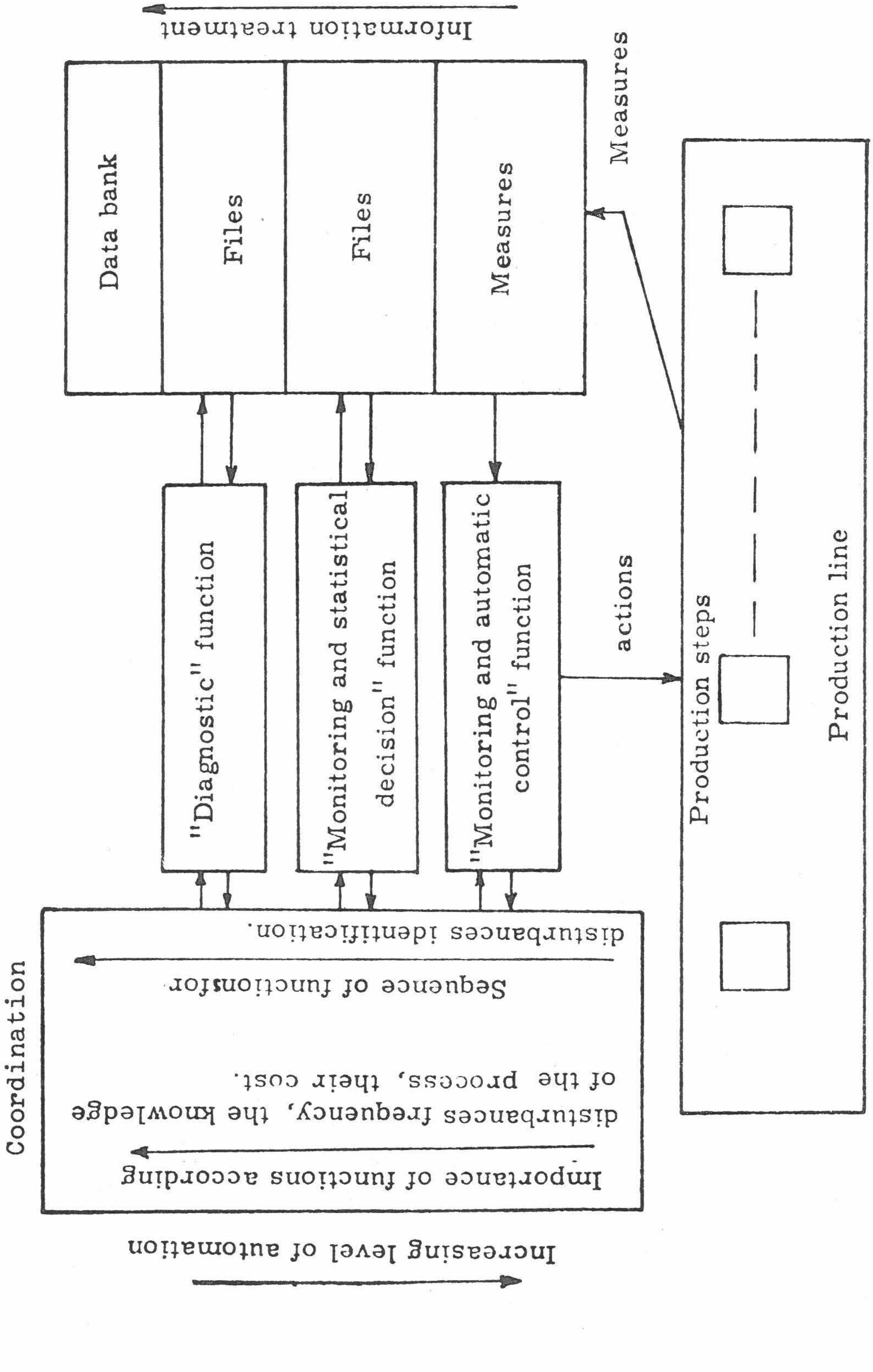

Figure 3. Monitoring Modes

$$E[\varepsilon_i \ \varepsilon_j] = \sigma_\varepsilon^2 \, \delta_{ij} \quad .$$

We will later be led to suppose that ε_K follows a normal law $\mathcal{N}(0,\sigma_\varepsilon^2)$.

A couple $(Y,\underline{X})_K$ makes up an observation or sample; the index K is the number relative to the set of components which is treated by this operation.

Two algorithms were developed to estimate the parameters of equation (1) in order to be able to follow their slow variations.

1) Least means squares method--algorithm using recurrent formulas on the observation.

a) Estimation: We define recurrences of the type

$$U\,V_K = U\,V_{K-1} + \frac{1}{K}\,(\underline{U}_K\,\underline{V}_K^{\,t} - U\,V_{K-1}) \qquad U\,V_0 = 0 \quad .$$

The estimator $\hat{\theta}^t$ of θ^t, in the sense of the least means squares is given by

$$\hat{\theta}_K^{\,t} = Y\,X_K \,.\, (X\,X_K)^{-1} \quad .$$

The estimator of the variance of residual noise ε_K, $\sigma_\varepsilon^2 = E[\varepsilon\ \varepsilon]$ is given by

$$\hat{\sigma}_{\varepsilon_K}^{\,2} = \frac{1}{K - MX} \sum_{i=1}^{K} (Y_i - \hat{\underline{\theta}}^t \underline{X}_i)\,(Y_i - \hat{\underline{\theta}}^t \underline{X}_i)$$

$$= \frac{K}{K - MX} \{Y\,Y_K - 2\,Y\,X_K\,\hat{\underline{\theta}}_K + \hat{\underline{\theta}}_K^{\,t}(XX_K)\,\hat{\underline{\theta}}_K\} \quad .$$

The estimator of the covariance matrix $\sum_{\hat{\theta}} = E[(\hat{\underline{\theta}}-\underline{\theta})(\hat{\underline{\theta}}-\underline{\theta})^t]$ is given by $\hat{\sum}_{\hat{\theta}} = \frac{\hat{\sigma}_\varepsilon^{\,2}}{K}\,(X\,X_K)^{-1}$.

We see that, without retaining memory of all the observations, we can compute explicitly an estimator of θ and its precision at each new sample.

b) <u>Prediction</u>: To test the model validity, it is interesting to compute the prediction--knowing the explicative variables--and to associate a confidence variable with it. We can then be assured that the output variable observed Y_{K+1} is included in this interval.

The confidence interval of a level α is given such that [2]

$$\text{Prob}\left\{\hat{Y}_{K+1} - t_{\alpha/2}\left[\hat{\sigma}_{\varepsilon_K}^{2} + \underline{X}_{K+1}^{t}\,\hat{\Sigma}\hat{\Theta}_K\,\underline{X}_{K+1}\right]^{\frac{1}{2}} \leq \underset{|X_{K+1}}{E}\,Y_{K+1}\right.$$

$$\left.\leq Y_{K+1} + t_{\alpha/2}\cdot\left[\hat{\sigma}_{\varepsilon_K}^{2} + \underline{X}^{t}{}_{K+1}\,\hat{\Sigma}\hat{\Theta}_K\,\underline{X}_{K+1}\right]^{\frac{1}{2}}\right\} = (1-\alpha)\,,$$

assuming that ε_K follows a law $\mathcal{N}(0,\sigma_\varepsilon^2)$ and where

$\hat{Y}_{K+1} = \hat{\Theta}_K^{t} \cdot \underline{X}_{K+1}$ is the prediction.

t is a student variable with $n = (K-MX)$ degrees of liberty.

To apply to the modelling of an operation, it is preferable--knowing that we dispose of few samples and to conserve the adaptive character of the model--to choose $\alpha = 0.1$ and to test that there is more than one observation out of 10 outside the interval.

2) <u>Kalman-Bucy adaptive linear filter</u>--We consider that the time variation of $\underline{\Theta}$ can be modelled by the following dynamic equation of the Gauss-Markov process

$$\underline{\Theta}_{K+1} = \underline{\Theta}_K + \underline{V}_K\,,$$

where $\{\underline{V}_K\}$ is a vectoral sequence of normal random variables $\mathcal{N}(0,Q)$. It is necessary to note that we suppose that the covariance matrix Q is known: the diagonal terms of this matrix correspond to the previous knowledge that we have concerning the variation speed of the parameters.

We observe the discrete state $\underline{\Theta}_K$ of the system by the following observation equation

$$Y_K = \underline{\theta}_K{}^t \underline{X}_K + \varepsilon_K \quad ,$$

where $\{\varepsilon_K\}$ is a sequence of normal random variables $\mathcal{N}(0, R)$.

The estimator $\hat{\underline{\theta}}_{K+1|K}$, that is, conditioned by observations up to sample K, is given then by

$$\underset{(MX,1)}{\hat{\underline{\theta}}_{K+1}} = \hat{\underline{\theta}}_K + \underline{G}_K \cdot \{Y_K - \hat{\underline{\theta}}^t{}_K \cdot \underline{X}_K\} \quad ,$$

where

$$\underset{(MX,1)}{\underline{G}_K} = \{R + \underline{X}_K^t \cdot P_K \cdot \underline{X}_K\}^{-1} \cdot P_K \cdot \underline{X}_K$$

$$\underset{(MX,\ MX)}{P_{K+1}} = P_K + Q - \underline{G}_K \cdot \{R + \underline{X}^t{}_K \cdot P_K \cdot \underline{X}_K\} \cdot \underline{G}_K{}^t \quad .$$

$\underline{G}_K$ is the filter gain which weights the innovation process: $(Y_K - \hat{Y}_K)$.

P_K is the covariance matrix of the parameters

$$P_K = E\ (\hat{\underline{\theta}}_K - \underline{\theta}_K)\ (\hat{\underline{\theta}}_K - \underline{\theta}_K)^t \quad .$$

We initialize the filter by the previous knowledge of the parameters, supposed to have a normal distribution $\mathcal{N}(\theta_0, P_0)$.

Remarks. The first algorithm poses no convergence problem relative to the choice of initialization. However, if we want to give it an adaptive character--while retaining the possibility of computing explicity and estimator at each new sample--we must, when the model is rejected, retain the past under the aspect of an averaged observation. Thus, the weight of the past will be less with each invalidation of the model. There is a compromise between the adaptation and the possibility of estimator computation which is to be realized since the algorithm is constructed according to recurrences on the observations and not on the estimator itself.

On the other hand, the second algorithm which necessitates a larger previous knowledge is of a more supple use for an adaptive identification. The implementation of this algorithm necessitates a good preliminary statistical study of the process.

The control variable for sample K is computed by using the model elaborated for sample K - 1 and knowing the set points and the explicative variables X_K (other than the control variable).

A problem is then posed. By acting in this manner, we tend to connect linearly the explicative variables. This implies:

- a poor conditioning of the information matrix X X_K and difficulties in numerical computation (case of the first algorithm), and
- problems of observability--all the components of the state vector Θ_K (parameters) are not observable (case of the second algorithm).

Dynamic Model and Control. The possibility of modelling an operation by a dynamic model--the recurrent index remaining the number of the treated set of devices--was also considered. The general form of a dynamic linear model of the first order is then written

$$Y_K = \alpha Y_{K-1} + \underline{\Theta}^t \underline{X}_K + \varepsilon_K \quad .$$

This amounts to introducing a new explicative variable (Y_{K-1}) and a new parameter (α) to be estimated in model (1); the other variables retain their signification.

The algorithms of parameter estimation, already written, can be implemented in these conditions without modifications.

The problem can, according to the separation theorem, be divided in two: a prediction (or parameter estimation) problem, and a control problem in view of minimizing as criteria the output variance in relation to the set point

$$V = E \left[(Y_K - Y_C)^2 \right] \quad .$$

The control law is, in this case, expressed in function of the estimated parameters and their precision.

Monitoring and Statistical Decision

Monitoring of the process can also be performed using the information acquired and stored in a data bank which is used upon decision by a human operator.

The essential difference from the preceding supervision mode is that: 1) correction action is not automatically taken after establishment of operation irregularities, 2) treatment of the information is at the discretion of a human operator, and 3) the scrutation period of the process is much longer. Under these conditions, it is said that for this monitoring mode, the decisions which can be made are of a statistical nature. At this level in particular it is possible to determine if a set of wafers should or not continue to go through the line. The elements for deciding can be the state of the stocks and the possibility of "making up" the quality of this set.

Diagnosis of Catalogued Incidents [1, 3, 6]

The method is based on a preliminary note which determines what is meant by incident. An incident is characterized by an output or a combination of outputs which are outside the norms for tests carried out systematically on the production line (e.g. measurements, points of command).

For an incident ascertained in this manner, if by the preceding supervision modes we were unable to determine the cause, it is necessary to obtain more information about the system using additional tests. The goal of diagnosis is to organize these additional tests.

Modelling the process in terms of interactions between operations is of great interest in building the catalogue of causes associated with the incidents. Note also that the incident diagnosis is a way to identify the process, because of the quantification of connections between variables by means of probabilities and incident frequencies.

The Incident Catalogue. The model is based on data grouped in a document called the "incident catalogue," which contains the description of all known incidents that can appear on the production line. Each incident description consists of:

1) A set of causes of failures that can explain every operational incident: $IE = \{E_1, E_2, \ldots, E_p\}$.

   Each failure is associated with a certain probability

   $e = \{e_1, e_2, \ldots, e_p\}$; where $\sum_1^p e = 1$; $0 < e_i < 1 \ \forall_i$.

Note that the set IE may contain not only singly occurring failures.

2) A set of tests that can distinguish between these causes.

$$\Pi = \{T_1, T_2, \ldots, T_n\} \quad .$$

Each test has an associated cost: $t = \{t_1, t_2, \ldots, t_n\}$ where $t_i > 0$, and induces a partition on the set of causes. The number of blocks in each partition is the number of possible answers of the corresponding test.

The Diagnosis Problem. This is a matter of finding a diagnosing procedure using the set of tests, which will identify the unknown causes of the incident, with minimal expected testing cost. If we introduce a particular failure corresponding to the correct operation of the system (empty failure), the diagnosis problem becomes a maintenance problem. Several ways are possible to resolve the problem, such as combinational solutions not considering the order of test execution.

Under these hypotheses, the best way is to construct an inspection schedule in the form of a test tree. Non-terminal nodes of the tree represent the tests to be performed. Especially the root indicates the first test; and terminal nodes correspond to the different causes.

Solution of this Problem. Some methods of solution have been programmed.

a) Aiming for an Optimal Schedule--We know how to find very easily an optimal schedule when all the tests are "simple" (i.e. dichotomic and isolating a single failure). If this is not the case, methods are used that are connected with dynamic programming, implicit enumeration or "Branch and Bound," improved by special considerations of the problem. But these methods are not fast enough for use in solving large-size problems. So it is necessary to develop heuristic methods.

b) Sub-optimal--A heuristic criteria supplied by the notion of entropy in information theory was chosen after statistical comparison with other criteria. The schedule obtained can be improved by local actions (exchange of successive tests). A program founded on such a method has been realized and implemented in an industrial site. It is also possible to fix constraints on the order of test execution.

Integrated Automatization

By integrated automatization we mean the simultaneous implementation of all the functions necessary for technical management (which were previously described) and for economic management which we shall introduce.

For this, the sequence of the different control modes is decided by a coordination organ; it is based on the failure or success of successive monitorings. Thus, having recourse to diagnosis is a final procedure since then the information available in the data bank has not made identification of the disturbances possible.

The relative importance of the different modes can only be decided in function of several criteria. The first is the disturbance frequency: the greater the frequency, the more we must implement detection and automatic correction procedures. Knowledge of the process is also an important criterion. Finally, the economic cost of these functions is a major decisive element.

Introduction of this economic data, to which the company policy itself is added, gives this notion of integrated automatization its true meaning (Figure 4).

The level of economic management--taking into account information on the state of the procedure--will set the objectives of technical management. We will attempt to define this relation between levels essentially for the two following aspects:

1) Pursual or Rejection Decision

The set points of the production line are in fact set ranges because of the random character of the process. The amplitude and limits of these ranges cannot be determined with certitude; decision problems arise when a measurement, in the course of production, deviates from these ranges.

At the level of the monitoring function and statistical decision, it is desirable to elaborate these elements of decision which allow us to choose, at each instant of production of a component, if it should continue or not on the line. These elements are the cumulated cost of the component, its expectation for good operation, the state of the stocks, etc.

2) Production Planning and Stock Measurement

If it is possible to have certain stocks, it is at the

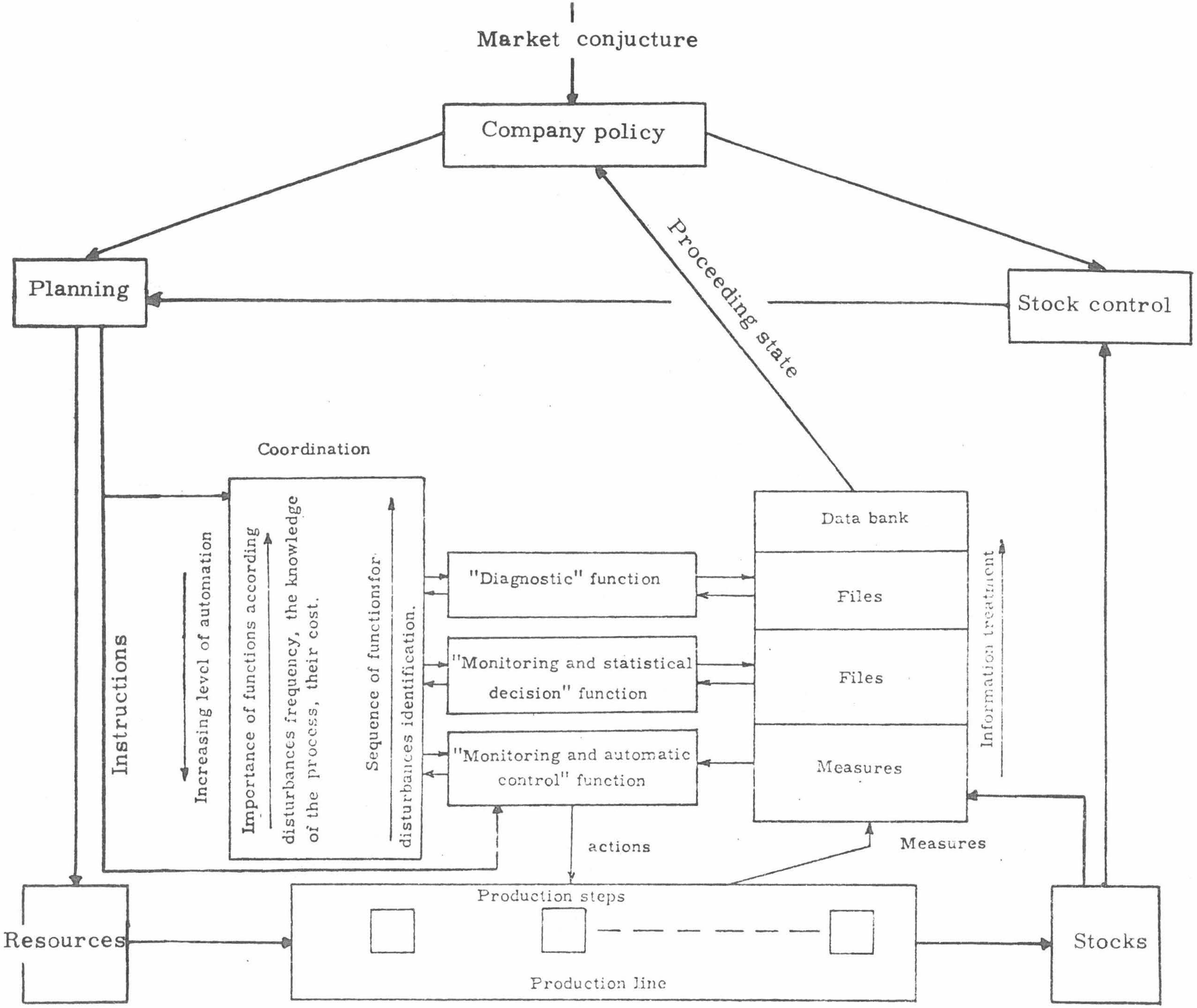

Figure 4. Integrated Automatization

second level that we must define the policy to be followed for certain regulatory parameters intervening the line control level, particularly at the stochastic control loop level.

This aspect of stock management could be completed by co-ordination of means of production whose goal is to obtain scheduling for operations compatible with the objectives defined at the economic management level (this point is presently under preliminary study by the research team.)

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Document D

An Integrated Model of the Firm*

(A progress report)

P. Fleissner, K. Hietler, A. Knauer, J. Mende

1. Introduction

Although productive forces have been highly developed by capitalism, the social costs of private enterprise have been rising during the last decennium. Governments are dealing with macro-indicators for the "quality of life" of the average individual but are not concerned with the different coping mechanisms of different social classes. This is reflected in most of the literature on the theory of the firm as a theory of capitalistic behaviour. Sometimes workers are completely absent in the models (BONINI) or they are reduced to "factors of production." Forrester's approach is dealing with the interconnections between different stages of the production and distribution process, but working conditions, political conflicts, etc. are lacking.

Therefore, the aim of this study is to investigate the antagonisms and convergencies between the interests of the entrepreneur and the workers, between profit-maximization and the situation of the employees.

We did not want to stay on a purely theoretical level in formulating definitions without connection to reality, mathematical exercises for privileged scientists. Our concept was to establish a causal structure of the processes within the firm and to discuss these concepts with the workers of a concrete firm. Only one out of twenty entrepreneurs was willing to give us the necessary informations and to allow the discussion process we needed. Therefore we could not choose freely the kind of firm we wanted. At last we had to apply our concept at a rather small firm of the steel construction industry, a very effective sector for making profits nowadays.

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To describe the main processes and conflicts in this firm we were obliged to build an integrated model in terms of economics, hierarchical structures, health conditions and politics. In the beginning of our investigation we had some difficulties to communicate with the workers, a consequence of the separating educational system, but we could learn a lot about their situation and especially the younger workers became very interested in this type of proceeding.

We decided to use the vehicle of a computer-oriented simulation model to communicate our results and our idea of the firm to our colleagues at the universities.

On the other hand workers organizations could find such models very helpful to articulate their interests against prevailing powers of capitalistic thinking. They could localize very clearly the limitations of the usual concepts of codetermination, recently discussed in the Austrian mass-media. By simulation they can easily find out the restricted possibility of capital-formation for workers and eventually this study could be an instrument towards the need for a changed organization of the production and distribution process, no longer imposing more and more social costs upon underprivileged classes.

2. Steps of Procedure (Organization of the Study)

(i) Thorough study of some basic economic, sociological, political and ecological books and articles.

(ii) Choosing a concrete firm.
Main criteria involved in choosing a firm:

1) Availability of necessary data (e.g. production, inventory, orders, prices, balance sheets),

2) Political component,

3) Ecological component,

4) Size and technology of the firm,

5) In order to analyse the process of development the firm should exist for some years.

It must be emphasized that it was relatively difficult to find a firm satisfying the desired criteria up to a certain degree. A description of the firm chosen is given in Section 3.

(iii) Modelling and Operationalization.
In order to describe complex nonlinear relationships and feedback structures adequately, the method of systems analysis in connection with causal modelling and model simulation was chosen.

The simulation model, based on the structure of the causally modelled loops, involved two steps of procedure.

Step 1: Formulating a system of equations which is equivalent to the theoretically derived structure of the system. According to the discrete nature of the data and to the importance of nonlinear effects the equations should be in the form of non-linear difference equations. The solution of nonlinear systems of equations in closed form is not possible. Therefore, Step 2 follows.

Step 2: Translation of the mathematically formulated equations in a computer programming language. Thereby it is possible to analyse

(1) the solution of the equations over time, and

(2) the effects of changing the structural relationships or parameters of the model (demonstrating actions of the labor force or management of the firm).

Most of the available programming languages (DYNAMO, SIMULATE, SIMULA, GASP, SIMSCRIPT, GSSP, etc.) are developed for special cases (algorithms, specific methodological approaches). In order to achieve greater flexibility, FORTRAN was used as a programming language in this study. In addition, the relevant sub-routines contain the most important features of DYNAMO and SIMULATE.

The model under discussion is a learning model; that is, the persons (labor force and management) of the enterprise, which is modelled, are integrated in the process of modelling. Thereby one can improve the degree of reality of the model. In addition the model can be used as a learning aid in evaluating actions within the firm.

In order to improve the operationalization of the learning model approach, a detailed questionnaire with the following main areas was developed:

1) Personal questions,
2) Firm in general,
3) Technology and division of labor,
4) Qualification, conditions of work,
5) Social climate,
6) Quality of working place,
7) Unions and other interest groups.

(iv) Simulations with the model.

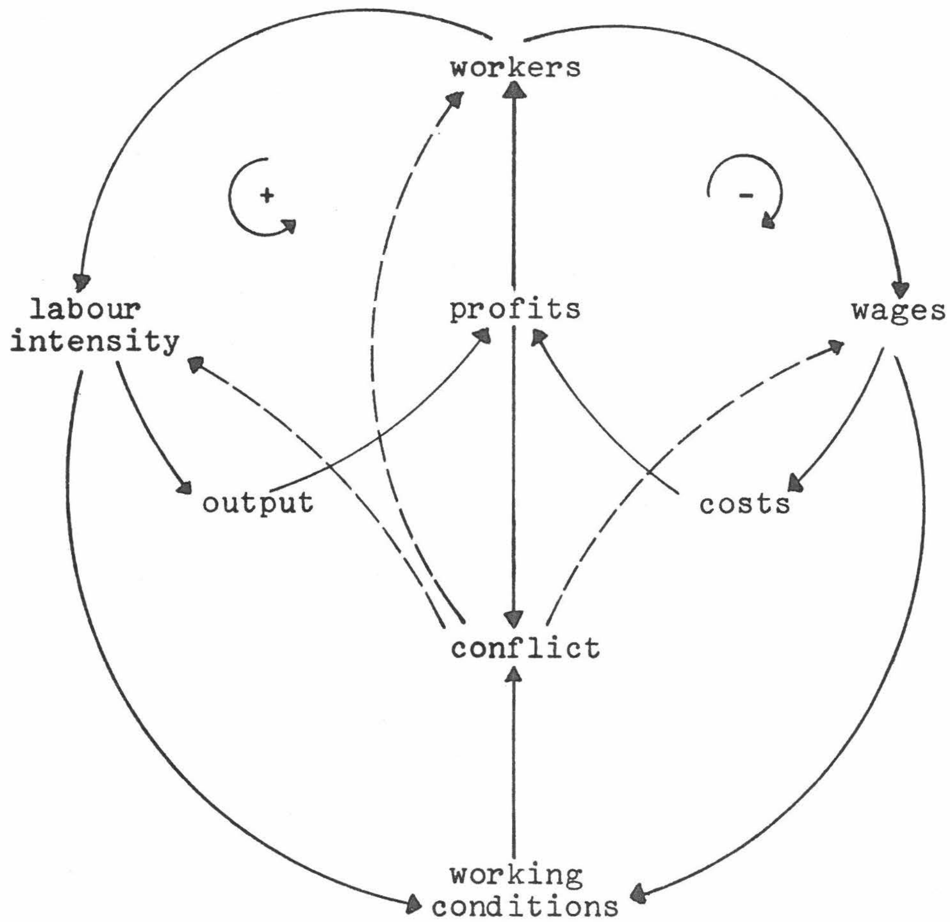
3. Description of the Firm

We selected a middle size Austrian firm. It is a steel construction firm; total employees are about 150. According to the production program we divided total production into three categories: steel construction, industrial ovens, and others (Type 1 to 3). The firm is not producing on stock; production starts after the order is received. The main bottleneck for an expansion of the firm is the availability of skilled workers. This fact determines production volume and order volume.

There are three hierarchical levels: management, foremen, and workers. The management is assisted by the technical department, the accounting department, and others. Throughout the three types of production work is organized in groups, headed by a foreman who manages the group and exercises pressure on his workers to finish the work within the time given by the management. Within the third hierarchical level a distinction between Austrian and foreign workers (workers from Yugoslavia and Turkey) is made because of the different wage level and qualification. To integrate the hierarchy in the model and to quantify the existence of organizational pressure, we constructed a variable called "organizational pressure" consisting of several parts. A bonus system of payment is the main variable to stimulate labour intensity of foremen and workers. Capacity can be expanded within a limited range by overtime.

The firm has no cost accounting system; the instrument for short term planning is a monthly statistic of order level and output of the three types of production. The balance of the books is available yearly. For every project a calculation is made which is checked after the project is finished. Gross profit is split up into two parts: retained profit and unretained profit. Investments are financed mainly by depreciations.

4. A Simplified Version of the Model-Structure



5. Model of the Firm

This chapter contains the equations of our model. Subscript i (i = 1,2,3) refers to the type of project (1 - steel construction, 2 - industrial oven building, 3 - others;) m and t are time indices (m - month, t - year;) variable names are abbreviations of the respective German words. Superscript Z refers to the kind of workers (H - Austrian workers, G - foreign workers, Z = H or G.)

Unfilled orders

$$a_{i,m} = a_{i,m-1} + ae_{i,m-1} - af_{i,m-1} \quad (1)$$

$a_{i,m}$ - stock of orders of type i at the beginning of period m,

$ae_{i,m}$ - orders received of type i during the period m,

$af_{i,m}$ - orders finished during the period m (output.)

Entering orders (orders received)

$$ae_{i,m} = f(hf_{i,m}) + \varepsilon \quad (2)$$

whereas

$$ae_{i,m} = 0 \quad , \quad \text{if} \quad f(hf_{i,m}) + \varepsilon \leq 0$$

$$= f(hf_{i,m}) + \varepsilon \text{ if } f(hf_{i,m}) + \varepsilon > 0 \qquad \text{and}$$

$\varepsilon \ldots N(\mu,\delta)$

$hf_{i,m}$ - number of labour hours still available (free capacity,)

ε - random variable indicating that $ae_{i,m}$ is dependent on other factors too (business cycle etc.)

Output (orders finished)

$$af_{i,m} = (1-k_m)\cdot d_m\cdot \beta_i\cdot hk_{i,m} \tag{3}$$

$hk_{i,m}$ - total labour hours for project type i in the period m,

β_i - average labour productivity $\left(\frac{\overline{af}_{i,m}}{\overline{hk}_{i,m}}\right)$,

d_m - organizational pressure,

k_m - percentage of production loss due to sickness.

Free Capacity

$$hf_{i,m} = \tau\cdot hk_{i,m} - a_{i,m}\cdot\frac{1}{\beta_i} \tag{4}$$

τ - period of planning of the firm (τ = 6 months).

Labour hours total

$$hk_{i,m} = (w^G_{i,m} + w^H_{i,m})hm(1 + o) \tag{5}$$

$w^G_{i,m}$ - number of foreign workers,

$w^H_{i,m}$ - number of Austrian workers,

hm - normal working time (at present 168 hours per month,)

o - overtime as a percentage of total hours.

Wage Sum of the Austrian Workers

$$L^A_{Hm} = \delta_m [w^H_m \cdot l^H_h \cdot hm(1+o)] + w^H_m \cdot l^H_h \cdot hm(\alpha-1)o \qquad (6)$$

whereas

$\delta_m = d_m$ for $d_m > 1$

$= 1$ for $d_m \leq 1$

l^H_h - hourly wage for Austrian workers,

α - additional payment for an overtime hour (expressed as multiple of a normal hour,)

d_m - organizational pressure.

Wage Sum of the Foreign Workers

$$L^A_{Gm} = \delta m [w^G_m \cdot l^G_h \cdot hm(1+o)] + w^G_m \cdot l^G_h \cdot hm(\alpha-1)o \qquad (7)$$

δ - as in (6)

l^G_h - hourly wage for foreign workers

w^G_m - number of foreign workers.

Wage Sum of the Foremen

$$L^{VA}_m = w_{VA,m} \cdot l^h_{VA} \cdot hm(1+\alpha o) + L^{PVA}_m \qquad (8)$$

$w_{VA,m}$ - number of foremen,

l^h_{VA} - hourly wage for foremen,

L^{PVA}_m - total bonus of foremen.

Total Bonus of the Foremen

$$L_m^{PVA} = (L_H^A + L_G^A)(\delta m-1) \cdot z \qquad (9)$$

z - bonus of foremen as a percentage.

Total Wage Sum

$$L_m = L_G^A + L_H^A + L_m^{VA} \, . \qquad (10)$$

Wage Sum in Type i

$$L_{i,m} = L_m \cdot \frac{w_{i,m}}{w_m} \qquad (11)$$

w_m - total number of workers

$w_{i,m}$ - total number of workers in project type i.

Total Number of Workers

$$w_m = w_m^G + w_m^H + w_{VA_m} \, . \qquad (12)$$

Workers in Type i

$$w_{i,m} = w_{i,m}^G + w_{i,m}^H + w_{VA_{i,m}} \qquad (13)$$

$w_{i,m}^G$ - number of foreign workers in type i,

$w_{i,m}^H$ - number of Austrian workers in type i,

$w_{VA_{i,m}}$ - number of foremen in type i.

Number of Workers

$$w_m^Z = w_{m-1}^Z + we_{m-1}^Z - wf_{m-1}^Z \qquad Z = G,H \qquad (14)$$

we_m^Z - workers entering the firm during the period m,

wf_m^Z - workers leaving the firm,

w_m^Z - number of workers at the begin of period m.

Workers Entering the Firm

$$we_m^Z = f\left(\frac{l_h^Z}{l_{h,Kon}^Z}\right) \quad \text{if} \quad \sum_{m=1}^{3} \frac{hf_m}{3} \leq 0 \qquad Z = G,H \qquad (15)$$

$$we_m^Z = 0 \quad \text{if} \quad \sum_{m=1}^{3} \frac{hf_m}{3} > 0$$

l_h^Z - hourly wage for workers,

$l_{h,Kon}^Z$ - hourly wage in the competing firms on the labour market,

hf_m - free capacity.

Workers Leaving the Firm

$$wf_m^Z = f\left(\frac{\sum_{m=1}^{3} l_{e,m}^Z}{3} / l_{h,Kon}^Z\right) + g(\Delta pr_{t-1}) \qquad Z = G,H \qquad (16)$$

$l_{e,m}^Z$ - effective hourly wage

Δpr_t - growth in the profit rate.

Number of Foremen

$$w_{VA,m} = \frac{w_m^H + w_m^G}{n} \qquad (17)$$

n - average number of workers in a group.

Effective Hourly Wage (normal wage + overtime wage + bonus)

$$l^H_{e_m} = \frac{L^A_{H_m}}{w_{H_m}\cdot hm(1+o)} = l^H_h(\delta m + \frac{(\alpha-1)o}{1+o}) \tag{18}$$

$$l^G_{e_m} = \frac{L^A_{G_m}}{w_{G_m}\cdot hm(1+o)} = l^G_h(\delta m + \frac{(\alpha-1)o}{1+o}) \ . \tag{19}$$

Organizational Pressure

$$d_m = d_{1_m}\cdot d_{2_m}\cdot d_{3_m} \tag{20}$$

d_{1_m} - motivation of the workers to work,

d_{2_m} - motivation of the foremen to change pressure on workers,

d_{3_m} - pressure of the management on foremen.

Motivation of the Workers to Work

$$d_{1,m} = f(\frac{l^e_{m-1} - l^e_{m-2}}{l^e_{m-2}}) \tag{21}$$

l^e_m - effective average wage bill per worker

$$(l^e_m = \frac{L^A_{G_m} + L^A_{H_m}}{w^G_m + w^H_m} \ .$$

Motivation of Foremen to Work

$$d_{2,m} = f(\frac{l^P_{m-1}}{l^{NO}_{m-1}}) \ , \tag{22}$$

l_m^P - average bonus per foreman

$$\left(l_m^P = \frac{L_m^{PVA}}{w_{VA,m}}\right) ,$$

l_m^{NO} - average wage per foreman (without bonus)

$$\left(l_m^{NO} = \frac{L_m^{VA} - L_m^{PVA}}{w_{VA_m}}\right) .$$

Pressure of the Management

$$d_{3,m} = f\left(\frac{\sum_{i=1}^{3} af_{i,m}}{\frac{1}{6}\sum_{\tau=1}^{6}\sum_{i=1}^{3} af_{i,m-\tau}\cdot\gamma}\right) \qquad (23)$$

$af_{i,m}$ - output

γ - parameter for planning the turnover.

Production Loss Due to Sickness

$$k_m = f\left(\sum_{\tau=1}^{6} \frac{d_{m-\tau}}{6}\right) \qquad (24)$$

Direct Costs

$$KD_{i,m} = L_{i,m} + m_{i,m}\cdot p^S \qquad (25)$$

$L_{i,m}$ - wage sum (direct wages,)

$m_{i,m}$ - steel used for production, in tons,

p^S - price of steel per ton.

Steel used for Production

$$m_{i,m} = f(af_{i,m}) \quad . \tag{26}$$

Indirect Cost and Gross Profit

$$MG_{i,m} = af_{i,m} - KD_{i,m} \tag{27}$$

$af_{i,m}$ - output

$KD_{i,m}$ - direct costs .

Indirect Costs

$$KG_{i,m} = \nu \cdot KD_{i,m} \tag{28}$$

ν - percentage of direct costs .

Gross Profit

$$P_t^B = \sum_{m=1}^{12} \sum_{i=1}^{3} (MG_{i,m} - KG_{i,m}) \quad . \tag{29}$$

Profit Rate

$$pr_t = \frac{P_t^B}{\frac{C_t + C_{t-1}}{2}} \tag{30}$$

C_t - capital stock.

Gross Investment

$$I_t = f(CF_t, pr_t) \tag{31}$$

CF_t - cash flow.

Cash Flow

$$CF_t = A_t + P_t^B \tag{32}$$

A_t - depreciation.

Depreciation

$$A_t = f(AV_{t-1}) \tag{33}$$

AV_t - funds.

Funds (equipment, machinery, building)

$$AV_t = AV_{t-1} + I_{t-1} - A_{t-1} \quad . \tag{34}$$

Working Capital

$$UV_t = f(af_t) \tag{35}$$

af_t - output.

Capital Stock

$$C_t = AV_t + UV_t \quad . \tag{36}$$

For simulation of conflicts it is necessary to quantify the bargaining process. The bargaining power of workers is e.g. a function of hourly wages and organizational pressure; the bargaining power of the entrepreneur is determined by unfilled orders or profit rate.

Because this model is a first version, all the equations are preliminary. The functional forms have to be specified and alternative versions have to be tested. Up to now the financing aspects are not contained, but they may be integrated later to answer liquidity questions. On the marketing side, the firm is not very active (no advertising); therefore, we used in equation (2) a random variable as a first version. Data problems exist since the balance of books is available only yearly and there is no cost accounting system.

6. List of Variables

Endogenous Variables

A_t	depreciation
$a_{i,m}$	unfilled orders of project type i
$ae_{i,m}$	orders received during period m
$af_{i,m}$	output (orders finished) during m
AV_t	equipment capital (machinery, buildings, equipment)
C_t	capital stock
CF_t	cash flow
d_m	organizational pressure and slack
$d_{1,m}$	motivation of the workers to work
$d_{2,m}$	motivation of the foremen to change pressure on workers
$d_{3,m}$	pressure of the management
I_t	gross investment
$hf_{i,m}$	free capacity (labour hours not utilized) with respect to the planning horizon
$hk_{i,m}$	total working hours for type i
k_m	percentage of production loss due to sickness
$KD_{i,m}$	direct costs
$KG_{i,m}$	overhead costs
L_m	total wage sum
$L_{i,m}$	wage sum in type i
$L^A_{G_m}$	wage sum of the foreign workers
$L^A_{H_m}$	wage sum of the Austrian workers
l^e_m	effective average wage bill per worker per month

$l^{G}_{e_m}$	effective hourly wage of foreign workers
$l^{H}_{e_m}$	effective hourly wage of Austrian workers
$l^{Z}_{e_m}$	effective hourly wage of workers (Z=G or H)
l^{NO}_{m}	average wage per foreman without bonus
l^{P}_{m}	average bonus per foreman
L^{PVA}_{m}	total bonus of the foremen
L^{VA}_{m}	wage sum of the foremen
$m_{i,m}$	steel used for production
$MG_{i,m}$	margin (indirect cost + gross profit)
P^{B}_{t}	gross profit
pr_t	profit rate
UV_t	working capital
w_m	total number of workers (including foremen)
$w_{i,m}$	total number of workers in type i
w^{G}_{m}	number of foreign workers
w^{H}_{m}	number of Austrian workers
w^{Z}_{m}	number of workers (Z = G or H)
w_{VA_m}	number of foremen

we^{G}_{m} workers entering the firm (foreign)

we^{H}_{m} workers entering the firm (Austrian)

we^{Z}_{m} workers entering the firm (Z = G or H)

wf^{G}_{m} workers leaving the firm (Austrian)

wf^{H}_{m} workers leaving the firm (foreign)

wf^{Z}_{m} workers leaving the firm (Z = G or H)

$\gamma_m - \gamma_m = d_m$ for $d_m > 1, \gamma_m = 1$ for $d_m \leq 1$

Exogenous Variables

h_m legal working time per month

l^{G}_{h} hourly wage for foreign workers

l^{H}_{h} hourly wage for Austrian workers

l^{Z}_{h} hourly wage for workers (Z = G or H)

$l^{Z}_{h,Kon}$ hourly wage for workers (Z = G or H) in the competing firms on the labour market

l^{h}_{VA} hourly wage for foremen

n average number of workers in a group

p^{S} price of steel per ton

o overtime as a percentage of total hours

α additional payment for an overtime hour (expressed as multiple of a normal hour)

β_i average labour productivity

γ parameter for planning the turnover

ε random variable

τ period of planning of the firm

z bonus of foremen as a percentage

7. Applications

From our point of view the model helps us to study the complex structure of a firm, the interconnections between economic and social categories. Through continuing dialogue between the management, the employees, and us we hope to improve the model and get closer to reality. Through the process of model building, better insights into the position of workers in the production process should be gained. A variation of several parameters (planning horizon, percentage of overtime etc.) allows us to study the effects of different management policies and to get a better understanding of the feedback mechanism for the entrepreneur. By quantifying the bargaining power of employer and employees, simulation of conflicts (wage conflicts) are possible.

The exact specification of the equations is the next step. Then the model has to be programmed for simulation purposes. Results are discussed with the members of the firm we are modelling. An extended version of our study will be published in the fall 1973.

Document E

PLANNING, SCHEDULING AND FLOW CONTROL

M. Florian

Considerable effort has been invested during the past 15 years in theoretical scheduling models that were inspired by scheduling problems encountered in industrial practice. While a very rich literature was developed on the subject, and a textbook, (Scheduling Theory, Conway, Maxwell and Miller), appeared in 1967, many of the real life, applied problems in scheduling have not been treated in a systematic way. Rather, a list of heuristic approaches were invented to solve problems of high dimensionality or of particular structure, that do not fit the elegant but restricted theoretical models that were developed in academic institutions.

Most scheduling problems are relatively short term and require the determination of how to order the items produced in the facilities of a plant - all these problems may be formulated as very large integer programs, usually by employing broken (0,1) variables. However, the state of the art in integer programing is such that large scale problems are not soluble by existing algorithms. Consequently, the only practical approaches are a combination of problem subdivision, application of heuristic rules, and local optimal algorithms for special structure problems.

There is a real challenge present in a unified approach to these large scheduling problems which are universal in nature. They occur in steel manufacturing, bath production industry, the pulp and paper industry, glass manufacturing, and other widespread manufacturing processes. The project proposed in this note is the identification of relevant problem prototypes in this area that are not still solved in a satisfactory way and the formalization of geion-optimal solution techniques for such problems.

We suggest a survey activity that would emphasize general interest problems that have been partially solved and match these with possible solution approaches. Also, it is hoped that this activity would identify problem areas that still represent "virgin" research interests. It is clear that such methods are practicable only by the use of powerful computer assistance and that the computer system that may facilitate such solution techniques represents an integral part of such a study.

Document F

Bulgaria:

Ongoing Research Developments in Automated Industrial Systems

G. Gatev

In our country, the R & D in Industrial Systems are going according to the unitary Plan for social and economic development. As a part of this 5-year plan there is a program for development, perfection, modernization, and automation of industry.

The main elements of this R & D in my opinion of interest to IIASA are the following:

1. Development of the technical means - devices, materials, all hardware. Let us consider computers. As a result, in our country one produces EC1020, a computer of middle size, including Disc Memory and Tape Memory with controllers. It is a computer from the unified system of computers which is developed and produced in the Soviet Union, GDR, Poland, Czechoslovakia, Hungary, and Bulgaria.

We are also working on mini-computers, sensors, transducers, regulators, amplifiers, comparators, executive organs (valves, positioners), and so on. These elements are needed to implement the automatic control of continuous and discrete technological processes, including numerical control of machine tools and they are produced and developed further on.

The research includes -

- new components;
- design of new devices,(e.g., memory, C.P.U., regulators, and so on) on systems - computer networks, multi-machine systems, etc.

The Centre of R & D and some institutes within the Academy of Sciences are engaged in this work.

2. Development of Software. Efforts are concentrated on:

SOS -- translators, organization programs and so on;

POS -- algorithm, programs for research and design works;
-- statistical treatments, computing statistics;
-- real time data acquisition and treatments;
-- modelling;

-- optimization (LP, other methods of mathematical programming), quantitative study and comparison of different methods;

-- planning;

-- stocks control, inventory -- previously for discrete systems in mechanical industry.

This work is done in a Centre of R & D , in several institutes within industry and the Academy of Sciences.

3. Systems Studies and Design. We are now working on several projects concerning automated systems in the chemical (ammonia plant, fertilization), petrochemical, cement, metallurgical, mechanical (numeric control of machine tools), paper and other industries. Some of them are implemented or quite near accomplishment.

This work is done in the Central Research and Design Institute of Automation and in other institutes or groups in industry.

4. The main functions are:

(i) data acquisition and preliminary treatment from the processes;

(ii) operational (operative) checking and control, including:
- computations of balance and technico-economic indices,
- "shutdown" and "start up" apparatus,
- finding optimal set of technological parameters (as advisor or automatically)
- distribution of loading between parallel consumers,
- registration, etc.

(iii) Short-, middle-, and long-term planning;

(iv) Stock, inventory control, etc.

The main arising problems are:
- determination of functional structure of the systems (level, distribution of tasks to level, etc.)
- choice of structure of the control computer system

-establishment of mathematical model (identification) taking into account control tasks and lack of a priori information,

-determination of control strategy,

-software packages,

-justification of real needs of control systems definition of the optimal rate of implementation of scientific and technical revolution topics.

Some work has been done in the field of methodology, including typization of algorithms used in the middle and high level of control systems for discrete processes, etc.

5. Education, formation of specialists. Changes have been made in the programs of High Schools, to fit better the needs of specialists oriented to computers; and postgraduate education on problems of automated industrial systems.

Proposals

The research program of IIASA should include:

1. Modelling (identification) oriented to technological (zero) level, operational control and high level of control system, based on concrete works in chosen plants with continuous, discrete-continuous, and discrete types of production.

Output should be: methodological materials, algorithms, programs for identification of typical elements of which a process consists (taking into account nonstationarity and control tasks).

2. Automated Design of Automated Control Systems. The design is difficult and time consuming. IIASA should do research in automated design including:

- automated or automatic establishment of mathematical models (of all levels -- technological, middle - operational control and high level) and control algorithms;
- algorithmic problem-oriented languages to design control systems. The existing languages deal with relatively restrained and simple functions (checking data acquisition and so on). It will be desirable and useful to include tasks as estimation and identification, optimal control, and so on.

Output should be: methodological materials, algorithms and programs to automated design of automated control systems, based on appropriate languages.

Such work should be done by exchanging results with the groups of computers and artificial intelligence of large scale systems dynamics and so on.

Document G

Project Proposal for Integrated Industrial Systems

(An attempt at the synthesis of the proposals of Drs. A. Cheliustkin, I. Lefkovitz, and J. Hatvany)

J. Hatvany

1. The aim of this project is to collect, analyze, test, and compare the system components of integrated industrial systems in the member countries, leading to the publication of the conclusions as guidelines for system design and implementation. The project should be a major multi-national experiment in the transferability of engineering technology and know-how through computer systems, both to accelerate industrial development in the developing countries and to homogenise the world stock of skill and experience.

2. The project will initially study two fields of industrial activity: Metallurgy and Machine-Building. The Integrated Design and Control Systems of these two large-scale production processes will be examined according to the following considerations:

2.1 Definition of the goal and criteria for the APLCS.

2.2 Definition of the optimal functional structure of the APLCS.

2.3 Methods of the APLCS subsystems formation.

2.4 Investigation of the information flow characteristics and their relation to the dynamic characteristics of the material flow in the production lines.

2.5 Methods for creating the subsystems mathematical models and their dynamic interaction.

2.6 Decomposition methods of the control problems in hierarchical systems as decision-making problems.

2.7 Adaptation principles for mathematical models of the subsystems and time quantification of the decision making problems.

2.8 Definition of the APLCS functional reliability.

2.9 Investigations of the relation between the functional reliability, the hardware reliability, and the information excess.

2.10 The methods for the definition of the APLCS and the structural hierarchy of the subsystems hardware.

2.11 Methods and algorithms for solution of the APLCS control problems (planning, scheduling, and flow control).

2.12 The APLCS software development (as a functional and hardware hierarchical system with human participation in the solution of decision making problems).

3. The project will--in both the above fields of study--comprise three main phases of activity. These will be:

3.1. To study and collate the present state-of-the art.

3.1.1 To commission reports by international exponents of the field.

3.1.2 To draft a report which should synthesize international experience, critically analyze it, and recommend a course for further work.

3.1.3 To organize the collective discussion of the report and publish it.

3.2. To test and compare system modules.

3.2.1 To use available in-house systems analysis tools.

3.2.2 To use available experimental and analysis facilities in member countries.

3.2.3 To collate, discuss, and publish the results of the test and comparison phase.

3.3 To prepare, check, discuss, amend, and publish guidelines for Integrated Industrial System design and implementation.

4. The project will, moreover, comprise the in-house development of a large-scale Modelling Tool of Hierarchical Multilevel Systems. The development of this tool will take place in parallel with the activities outlined in items 3.1 through 3.3 above, and parts of it available at the required time will be used for activity 3.2.1. The objectives of developing this modelling tool shall be:

4.1 Assessment of the contributions the approach has to offer in the areas of modelling system design, implementation of computer control and on-line decision making, integration of subsystems with respect to higher goals, etc.

4.2 Identification of common features that render the approach transferable to a broad range of industrial systems, e.g. discrete manufacturing and continuous process control.

4.3 Study tradeoff questions relating and distribution of tasks among the various levels of the control hierarchy. Tradeoffs include software considerations, communication requirements, reliability factors, the nature of the interactions among subsystems, and the disturbance characteristics as reflected in the tasks assigned to each level.

4.4 Study the interrelationship between the hierarchical structure and the modelling problem.

a) Use of decomposition as basis for developing the model for large scale systems and for large scale systems and for identifying parameters, e.g. via computer simulation.

b) Incorporation of adaptation into hierarchical scheme for feedback of input/output data in updating model

4.5 Examine the flexibility of the approach to accommodate the variety of control and decision making functions common to industrial systems, e.g. direct control functions, optimizing control, scheduling, parameter identification, etc.

4.6 Formulate basic structures and consider questions of software, data base management, communications among computer functions, compatability, etc.

4.7 Examine the flexibility of the approach in accommodating multiple objectives as might be imposed by environmental considerations, energy constraints, etc.

5. The procedure for developing the Modelling Tool of Hierarchical Multilevel Systems shall have five main phases:

5.1 Survey the field to ascertain and document "state of the art" with respect to

a) conceptual formulations and theoretical results,

b) conjectural properties and attributes as presented in literature, in proposed system applications in common acceptance ("folklore"), and

c) results of actual applications and experiences.

5.2 Examine some of the questions posed among the objectives by use of computer simulation facilities, analytical study, contributions from other people and groups with expertise in the field.

5.3 Coordinate development of the Modelling Tool with the activities in 3.1 and 3.2 above, for these to serve as vehicles and motivating forces for study.

5.4 Develop results in the form of recommendations to working groups in IIASA and other organizations pointing out:

a) needs for further research and development in suppositive theory, and analytical tools, and know-how, e.g. in optimization techniques, scheduling methods, software coordination theory, etc.; and

b) directions for further research in the areas outlined.

5.5 Prepare a summary of the study results to serve as guide in the structuring, organization, and implementation of computer control of large scale industrial systems.

6. The time scale of the project shall be as follows:

6.1	Commencement	Jan. 1974.
6.2	Conclusion of phases 3.1 and 5.1.	Dec. 1974.
6.3	Conclusion of phases 3.2, 5.2, and 5.3	Dec. 1976.
6.4	Conclusion of phases 3.3, 5.4, and 5.5	Dec. 1977.

7. The personnel required will be one senior research worker in each of the following fields

7.1 Metallurgy

7.2 Machine-building

7.3 Modelling Tool development.

Each of these will need to organize a team of three or four people. One of them (or each in turn) could be head of the overall project.

Document H

Outline and Justification for the Industrial Systems Project at IIASA

J. Hatvany

Program

1. Study and collate state-of-the-art

   Commission (pay for, and require appropriate standard) reports by international exponents.

   Draft, discuss, and publish report, which should synthesize international experience, critically analyze it from the point of view of a future transferable, modular system and recommend course of further work.

2. Use available experimental and pilot plant facilities in member countries (e.g., NEL - U.K., Aachen - GFR, Csepel - Hungary, Japan Mechanical Laboratory, WMW of GDR) to test and compare system modules--collate and publish results.

3. Prepare, check, discuss, amend, and publish guidelines for integrated industrial systems.

Contact interfaces with other IIASA activities

Computer-aided design

Techniques
Representation of entities
System structures--tradeoffs
Machine description

Mechanical — static / dynamic

Connectivity — functional / topological } algebraic

Data-base management

Large data base management--retrieval strategies,
Mutual convertibility of differing representations,
Methods of creating common (national and international level) technological data banks.

Artificial Intelligence--Robots

Derivation of assembly information from CAD,
High-level, interactive programming of transfer and assembly robots.

Scheduling, MIS

What are common areas with other industrial production control,
Hierarchical systems of macro- and micro-scheduling,
Real-time re-scheduling problems.

Man-machine interface problems

Ergonomic,
Sociological,
Technical.

Why IIASA?

1. Because of global problems of a technology gap and the attempt--through this model task--of investigating the transferability of technology through computer systems.
   No one else is motivated to do this.

2. IIASA alone can provide integral link with world efforts in:

   (a) other industrial systems,
   (b) other disciplines (AI, OR, Computer Science, etc.)

   on the requisite scale.

3. None of the existing truly international organizations has funds and an organization (permanent office) of its own to commission participation by national bodies.

4. IIASA's central and prestige position alone can put it above present national divergences.

Document I

Technology Transfer through Total Manufacturing Systems in the Mechanical Engineering Industry

J. Hatvany

1. Introduction

The mechanical engineering (machine-building) industry --since it manufactures the means of production for all other branches of the economy--occupies a special place in the development of every industrial nation, and its level is generally a fair measure of the advancement of a country's economy as a whole. The standards by which the level of a mechanical engineering industry can be appraised have undergone two full-cycle changes in the past 100 years.

At the time of the Industrial Revolution the predominant feature of merit was the personal skill of the engineers and craftsmen of the industry, based partly on a country's general educational level and partly on tradition accumulated over a number of generations. At this stage the mechanical engineering industry of a particular country could earn a reputation for the excellence of its products (e.g., Britain and Germany), but skilled itinerant artisans of other countries could also acquire their know-how and brilliant engineers in the more backward countries could produce "islands of excellence" even amid relatively poor industrial environments. (The Hungarian Bánki was able to invent the carburettor in 1893, and Hungarian automobiles made in 1905 were fully competitive with the products of contemporary foreign workshops.) The difference lay in the number of these highly skilled people, the number of trades in which they were active, and the receptiveness of the country's economic environment to their efforts.

During the course of the twentieth century the feature of merit became the scale of production, particularly with the introduction of mass-production techniques into a country's engineering industry. The mechanised assembly-line, the conveyor-belt, the practice of the new discipline of production engineering, standardisation, and the division of labour were the main characteristics of advance in this period. Since these required substantial capital investments and large markets, they were no longer transferable to small enclaves of skill in the less advanced countries. Along with the concentration of productive resources came a concentration of technological and organizational know-how which increasingly became proprietary secrets. It was no longer possible for journeymen and engineers to import the skill of more advanced nations as they had previously done. A seemingly unbridgeable technological gap developed.

In the second half of this century, mass-production has become increasingly separable from the advanced technological and scientific specializations which it brought into being. In many parts of the world the assembly-line facilities which were formerly the pride of an industry have been relocated to economically backward areas and the advanced industrial nation has retained the skills of research, development and the extremely lucrative, expanding market of highly specialized one-off and small-batch production in the production of the complex tools required for the mass-manufacturing industries. The new feature of merit is thus once again that of skill: skill in the scientific, technical and market research leading to new products, in the development of new manufacturing technologies, in the organization of production, in the production of the complex tools required for the manufacture of the new products. These skills are incorporated in a complete new "industry", with its own new technology, tools and organization, comprising the computer, advanced laboratory resources, and the increasing automation of the phases of research, design, analysis and planning. The technological gap is consequently widening still further.

How can this trend be reversed? How can the less advanced nations of the world escape the fate of permanent technical (and consequently economic) subservience to the bigger and more advanced ones? The only way this can be done is to accelerate the international transfer of technology. The latest achievements in the development of Integrated Manufacturing Systems now indicate that this is a distinct possibility, which would benefit not only the receiving countries, but also through the consequent elimination of a vast amount of duplicated effort, (to at least the same extent), the "donors".

2. Integrated Systems

It was pointed out at a Discussion Meeting of the Royal Society of London* that the new feature of the computer-aided drawing, analysis and production projects which were reported, was that they were tending to evolve into homogeneous, total manufacturing systems. The main components of these systems have been evolving separately over the last ten years. Let us consider them briefly.

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*Discussion Meeting, Proc. Roy. Soc. Lond. A., 321, (1971), 145-243.

2.1. Computer-Aided Design has evolved in all four main areas of the design field:

2.1.1. Conceptual design, where mass data storage, file handling and retrieval techniques have been developed to aid the designer and market analysis and prediction programs made available to him;

2.1.2. Design analysis programs have been evolved for a very large number of mechanical constructs, ranging from gear-trains to linkages, from finite-element stress analysis techniques to full dynamic simulations;

2.1.3. Detail design aids have been developed for automatic digitizing, drafting, lofting, plotting and the mass storage, retrieval, handling, updating and output of detail drawings;

2.1.4. Design communication has been helped by software and hardware aids to automatic documentation, parts listing, cable listing, etc.

The Computer-Aided Design (CAD) field has been greatly helped by the introduction of such highly flexible devices as the interactive graphic display terminal. The hitherto distinct phases of Concept, Analysis, Detailing and Communication have, in an increasing number of systems, been intrinsically interlinked, with the aim of having data trasferred from one phase to the next through a common, structured data-base.

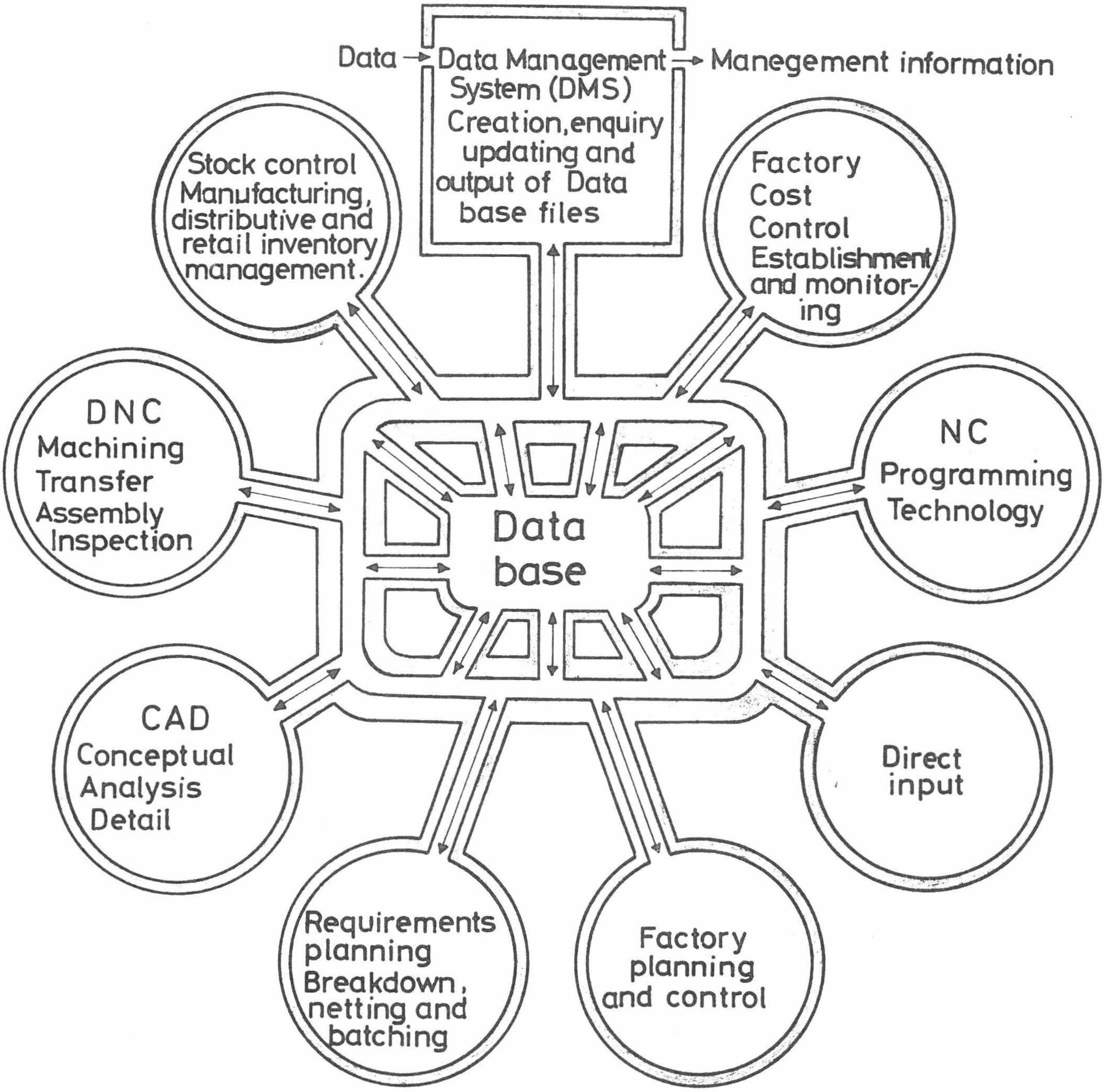
2.2. Computer-Controlled Production has also developed from a number of separate antecedents:

2.2.1. Computer programming languages for Numerically Controlled (NC) machine tools, have been written by the dozen (close to 100 are in industrial use) for various types of computer, control unit and machine tool;

2.2.2. Programs to compute machining technology - some using large machineability data bases - have been evolved;

2.2.3. A large variety of control schemes for the direct computer control of groups of numerically controlled machine tools (DNC) has been developed;

2.2.4. Complete machining systems including the computer controlled transfer of workpieces and tools, the automatic measurement of dimensions are now available;


Data
Data Management System (DMS)
Creation, enquiry updating and output of Data base files
Manegement information
Stock control Manufacturing, distributive and retail inventory management.
Factory Cost Control Establishment and monitor-ing
DNC Machining Transfer Assembly Inspection
Data base
NC Programming Technology
CAD Conceptual Analysis Detail
Direct input
Requirements planning Breakdown, netting and batching
Factory planning and control

2.2.5. An increasing number of flexible automatic assembly systems, some involving pattern recognition and robot techniques, is being built, which can be operated under computer control.

The integration of NC programming, DNC, and complete machining systems (possibly also comprising assembly) has become a task whose realization is being attempted in an increasing number of countries.

2.3. Production control, scheduling, management information, stock control, order registration, purchasing, invoicing and similar programs and program-packages have been introduced into industrial practice in large numbers. There is a notable tendency to amalmagate them into integrated management systems.

From even this very cursory listing the trend towards the development of large, self-consistent sub-systems will be apparent and the portent realized, of their eventual further integration into total manufacturing systems. In such a system the CAD, NC programming, DNC, and management components will all be part of a single, homogeneous system, with internal communication within the system among all its modules.

Arrangements such as this are now entering the stage of experimental realization in a number of the leading countries. If there is some degree of mutual compatibility between the sub-systems the process of integration is evidently eased, but this is, unfortunately, usually lacking.

It is suggested that:

a.) The software and hardware of an advanced total manufacturing system such as outlined above, of necessity contains a very large amount of highly concentrated manufacturing know-how and skills in an easily accessible and usable manner.

b.) Consequently the transfer of such systems from one country to the other and generally their international dissemination will be a powerful means for the transfer of advanced technology, the international interchange of technological information and the long overdue homogenization of the world's mechanical engineering industry.

The total manufacturing systems of the above outline will contain large data-libraries of extant technical information (patents, bibliographies, standards, catalogues) as required for conceptual analysis. They will have a library of analysis programs and design algorithms for a large variety of mechanical constructs; an automatic transfer of design data to NC programming systems including full machining technology planning, based on the best machineability data and calculation; proven man-machine dialogue packages for the DNC-operator interface; and so the list could be continued. The transfer and updating of such a system will be the equivalent of transferring a large, permanent staff and library. It will enable the recipient, with very few highly skilled people and many who can be gradually (e.g. through tutorial computor-operator dialogues) trained, to engage in design development and production of almost the same level as the place for which it was originally developed. The saving of duplicated effort for the developers will also be apparent, if international transfer in this field should become a reality.

3. Present difficulties

The very large effort at present being expended on the development of total manufacturing systems in the leading industrial countries is, unfortunately, in many respects, not optimally oriented towards achieving an international transfer of technology. One reason is that this is not the main (or in many cases even a subsidiary) aim. Many systems have been, or are being, developed in military environments. A number are evolving as strictly proprietary schemes. Some nations have begun to develop government-backed systems with aspects intended to emphasize their national entities, rather than international compatibility.

A number of international, or partly international, organizations have been engaged in coordinating various aspects of system development. The International Standards Organization has attempted to establish common foundations for an NC programming language and at the recent Budapest session of the Committee concerned, considerable progress was made. But ISO is not (and cannot be) concerned with advance planning; its work is of necessity more analytical than synthetic. Working Groups have recently been established in IFIP to consider CAD and Discrete Manufacturing Systems. These are, of course, consultative bodies for an exchange of ideas, and their task cannot be the fundamental analysis or the detailed coordination required. CIRP - though a prestigious international body in this field - is again more suited to a general exchange of ideas. The commercially-engaged national organizations like CAM-I (USA), the EXAPT-Verein (GFR), ADEPA (France) or the Government sponsored NEL (UK) are, of course, working on the expansion of their own systems towards the total manufacturing systems philosophy; but the international transfer of technology, the use of their systems to narrow the technological gap, naturally does not figure among their considerations and their deliberations are confined to their own membership.

4. Proposal

It is proposed that IIASA should, in the scope of Research Theme 6.4 (Automated Control of Industrial Production) outlined in Professor Raiffa's Initial Research Strategy, commission a preparatory study of total manufacturing systems in the mechanical engineering industry, with a view to establishing their system components, analysing their requirements and alternative realizations, and collating extant international work on the subject. This study would then lead to a research project aimed at the elaboration and multi-national testing of a model system and the publication of the conclusions as guidelines for system design and implementation. The aim of this work would be finally to evolve and consolidate a systems facility for the continuous international transfer of mechanical engineering technology and know-how, thus to accelerate industrial development in the developing countries and homogenise the world stock of skill and experience in mechanical engineering.

IIASA should be particularly suited to this task because of the multidisciplinary nature of the problem area (requiring mathematical, computer science, OR, data retrieval, AI, metalworking, management, business data organization and other specialists) and because only a supra-national body can hope either to attract people of the right calibre for such a job, or to enjoy the prestige that will help persuade national organizations to unite for the sake of global progress.

Document J

Research at the Institute of Applied Systems Analysis of Slovak Industry

K. Kacir

I would like to briefly introduce the research program of our Institute, e.g., the Institute of Applied Systems Analysis of Slovak Industry at Bratislava from the point of view of possible interest to IIASA.

Our Institute is concerned with applied research in the area of production management and production control systems for industrial enterprises.

Our research program can be divided into two main directions. The first direction is devoted to methodological problems, the second one to the problems of design and development of concrete production mangement systems in concrete enterprises.

A. When talking about the first direction, I would like to mention four basic research areas:

(1) The research of the problems of the rational structuralization of production management systems. Applying hierarchical concepts of structuralization based on five levels of criteria, we have analyzed the organizational and functional structure in five chosen enterprises. It has been proven that there exists some uniformity (and basis for standardization) in the structure. The degree of uniformity depends on the depth of structuralization, on the type of subsystem chosen and on the similarity of technologies used.

The results of this research are now used as the basis for comparison and standardization in systems design and development. They also can be used as vocabulary of systems work in the whole Slovak industry.

(2) The second area of methodological research is devoted to the problems of unified description of systems and subsystems to some appropriate degree. As one of the important results of this work I can mention the standardization of procedures and documentation in system work.

(3) The following area of methodological research is concerned with the problems of organization and control of systems work itself. We are developing the system of control of great system projects.

(4) The fourth field of methodological research of our Institute is applying operations research models in solving some special problems, such as:

-- applying linear programming for optimization of product mix in textile industry,

-- applying linear programming for optimization of wood as raw material in wood industry,

-- applying inventory models in wood industry.

This methodological research gives us the good basis for coordination of all system work in our industry. On the other hand, it might be useful for IIASA also.

B. Second research direction is oriented to the problems of concrete design of concrete production management systems based on the unified methodology. We are designing and developing the following main subsystems of production management systems in Slovak industry:

-- subsystems for production control in machine-building, textile, wood and chemical enterprise;

-- subsystem for sales management in textile industry;

-- subsystem for labor force management in machine-building enterprise;

-- subsystem for inventory management in wood enterprise;

-- subsystem for equipment control in chemical enterprise;

By designing these subsystems, we parallelly:

-- follow the requirements of the users of the subsystems developed;

-- test the methodology and modify it according to the special conditions in different enterprises;

-- complete and improve the methodology developed initially.

I know it is very difficult to describe briefly such a complicated and complex research program in a few words. I hope that on the basis of the present information it can be seen that there are some problems which can be of interest for IIASA and could serve as the basis for later collaboration with our Institute. In case more detailed information will be requested, we are prepared to provide the management of IIASA with such information in some reasonable period of time.

We also hope, on the basis of the program of IIASA described in the small red booklet and introductory explanations of Prof. Raiffa, that the work of IIASA staff can be very helpful for us.

We are especially interested in the research areas described in the booklet under the points 6.1, 6.2, 6.3, and 6.4.

In concluding, allow me to express my hope that we will find a good basis for collaboration between our Institutes and that such collaboration will be fruitful for both partners.

Document K

Project of Conclusions

M. Knoter

1) Include the project "AUTOMATED CONTROL OF INDUSTRIAL SYSTEMS" in the program of IIASA.

2) As the base of the project, take the Memoranda of Professors Cheliustkin and Lefkowitz and add them to the Memorandums about the discussion during Monday and Thursday (during the seminar).

3) Organize the working group under the leadership of Professors Cheliustkin and Lefkowitz until the end of 1973.

4) Ask the working group to prepare:

   a) a review of state of art of our project,

   b) a summary of the state of solution of our project in the member countries, and

   c) a detailed research project with time schedule, etc.

5) Organize a working seminar in the middle of 1974 which will judge, discuss the result of proposals of working group.

Document L

On a Few Experiences and Methods of a Cybernetically Substantiated Stability Analysis of Company Processes

H. Koziolek

The first experiences with relatively simple forms of a cybernetically substantiated stability analysis of company processes have been gained in a few large companies of the GDR in recent years. They were gained during the preparations for automation schemes. Preliminary analytical work had to be conducted for internal decision problems of a high degree of interdependency.

The work proceeded from the establishment and formulation of a coupling network of the systems of existing automation complexes, including their effects and reactions on preceding and subsequent systems. The nature of stability analyses based on valuations lies in the establishment of the actual or possible points of disturbance in the inter-action of the system elements. Such points of disturbance can arise due to impermissible or excessive deviations from the actual material or informational courses of the processes.

The fundamental structure of the system approach with the help of matrix models is usually based on the selection of the interaction of:

- Economic targets
- Prerequisites to the highest-possible measure of effectivity
- Structure of the automation scheme
- Subsequent spheres outside the automation scheme in the order of a maximum total of 50 to 60 lines and columns.

Compared with the existing theoretical arsenal of methods of applied systems analysis, this is undoubtedly a still very important form of systems approach and systems analysis. The imperfection lies mainly in the limitation to valuation rather than measurement of the courses of processes. This is due to several reasons, but chiefly to practical considerations of data procurement. Despite this limitation, this manner of systems analysis has proved useful in two respects:

1) One gains measure of transparency of the complex decision problems and of the weaker points in the automation schemes, or in those sections of the company which are not envisaged for automation: this is impossible by other analytical methods all the more so, if one takes into account the practical possibilities that exist for the procurement of the primary data at an economically justified cost.

2) During the application of systems analysis, a desired model of management information is worked out which proceeds from the real economic and technical requirements and conditions of the automated and non-automated production sections. A comparison of this model with the existing management information system reveals, among others, vital starting points for the necessary perfection of the information system of the company under the new conditions of automated production.

In connection with the questions we deal with of the IIASA research programme, I believe that it is permissable also to consider such practical experiences gained by relatively imperfect forms of systems analysis. We should always consider that practical management activity does not only include large-scale systems analysis that is backed by a computer. We also encounter forms of systems approach and applied systems analysis of the problems of industrial enterprises that have been comprehensively substantiated from the standpoint of theory, but greatly simplified with regard to their methodology. Nevertheless, such forms could also be included in the methodological work of IIASA.

Document M

On Eventual Research Problems for the IIASA Research Project "Control of Integrated Industrial Systems" (Proceeding from Experiences Gained in the Industry of the GDR)

H. Koziolek

Introduction

Work on the creation of automated production control systems has been conducted in the GDR for several years. As in other countries, interest in these problems in the GDR is mainly evoked by the following factors:

- Effective production control is decisive for a flexible and fast response to the satisfaction of demands, as well as for higher economic returns.
- A multitude of production, controlling, planning, and management processes must be co-ordinated in space and time with a high speed of reaction.
- Such co-ordination necessitates the transition from the isolated solution of problems to a system-conforming solution of problems.
- The traditional "manual" methods are insufficient for this purpose; thus, methods of systems theory and operations research (OR), as well as various mathematical disciplines based on electronic computation, must be utilized.

In our opinion automated production control systems are large systems in the sense that they contain various aspects which must be considered in the light of their interactions. On the one hand it is necessary to establish and define production systems by their principal internal elements and relations as

- economic systems
- technical and technological systems
- sociological systems,

and on the other hand, to master the relations between these systems. All these elements must be therefore controlled in their interactions by the actual control system. The linkage of process control and planning is of primary significance in this connection.

Our experience has shown that a larger complement of specialists is required for the creation of such systems and for the solution of the requisite problems. Furthermore, close contacts are necessary with the system that is to be controlled, i.e. with a concrete object that is active in industry or that must be created.

The potential number of scholars envisaged for the IIASA research project "Control of Integrated Industrial Systems" should prove to be insufficient for empirical treatment of such systems so that decentralized treatment of this project in the individual countries will be the most convenient solution. The IIASA group should be employed to generalize the experience gained in the individual countries and to mediate the exchange of experience. Above all, the group could work on the generalization of the construction principles of automated production control systems. At a later date, it would then be possible to decide whether the group should a) specialize in the elaboration of sections of such systems that are of particular scientific interest, or b) participate in the elaboration of control systems for other projects of IIASA when a certain standard of development of these projects has been reached.

Procedure, Experiences, and Problems in the Creation of Automated Production Control Systems in the GDR

Approach

The corresponding activities in the GDR are mainly conducted by scientific institutes of the various branches of industry, as well as by the systems analyses and computing centres of large combines. The decentralized approach has established close ties with production. Furthermore, software for automated production control systems is drawn up by Kombinat ROBOTRON (Dresden) and placed at the disposal of industry. In this connection, work is being conducted on certain questions concerning the standardization of such software. Modification of the software to meet the demands of special control systems is, nevertheless, still necessary. Two conceptional approaches have played a major role in the activities in this particular field in the past, namely:

1) the creation of Integrated Systems of Automated Information Processing (ISAIV), and

2) the creation of Model Systems of Operations Research.

The purpose of Integrated Systems of Automated Information Processing (ISAIV) is the comprehensive penetration and rationalization of the process of information in economic units with the help of electronic data processing. Numerous analyses were conducted on existing information systems, and conceptions were drawn up for "total systems." Such conceptions are no longer drawn up in the GDR today. Instead, endeavours are being made to devise partial solutions that are suitable for integration, and to introduce them progressively. In this connection priority is given over to the following fields:

- Automated production preparation (project planning, construction, etc.)
- Annual production planning
- Flexible production planning
- Process control
- Accounting.

Orientation to a step-by-step solution of the requisite problems has made it possible to achieve good results in certain fields. Later in this paper I will deal with these experiences that are closely related to the corresponding project of Integrated Systems of Automated Information Processing (ISAIV).

Whereas the original ISAIV concept placed emphasis on investigating and modelling the flow of information so that the operations research models were of subordinate significance, the situation was reversed in the original concept of model systems of operations research. The latter was mainly concerned with the integration of operations research models for various problem categories in the economy. Investigations on the flow of information were conducted principally with regard to operations research models.

The work conducted on such model systems has not yet led to the complete mathematical description of economic units, as had been originally anticipated. But operations research models have successfully been built for a few significant fields of economic management, and coupled in certain combines of the chemical industry (among others, with mathematical statistics). This applies mainly to:

- Marketing
- Annual production planning with the help of linear programming and/or input-output models
- Planning in quarterly periods
- Flexible planning
- Process control and/or optimization (among others, simulation models)

- Statistical quality control (among others, with the help of the statistical decision theory)
- Repair planning (among others, network planning - PERT, CPM).

Third generation computers form the technical basis of these model systems.

As a result of our activities we are particularly interested in solving a few specialized problems:

- How is the control of the entire computerized system for the purpose of production control substantiated?
- How should the different criteria of optimization for the operations research models be selected, and how are their mutual interdependencies matched?
- What are the most effective methods of optimization with vectorial criteria (PARETO) for this purpose?
- What experience has been gained on the selection of the co-ordination variables of a model system?
- Where is the most favourable entering point for a model system with regard to the required iterations?
- How is the most favourable computer hierarchy set up?
- How can computers of different firms, particularly central processors and computers, be coupled?

Moreover, further problems usually arise in the creation of production control systems that concern the relations with the larger system. In this connection, we are greatly interested in the possibilities of utilizing systems analysis.

Last not least, the creation of automated production control systems gives rise to problems which concern the relationships to the organization of a company for improving the basis of information, as well as for improving social planning and social relations. These relationships are still often underestimated so that the assembly of corresponding scientific principles should be the concern of the subject under discussion. In this connection, the first experiences have been gained in the GDR with relatively simple forms of a cybernetically substantiated stability analysis of company processes which I shall outline further on in this paper.

In conclusion of this point, I would like to emphasize that there has been a definite trend towards standardization in the GDR in recent years, following a broad spectrum of activities in this field which proceeded from different conceptions. This trend has been brought about by the demand for visible practical results in this field with the result that the problems concerning the system have come more to the fore.

The following will deal with some of the results of the activities mentioned above which have a close bearing on the planned investigations of this IIASA Research Project "Control of Integrated Industrial Systems," and I will bring up a few problems which we are interested in solving.

Experiences and Problems in the Creation of Automated Production Control Systems in the GDR

A number of firms and combines important for the German Democratic Republic national economy have developed automated production control systems into one of the most important and effective fields of application of electronic data processing. Thus, projects for the use of automated production control systems have been successfully implemented in various spheres of metallurgy, the chemical industry, machine building and electrical engineering, as well as in other branches.

One example in the oil refining industry is a hierarchic model and computerized system with which certain problems associated with important technological processes--e.g. crude oil distillation, synthesis of ammonia, and production of terephthalic acid--have been solved, such as:

- Data logging
- Data correction
- Supervision of limit values
- Signalling of limit-value transgressions
- Computation of technical-economic index figures
- Throughput integration.

Such integrating problems as balance adjustment are solved by a central master computer to which the process computers are linked. Next to the considerable savings achieved, the gains derived from the operation of this process computer system are mainly reflected by the fact that the number of disruptions resulting from subjective errors in the operation of the installation have been considerably reduced.

Efforts have been made in the metallurgical industry to rationalize and intensify the exceptionally complicated process of supplying the national economy with the complete and correct assortment of metallurgical products at the right time and place with the help of methods of operations research and electronic data processing. These efforts cover both measures to master the processes of long-term planning at the level of the national economy by the corresponding ministries, as well as the perfection of the control of the production processes concerned in the companies and combines. Thus, a so-called strategical planning model has been created for this branch of industry with which a large number of possible variants of development covering a period of fifteen years can be computed and valuated with the help of balancing and optimization methods.

This model is used to compute both the material inter-dependencies existing within the metallurgical industry, including the effects on the necessary exports and imports at the individual stages of metallurgical production, as well as the economic returns of each individual variant. Among others, the following material and economic index figures were established:

- Balance, demands and yields by products
- Quantitative total output and raw material requirements by products for combines and companies
- Goods production by products for combines and companies
- Raw material inter-dependencies between the combines and companies
- Distribution of crude steel and semi-finished goods by companies
- Computation of the input and consumption of basic materials.

The model covers about 250 sources of supply (combines and companies) as well as about 1000 items. The strategical planning model is supplemented by models for planning by annual and quarterly periods. The focal point of these planning models is formed by the questions concerning the balancing of material consumption and available material, as well as the optimization of available materials.

A number of production controls for semi-finished goods have been implemented in the metallurgical industry at company level. A large number of orders (25,000 to 30,000 orders per quarter), and an exceptionally large diversity of different machining stages are characteristic for this level of production. The production control system is used to solve such problems as: balancing of raw materials and capacities, subdivision of orders by months and shorter planning periods, specification of the optimum technological variant and optimum material utilization, optimization of the sequence of order settlement, etc.

Existing experience in the preparation and utilization of automated production control systems allow the deduction of a number of conclusions and problems which require further scientific investigation.

1) No practice-proven method exists at present for a well-founded selection of process plant that is to be controlled by a process computer, or for the determination of an economically justified level of automation for a given plant.

The choice of the fields of application of a process computer requires thorough analyses of the technological processes and influencing variables, particularly the influence of disturbing variables and the susceptibility of the processes to these disturbing variables. Such analyses necessitate comprehensive scientific studies. They are needed in order to gain information on whether the intended processes or process sections offer adequate resources for increasing effectiveness, and whether this can be achieved by the controlling functions of a process computer (or process computer system). The planners of the control system must concern themselves in great detail with the technological processes and the disturbing variables influencing them. They must also determine with meticulous care the optimum criteria and the assignments of the control system. Moreover, they must acquaint themselves with the principles and ideas guiding the operatives who control the plant when no process computer is present.

Thorough evaluation of existing experience on plant control often makes it possible to formulate simple assignments that may appear trivial at first sight, but which involve only low expenditures for their solution and yet bring high returns.

The use of mobile process computers has proved its worth in conducting such analyses for the determination of the fields of application. The mobile computers are used to investigate the technological processes and to define the eventual economic gains derived from the operation of a stationary process computer.

The main advantages of operating a mobile computer for automatic acquisition and utilization of measuring values to determine the external influencing variables of a plant that is to be controlled are twofold. First, the analysis and valuation of the disturbing variables is simplified and accelerated. Second, expenditures are lower compared with the conventional means of analysis. Other advantages are: a) a high standard of accuracy in the transmission and processing of the measuring values, b) the guarantee of complete synchronism of time when several signals are analyzed during the processing and storage of a massive volume of data, c) the possibility to conduct active experiments with the help of the computer, d) the use of complicated algorithms to process the measuring values, and so on.

The fact that there is no practice-proven method for a well-founded selection of the fields of application of process computer techniques and for the determination of the required level of automation--as mentioned earlier in this paper--should therefore be the motive for analyzing and generalizing corresponding international experience. A method that is applicable in practice could be created in this way. The solution of the task simultaneously includes the necessity to create a method for the determination of the economic gains from the application of various forms of automated production control.

2) Mathematical modelling of the control object is one of the decisive problems of preparing for the operation of process computers. The following contradiction arises more or less invariably in this connection--namely the contradiction between the desire to create a model of the process to be controlled that is as accurate as possible, and the need to keep at a minimum the expenditures for formulating and solving the model equation. The solution of this contradiction often requires a differentiated approach to the problem, i.e. to proceed from the fact whether the solution of the tasks belongs to the project planning stage or to the application stage of the control system. In the project planning stage of the control system, it is frequently necessary to work with more comprehensive and detailed (analytic) process models to conduct an all-round, yet thorough investigation of the peculiarities of the process and its susceptibility to disturbing factors in order to establish, among other magnitudes, the optimal condition of operation. Moreover, it is often necessary to draw up a series of different models for one and the same complicated object in order to define the control algorithm with greater accuracy.

In contrast, more simple process models will be employed in the application stage of process control, particularly under the aspect of limiting computer time.

It is an established fact that the creation of the mathematical apparatus for automated optimization of technological processes--but particularly for the implementation of direct digital controls--is one of the most complicated and elaborate tasks in the establishment of an automated production control system. This makes it necessary to exploit all possibilities for the rationalization of this job.

One of the decisive aids in this connection is the creation of suitable program libraries containing programs for potential multiple use and covering typical mathematical assignments (linear and non-linear algebraic equations, systems of differential equations, problems of linear and non-linear regression, etc.) for use by interested parties. IIASA could handle the problems associated with the systematic compilation of program libraries for typical mathematical assignments to solve the complex of technological process control.

3. Another problem that has not yet been satisfactorily solved concerns the manner of transmission of the controlling functions of the computer to the object. Three variants can be adopted for this purpose:

a) On-line open-loop

b) On-line closed-loop with computerized adjustment of the desired values for local analogue controllers

c) On-line closed-loop with direct action of the computer on the final control elements (DDC).

Although experience on applying these individual forms is available, it is still insufficient for drawing final and generalized conclusions to allow valuations and recommendations. Of major scientific and practical interest in this connection are the questions of which assignments should be transferred to the computer and which jobs should be allocated to man in the process of production control.

In this connection it is necessary to investigate the interaction of man and machine in such processes, and to learn how effective dialogue systems should be devised for control systems.

4) In order to secure a high measure of effectiveness of the automated production control system in practical operation, it is essential to set up competent work teams for project planning and for implementing the system. Such teams must be properly integrated in the management system of the company. Our past experience has confirmed that the founding of a project planning team is the most suitable form. Such a team should be composed of:

- specialists of automation and control systems
- process technicians
- computer technicians
- representatives of departments that will eventually be involved in the project
- maintenance and operative personnel for the technological, computer, and engineering equipment.

Our experience underlines the great importance that must be attributed to close contacts and a mutual understanding of the requisite problems between the project designers of the automated system on the one hand, and the personnel that will be using the system on the other. Such ties must be maintained throughout all stages, from the preliminary studies of the problem and project-planning activities right up to the stage of project implementation.

In view of the great significance of the problems concerning proper supervision of project planning and the introduction of the automated production control system to secure the highest standards of effectiveness, detailed studies should be conducted on this complex of problems. The aim of such studies must be to gain information on the most appropriate composition of the project planning team, its integration within the management system of the company, the forms of planning and stimulating the activities of the team, and the manner of work within the team and cooperation with other sections of the business.

Experience and Problems in the Automation of Technical Production Preparation

Considerable attention is being devoted in the GDR to the problem of rationalizing technical production preparation--particularly in the field of design work, project planning and technology--through the use of electronic data processing. This is because the preliminary stages of production have a major bearing on the ultimate standard of productivity and on the effectiveness of production achieved. Here the important concerns are to:

- increase the productivity of the work of the engineering personnel
- reduce the share of repetitive routines that can be formulated so that they can be worked off by electronic data processing
- increase the share of the creative activity as a result of the previous measure
- increase the standard of the technical and technological information for production
- apply optimization for the design of the products, assemblies and units as well as for the technological processes.

Work is being conducted on an AUTEVO system to rationalize automated technical production preparation. The AUTEVO system (the abbreviation of the German "automatisierte, technische Vorbereitung der Produktion"--automated technical preparation of production) is characterized by standard problem solutions, organizational principles, and technical facilities. It is concerned with the creation of the theoretical fundamentals, methods, processes, algorithms, and programs on the basis of standard EDP hardware.

A difference is made between two fields of application within the AUTEVO system:

- Automated project planning and automated design work
- Automation of technological production preparation.

Basic solutions, as well as user solutions peculiar to certain branches of industry, exist for both fields of application.

Automatic project planning and automated design work consist of methods and processes for automating the jobs associated with the drawing up of the product documentation, as well as for optimizing the utilitarian properties, material consumption rates, and other factors concerning parts, assemblies, and products. Only certain sections of the flow of work can be automated because the active influence of man dominates here (man-machine system).

The automation of technological production preparation consists of a) methods and processes for automated production of process documents, and b) procedure instructions for the material production of products, assemblies, and parts. The documents drawn up by the machines may include work plans, work instructions, punched tapes, program cards, etc.

The use of electronic data processing for technological production preparation is being practiced by many branches of industry, and also in building and transport. Specifically, it is currently being used for the following assignments in technical production preparation:

- Design of printed circuits and wiring diagrams (e.g. for switchboards)
- Computation of the spatial arrangement of rod structures in building
- Computation of systems for the generation of the geometry of ship bodies.

Electronic data processing for rationalizing technological jobs is also being employed for the automated production of punched program tapes for flame cutters, and for machine programming for NC lathes. Technological and organizational project planning assignments are rationalized by the automated establishment of the pattern of equipment for the manufacture of parts and their assembly.

The efficient completion of these tasks--particularly the possibility of multiple usage of projects that have been worked out a single time, and the exchange of technological records--requires standardization measures on an international level. Thus it would be wise to tackle the following problems:

- The establishment of central design catalogues, including the guiding rules for economical material usage, for the reliability of designs
- Work on the standardization of computing methods and on guiding rules for the layout of design and technological documentation
- Rationalization of drafting work (a corresponding program package of automatic drafting has already been worked out in the GDR, and it is being used by a number of companies and research institutes)
- Creation of a methodical system to rationalize the settlement procedure for offers and orders
- Establishment of a data bank to be used while creating the technical and technological records
- Creation of problem-oriented programming languages for technical production preparation
- Creation of an efficient dialogue system covering the needs of technical production preparation.

Summary of the Problems That Are of Interest to Us

The problems associated with the subject "Automated Production Control Systems" that are of interest to us can be summarized from our point of view as follows:

- Generalization of scientific design principles for such sytems based on systems analysis methodology and on the most advanced experiences made in other countries
- Combination of differing mathematical models of operations research in this system, including the problems of model parameter adaption
- Creation of effective computer hierarchies for this purpose, including corresponding dialogue systems
- Questions concerning the integration of these systems into larger systems
- Consequences of the alterations for the organization of companies, for existing information systems, and for the social (sociological) relations of the workers as a result of the application of these systems
- Control strategies for complicated machining and processing operations
- Principles of automated production control
- Creation of program libraries.

In the first stage of the work of IIASA on this subject the experiences of the different countries should be compiled and generalized.

Relationships to Other IIASA Subjects

The utilization of the results of other projects for this project appears to be a wise proposition. The results of methodological research and of the handbook can, in my opinion, be relevant for compiling the scientific design principles of automated production control systems, and for the various elements of these systems. The same applies to the optimization of large scale systems. The project of organization systems (large scale systems) also furnishes certain prerequisites.

It is likewise necessary to draw certain conclusions from the discussed project for organization systems. Finally it is desirable to use the results of the discussed project for control problems of energy systems (possibly also for water systems, among others). It is necessary to consider in this connection, however, that the specifics of the controlled systems only permit the utilization of certain general results.

Document N

Some Issues for Research on the Control of Integrated Industrial Systems

C. Kriebel

Although my participation in this I.I.A.S.A. research conference is as the N.M.O. representative of the National Academy of Sciences, U.S.A., I wish to qualify at the outset that my remarks do not constitute a national report on the topic. I am not a spokesman for and am not aware of any official U.S. position on the subject of industrial automation. My comments are extemporaneous and necessarily reflect my personal view, priorities and professional specialty. I will rely on the other U.S. participants present to offer their own comments on pertinent developments in their respective fields of interest.

The automation of industrial systems is a natural topic area for consideration by an international research institute for applied systems analysis. While the denotation of the subject is not unambiguous, there is little doubt that it encompasses problems which are of both global (e.g., world supplies of industrial output) and universal (e.g., technological unemployment) importance as described by Professor Raiffa. The area includes many issues which overlap and have potential synergism for other research themes at I.I.A.S.A., e.g., in organizational design, or artificial intelligence, or computer systems, or optimization, etc. It is also apparent that an "applied systems analysis approach" to problems in the area is mandatory in order to realize a common and consistent language for communication among principals and to capture the comparative advantages of interdisciplinary research. These attributes notwithstanding perhaps, a logical departure point for a research program on the control of integrated industrial systems might well be to define the area of concern. How broad or how narrow in scope should the topic be circumscribed? (For example, in what aspects does this topic differ from the other research themes proposed for I.I.A.S.A.?) Given its charter and resources, what specific project alternatives on the control of integrated industrial systems are feasible for I.I.A.S.A. to undertake which promise a high probability that a unique contribution can be made in terms of results?

Several of the position papers at this conference have already begun to sketch alternative answers to these questions; and I might add that I sympathize with the view that connotes a broad research mission for the area. In particular, I think a fair categorization of research developments which bear on industrial control systems logically includes contributions from: mathematics (e.g., operations research techniques, optimal control theory, simulation of dynamic models, systems analysis, etc.), engineering (e.g., chemical, mechanical, electrical and civil on the technical or technological level of control), the management sciences (e.g., production-operations management on the functional, planning or managerial level of control, the modeling of decision processes, etc.), computer sciences (e.g., hardware and software configurations, man-machine task subdivision, reliability and instrumentation, etc.), and direct industrial experience (e.g., control technology from various industrial sectors such as chemistry, pharmaceutical, petroleum, steel and primary metals, power, wood products, cement, ship building, aerospace, food processing, and so on). Obvious time, space and personal qualification constraints preclude my attempting to review the panorama of these research activities in the United States.* Instead, I wish to outline four problem areas within the scope of concern which have been receiving some priority in U.S. research and development, and which I believe satisfy the criteria guidelines of I.I.A.S.A.'s research strategy.

1. Network Control Structures. The research activity encompassed by this problem area would concern the design decisions with respect to the decomposition, partitioning and distribution of control functions within a system hierarchy.

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* It is appropriate (if redundant) to note here that professional societies in the respective disciplines regularly publish proceedings and journals which include state-of-the-art surveys on research and development activities. In this regard there also have been a number of occasional reports in recent years; for example, J. Aronofsky (ed), Progress in Operations Research, Vol. III (J. Wiley 1969); H. L. Cornish, et al, Computerized Process Control (Hobbs, Dorman, 1968); T. I. Peterson and M. Tayyabkhan (ed.), Advances in Chemical Engineering Computing (AIChE, 1972); the CODASYL Systems and Data Base Task Group Reports of 1968, 1969, 1971; and so on.

The analysis would look to the development of hybrid designs which equitably balance the relative technical, economic and operational consequences of centralized and decentralized control structures. Consideration would also be given to the comparative dynamics of vertically integrated networks where the time domain for control response varies from second-by-second real time control of a physical process to, say, month-by-month discrete time control by a manager. One example of this dynamic aspect is the sequence of sub-processes and control points in a large vertically integrated oil company beginning with the producing fields (or well) and continuing through transportation and refining to final storage of the finished product and retail marketing.

Allied research and/or project efforts might include: capacity allocation mechanisms among network nodes, such as through the implementation of market, transfer or administrative pricing systems; computer network system design, including distributed data processing for resource, program and data sharing in multi-processor systems and/or distributed computing under multi-miniprocessor configurations; integrated digital process control design, such as through the employment of parallel, analog microcomputers on sub-processes to decentralize real time process control and reduce centralized communication and synchronization; modeling of "higher-order" control system structures that include memory facilities for learning, adaptivity and goal changing modes in proximity to planning processes; the decomposition and modularization of large scale optimization problems (e.g., as an allied effort with "initial research project, 7.5").

2. Management Information Systems. Problems accompanying the design, development and implementation of management information systems (MIS) have become notorious in the United States since the early 1960's. A continuing perceptual barrier in this regard is the misconception that a system or MIS is one, unified and usually computer-based information processing entity that is designed "in total" as of a given point in time and then subsequently developed according to a "master plan" based on that design. An accompanying difficulty for potential users of contemporary technology is the continued proliferation by manufacturers of relatively inexpensive and increasingly powerful electronic digital computers and allied peripheral equipment. The focus of this proposed research activity would be to study the design and development of requisite information system resources for the functional direction and control by

management of (production and other) operations in large (vertically integrated facilities of) industrial systems. The analysis would include the investigation of sub-stage information processing activities (i.e., monitoring, measurement, data collection, storage, retrieval, communication, reporting or display, and use) as modular subsystems, the interfaces between these modules, and the synthesis of these component structures into coherent systems.* Operational criteria for the evaluation of design alternatives vis-a-vis potential application opportunities would also be developed. One example of system modularization and software synthesis for MIS in this case has been some of the pioneering efforts by the large wood products and/or paper companies in the United States where mathematical programming has been employed for the "optimal" harvesting of timber, paper manufacturing processes are computer monitored in real time, paper milling machines are scheduled by operations research models to minimize trim and scrap losses, product shipments and distribution are guided by transportation-transhipment model analysis, and profitability accounting has been applied for marketing and inventory control. A point of departure for this research effort might well be a comprehensive review and appraisal of this experience (or for a comparable industry) world-wide.

Allied research and/or project efforts might include: the programming of management decision processes in systems through computer resident operations research models in various functional management areas, such as scheduling, inventory control, etc.; automatic data collection and instrumentation; data storage and data base management; communication and display technology (hardware and software); programming language developments, particularly special purpose languages for specific user application areas; technology transfer through software exchange between developed and underdeveloped organizations, regions or countries; MIS and organization design; information economics and decision analysis.

3. Man-Machine System Symbiosis. The basic objective of this research effort would be to further contemporary understanding of the control decision process in a normative sense as a basis for improving the balance and sub-division

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* For an extended discussion of these considerations see C. H. Kriebel, "M.I.S. Technology: A View of the Future," 1173-1180 in Spring Joint Computer Conference Proceedings, Vol. 40 (A.F.I.P.S. Press, 1972).

of effort between the human or managerial component and the machine programmable components for structured and (where possible) ill-structured tasks. In this regard the research would consider not only direct labor intensive activities (e.g., equipment operators or mass production, assembly operations) but managerial work activities as well. There exists already a considerable volume of empirical research on this general area, much of which implies that effort to achieve <u>complete</u> (closed loop) automation of nominally complex tasks through mechanization often is technically and economically infeasible. The identification of key elements which impinge on the decision in various situations and the timing of implementation of increasing stages of automation (programming) would be an integral part of this effort. One illustration in this context has been interactive simulation models of operator-machine systems developed to investigate performance tradeoff under a variety of exogenous conditions, e.g., process instrumentation, say for the press operator in an industrial printing plant where color detection and quality control is a critical element particularly as it might concern product trademark characteristics. Another commonplace illustration today is the implementation of a variety of operations research models on time-shared computer systems to facilitate conversational interaction by organizational staff groups in direct support of line management decisions.

Allied research and/or project efforts could include: a variety of behavioral science investigations on human factors elements in job design, enrichment and enhancement of the job environment and/or work place, etc.; measurement, pattern recognition, and process instrumentation devices and techniques; industrial manipulators and robotry (e.g., allied with the research theme on "artificial intelligence"); managerial use of models and management science in problem solving; organizational design (in the micro sense); numerical control and direct numerical control in mechanical engineering systems.

4. <u>Automation of Design Processes</u>. The system design "problem," as such, can be characterized by three contemporary factors. First, design and development activities are labor-intensive. Second, skill requirements for personnel are high (often to the extent that the critical decisions and major work are handled by only a few key members of the design team). Third, individual designs appear to experience high rates of obsolescence; i.e., before the "current" system becomes fully operational, it is apparent that a "new design" is more desirable.

A research effort on "design automation" would seek to mitigate against these characteristics through developments which: increase productivity by substituting (hardware and software) capital for labor, increase productivity directly by modifying the task to better fit human capabilities, and eliminate or reduce the demand for design and development (e.g., general purpose software, so-called "automatic programming" systems, etc.). Some progress has occurred in this area (notably in the computer systems field*), however, the total improvement has been noticeably small in situations involving any measure of technical competence and/or creative skills. A further consideration here for the design and development of management support systems could be the use of prototype experimentation (a common approach in more traditional engineering fields).

Clearly there are complimentary aspects of research across the four areas outlined above and with other I.I.A.S.A. research themes. Consequently, a concerted effort on any of the areas as packaged above may not be a deciding factor in the final analysis. However, these four areas appear to me to possess the quality of universal importance for the "automated control of industrial production"; and I would set my research priorities accordingly.

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* A recent survey on the state-of-the-art in one aspect of this effort is available in: J. D. Couger, "Evolution of Business System Analysis Techniques," A.C.M. Computing Surveys, Vol. 5, No. 3 (September 1973), 167-198.

Document O

Proposal for IIASA Research Project on Theme of Control of Integrated Industrial Systems

I. Lefkowitz

Examine the hierarchical, multilevel approach with respect to the general problem of control of integrated industrial systems. Specific objectives that might be imbedded in the investigation are:

1. Assessment of the contributions the approach has to offer in the areas of modeling, system design, implementation of computer control and on-line decision making, integration of subsystems with respect to higher goals, etc.

2. Identification of common features that render the approach transportable to a broad range of industrial system, e.g. discrete manufacturing and continuous process control.

3. Study tradeoff question relating to distribution of tasks among the various levels of the control hierarchy. Tradeoff includes software considerations, communication requirements, reliability factors, nature of the interactions among subsystems, and the disturbance characteristics as reflected in the tasks assigned to each level.

4. Study the interrelationship between the hierarchical structure and the modeling problem.

   a) use of decomposition as basis for developing the model for large scale systems and for identifying parameters, e.g. via computer simulation;

   b) incorporation of adaptation into hierarchical scheme for feedback of input/output data in updating model.

5. Examine the flexibility of the approach to accommodate the variety of control and decision making functions common to industrial systems, e.g. direct control functions, optimizing control, scheduling, parameter identification, etc. Formulate basic structures and consider questions of software, data base management, communications among computer functions, compatibility, etc.

6. Examine the flexibility of the approach in accommodating multiple objectives as might be imposed by environmental considerations, energy contraints, etc.

Procedure

1. Survey the field to ascertain and document "state of the art" with respect to:

a) conceptual formulations and theoretical results,

b) conjectural properties and attributes as presented in literature, in proposed system applications in common acceptance ("folklore"),

c) results of actual applications and experiences.

2. Examine some of the questions posed among the objectives by use of computer simulation facilities, analytical study, contributions from other people and groups with expertise in the field.

3. Select representative "real" system to serve as vehicle and motivating force for study. Possible candidates include:

a) system for which data is available, pilot plant exists in lab of member nation or collaborating group;

b) system that will be studied by IIASA research team on energy, waste disposal, or pollution control, where there exists significant technological components and where control can play an important role.

4. Develop results in the form of recommendations to working groups in IIASA and other organizations printing up

a) needs for further research and development in supportive theory, and analytical tools, and know-how, e.g. in optimization techniques, scheduling methods, software, coordination theory, etc.

b) directions for further research in the areas outlined in this proposal.

5. Prepare summary of result of study to serve as guide in the structuring, organization, and implementation of computer control of large scale industrial systems.

Document P

A Brief Description of Activities at INORGA, Prague

B. Mazel

Systems analytical techniques have been applied in many large-scale systems which we prepared in the last fifteen years for the control of large industrial enterprises in Czechoslovakia.

As you know, our country is not a big one, but our Institute, which I am representing here, is one of the first of research organizations which started applying computers and mathematical methods for management and control in practice. My presentation should not be viewed as a national report, but as a brief review of the techniques and methods we are using in our Institute for Industrial Management Automation in Prague (INORGA).

The research of the applied systems analysis includes these topics:

-- development of design and programming techniques and application of middle and large scale EDP for metallurgy and engineering;

-- design of automated control systems including utilization of mathematical-computing techniques;

-- data processing and operational research consultation in the field of organization and management;

-- cooperation with other specialized engineering organizations to lay out preliminary projects for building up new capacities, especially in metallurgy.

Let me mention some of these projects we have solved in our country during a short period:

METALLURGY

-- construction of automated control system (ACS) for steelworks;

-- production control of steel plant with electric arc furnaces;

-- control of steel plant with open-hearth furnaces;

-- pig iron production control;

-- basic oxygen furnaces control;

-- soaking pit control and blooming mill control;

-- control systems for rolling mills and for metallurgic plants power systems;

-- optimization of rolled material production;

-- mathematical model for section mills;

-- operative control of ingot stock;

-- operative record keeping of finish mills;

-- production planning and scheduling by usage of adaptive models of LP and DP; etc.

ENGINEERING

The tasks solved in the area of technical and economic planning:

-- final production scheduling;

-- capacity calculations;

-- operative record keeping and statistics;

-- cost calculations, work plan calculations, price calculations;

-- making out production documents automatically, etc.

At present, we have satisfactorily brought to full operation in the CSSR such big projects of automated control systems such as the SKODA car factory, plants with a very complicated structure of production, such as CUD in Prague and the SKODA works in Pilsen (job-shop and small-series production).

DEVELOPMENT OF ACS METHODOLOGY

The principal tendencies of ACS ideology and methodology we are planning:

-- to develop uniform methods of ACS solutions and project management;

-- to formulate methodical principles and tasks for program blocks formation (these methodical principles should guarantee block universality and maximum adaptability in diverse conditions).

The uniform applicability of principal ideas and conceptions will be presented in the form of model conceptions and project solutions which however -- with regard to the necessity of respecting some architectonical freedom for concrete application -- will not exceed the level of the conception part of a project.

The unification of project solutions will be concentrated on functions being chosen as suitable for automation or on their elements. The resulting type operative projects -- type macroinstructions or algorithms will be incorporated into concrete standardized projects. As a by-product of this approach we would establish a library of algorithms, with a mathematical description and recommendation of usage.

The whole-state methodology of ACS project solution and management is to be considered an effective and positive element for project management.

We suppose that some of our experiences in this field of research would be useful for the teamwork of IIASA as well.

Document Q

Comments

F. Rabar

I propose that we not prematurely reject the idea of Dr. Brioschi. His approach overlaps that of Dr. Haefele and to a certain extent what we are going to do in the Water project as well. Therefore, I advocate the reconsideration of his points on the following grounds.

(a) We will badly need this complementary field to the Energy and Water projects.

(b) The underlying idea (global problems which have to be solved from the point of view of humanity as a whole) can be the common thread to find the otherwise scattered projects together. It is not enough to keep saying that there are many interconnections between our planned projects; rather, what we need is a world view which should be reflected in all of them.

(c) The methodological difficulties which arise from dealing with these problems are common to the Energy and the Water field and must be solved anyway; e.g. the problem of clashing local and business interests which result in a different kind of method--not optimization but solving conflict situations, game theory, etc..

(d) A small group of people with a broad point of view can do much more in this field than can be done by solving a very special control problem which cannot be generalized anyway. However, the points of Dr. Hatvany can be built in as methods for the transfer of technology from one country to another.

(e) The question proposed by Dr. Brioschi is extremely important: how can technical development and structural changes in industry be influenced to be consistent with a circular economy and with the development of ecological research and with the future energy structure.

(f) The problem proposed is a problem of the future. The unfolding of the present research projects will at any rate take two or three years, and by that time this problem will have become one of the burning issues which should be solved.

APPENDICES

APPENDIX I

An Experimental Model of an Integrated CAD/CAM System

(A Demonstration at the Computer and Automation Institute, Hungarian Academy of Sciences on April 13th 1973.)

One of the main current projects of the Institute is the development of CAD methods in the engineering industry and research in the development of integrated CAD/CAM systems. The project is conducted in close cooperation with other members of the Hungarian Association for Machine Tool Programming (SPE.)

Work so far was concerned with the implementation of different elements of NC, CAD and CAM--the interconnection of which was not always plausible. These building blocks are:

- adaptation of APT-like languages
- a small computer dialogue to prepare error-free APT-like language programs
- control tape verification with graphic display
- the development and manufacture of a graphic display (GD'71)
- general software for graphic design
- a prototype DNC configuration with two NC lathes.

The model system built up of these elements provides useful estimates on the hardware and software requirements of large systems and helps people to learn to think in systems. It is not meant to be a production system.

The hardware configuration used is shown on Figure 1 and consists of:

- a local graphic design terminal; modelled by two linked VT 1010B small computers, with disc store and a GD'71 graphic display (with other peripherals),
- a CDC 3300 located in a different part of the City, which models the background large computer, and
- a 24K Baud telephone line to connect the two configurations.

The whole system is grouped around two main facilities:

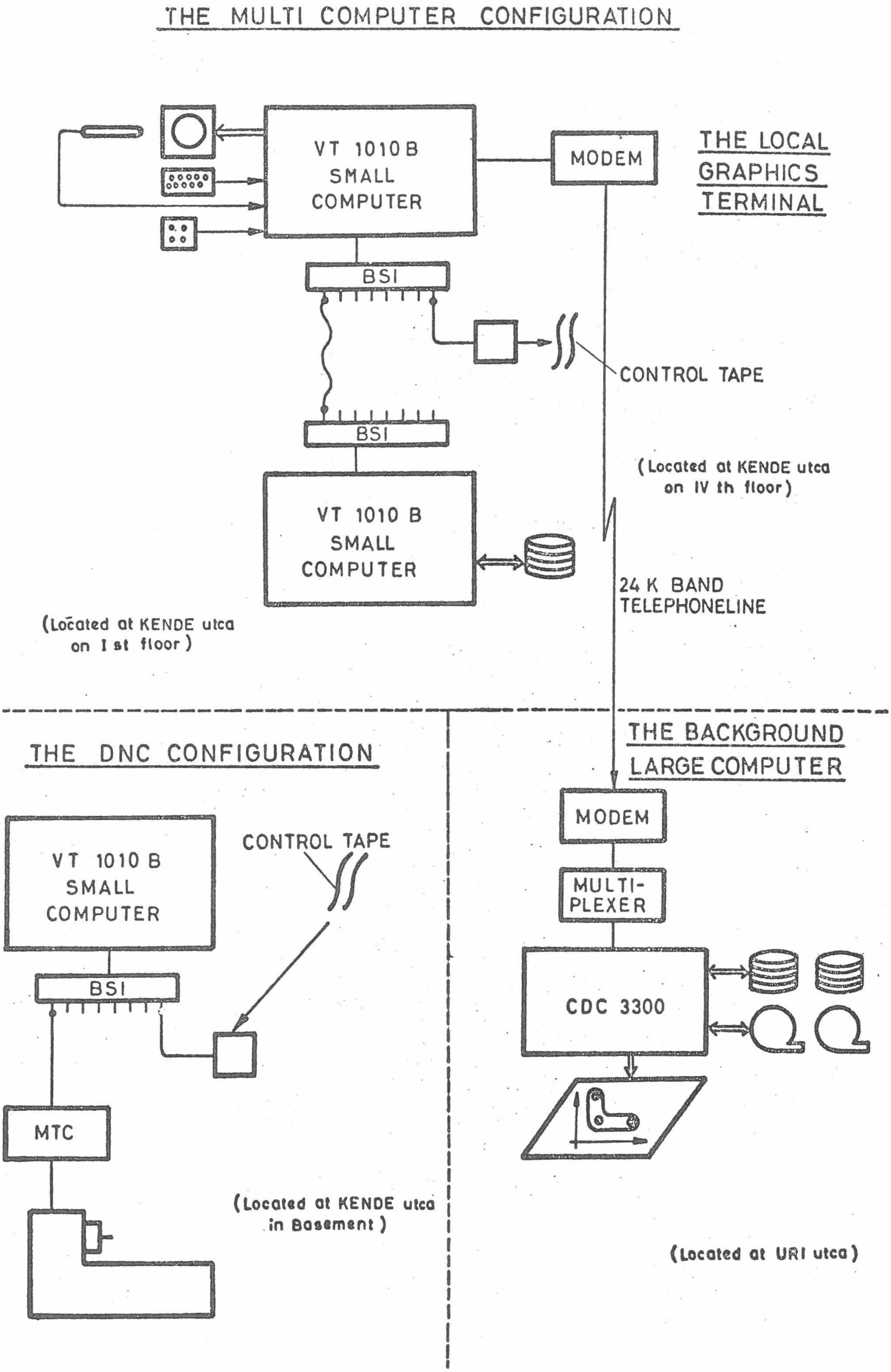
THE MULTI COMPUTER CONFIGURATION
VT 1010 B
SMALL
COMPUTER
MODEM
THE LOCAL
GRAPHICS
TERMINAL
BSI
CONTROL TAPE
BSI
(Located at KENDE utca
on IV th floor)
VT 1010 B
SMALL
COMPUTER
24 K BAND
TELEPHONELINE
(Located at KENDE utca
on I st floor)
THE DNC CONFIGURATION
THE BACKGROUND
LARGE COMPUTER
MODEM
VT 1010 B
SMALL
COMPUTER
CONTROL TAPE
MULTI-
PLEXER
BSI
CDC 3300
MTC
(Located at KENDE utca
in Basement)
(Located at URI utca)

Figure 1.

- part program writing, processing, and checking
- machining the parts on a DNC system.

The demonstration shows these two facilities: the designer using his graphic terminal (on the fourth floor) and the DNC system (in the basement).

The elements involved (in the order of their use--see Figure 2):

i) the designer at the GC'71 console compiles an ADAPT part program, using the dialogue program: AIR;

ii) the part program is passed to the large computer and processed by the ADAPT processor; the CLDATA output is stored on a disc file;

iii) a Display Post Processor is invoked to produce output on the display for visual checking of the part program. There is a possibility to correct the part program or take a completely new start at (i);

iv) if the designer is happy with the results the CLDATA may be filed and the MID Post Processor written by the Institute for Technology of Mechanical Engineering is invoked to process the CLFILE and produce the machine control information in MID format--the internal machine tool independent format of the DNC system;

v) the MID file may be transferred to the graphics terminal where it is punched onto paper tape (the paper tape is to be replaced by a direct link in due course).

Finally, this paper tape may be entered into the DNC configuration:

vi) the MID file is read in into the DNC computer, stored in the internal format. The machining then proceeds.

THE INTERACTIVE NC LATHE PROGRAMING AND DNC SYSTEM

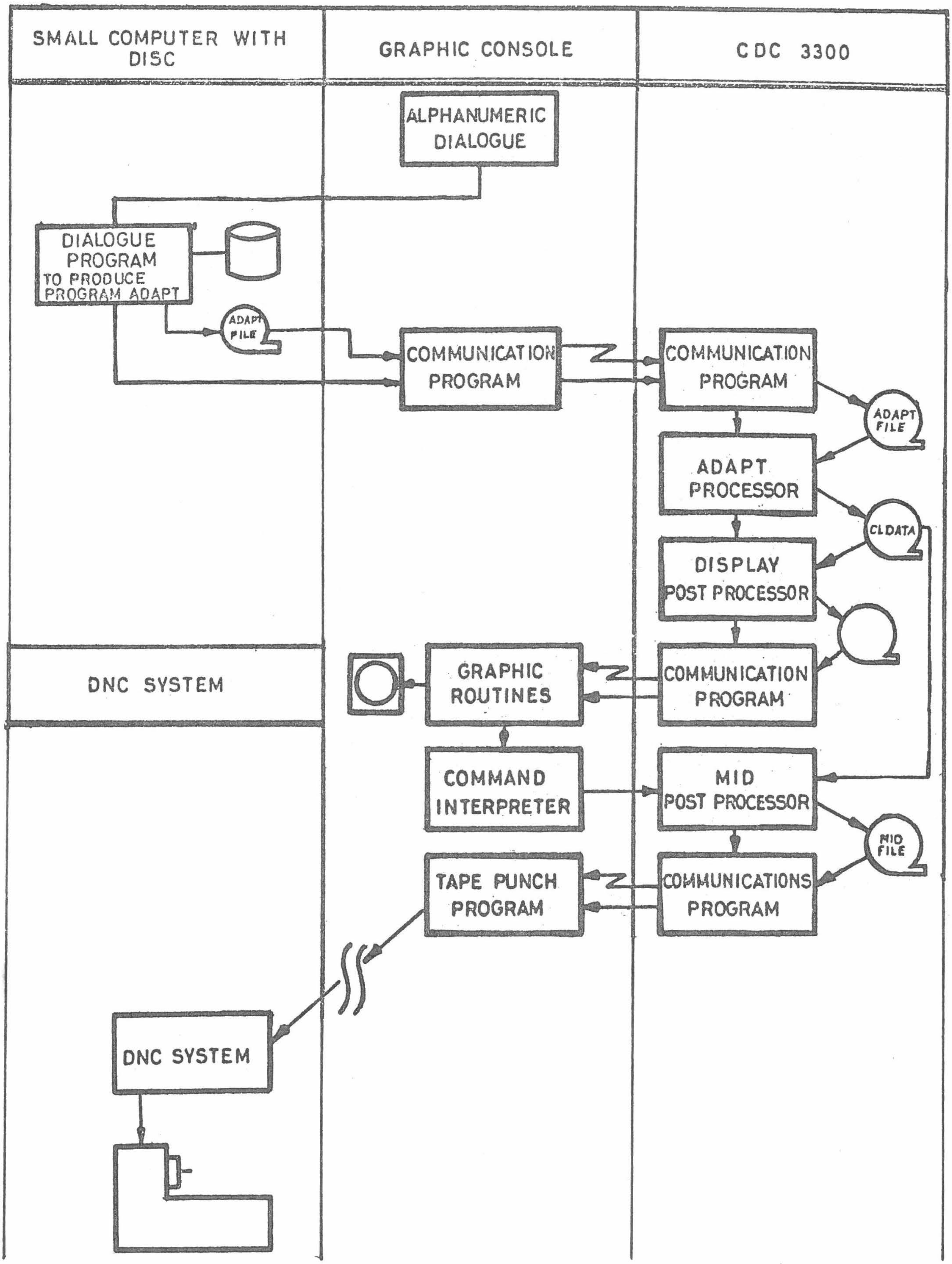

Figure 2.

APPENDIX II

Overview of Fields of Research in the
Laboratory of Machine Tools and Factory Management,
Technical University, Aachen, F.R.G.

(From Descriptive Brochure)

Industrial Organization and Manufacturing Planning

I. Product Planning and Information Systems

A) System for the Planning and Development of new Products

Methods for planning and development, long-term market demand analysis for industrial goods, technological substitution, assessment of ideas for new products.

B) System for Product Control

Market analysis of existing products, improvement of products and elimination of weak products, product-orientated organization structures.

C) Method for the Long-Term Planning of Company Potentials

Planning of strategies, investment and financial planning, planning of personnel, criterions for the selection of products.

D) Information System for Product Planning

Investigation on systems for collecting, storing, condensing and finding of information, systems for describing production processes and products: development of information systems for:

- planning of strategies
- product planning
- product development
- product control.

II. Production Planning

A) Production-Planning

Optimal coordination of market demand and production capacities.

B) Planning of Offers

Determination of costs and terms of delivery.

C) Production Planning and Control

Development of an integral date planning system by using networktechnique, procedures to level capacities, simulation by computer.

D) Generation of Networks

System for generating networks. Use of the same networks for offer and order planning. Automatic generation of networks and development of standard networks.

E) Bill of Material's Systematic

Function of part lists for the handling of orders, their coherence to date planning, different structures of part lists, relation of part lists to the structure of products: Functional structuring and structuring with respect to assembling; splitting and setting up of part lists.

III. Rationalization in the Design Department

A) Technical offering and order handling

Systematic offer handling, optimal transformation of customer problems into technical solution, automatic generation of offering data, integration of technical offering and order handling.

B) Analysis of Design

Structure of design activities. Complexity of products, application of technical and organisational auxiliary means in different design stages, effect of changes on integrated information processing.

C) Analysis of Products

Functional structuring of products, assignment of products or assemblies to functions, outlines for product structuring, combinations of functional units (morphological method) with the aid of computer.

D) Application of Graphical Display Units in Designing

Determination of working principles and geometry using graphical display units and plotter, information contents of drawings and their representation on graphical display units, symbolic representation of technical units, generation of components with graphical display units and digitizers, calculation of economic efficiency of computer aided design.

Development of an integrated work planning system composed of the following functions:

- production planning and control
- material planning
- cost planning
- jig and fixture planning
- technical investment, planning
- method planning.

IV. Work Planning

A) Automatic Generation of Working Plans

Automatic information processing starting from work piece description up to the delivery of the working plan.

B) Material Planning

Automatic calculation of the needed optimal raw materials, medium-range planning of stocks for semi-finished products, minimization of waste material.

C) Organization of Production Facilities

Systematic planning and supply of production facilities.

Standardization and re-use of:

- tools
- measuring instruments
- jig and fixtures.

Selection of suitable production facilities.
Automatic design of jig and fixtures.

D) Technical Investment Planning

Long term investment planning on the basis of product statistics. Medium term investment planning on the basis of assembly and workpiece statistics. Short-term investment planning on the basis of workpiece statistics and analysis.

E) Projection of Flexible Production Systems

Automatic planning and development of flexible production systems composed of inter-linked NC-machines and/or NC-processing centres:

- selection of suitable workpieces
- investigation of the processing profile
- development of alternative production systems
- selection of the optimal production system.

Organization and operation of flexible production systems.

F) Assembly Planning

Rationalization of assembling in individual and small-series production with regard to:

- optimal material flow
- short production flow time
- optimal assignment of personnel, jig and fixtures and other auxiliary means.

V. Individual Projects

A) Workpiece Systematic

Layout of machine tools on the basis of workpiece analysis.

B) Object Numbering

Object numbering system on the basis of parallel identification and classification.

C) <u>Classification Systems</u>

Systematic order for components, assemblies, production facilities etc. as a basis for rationalization.

1) Classification of plants and machines

Purpose: Survey, clearing up and standardization of the production program, references for development, marketing and sales statistics.

2) Classification of assemblies

Purpose: Standardization, improvement of methods for designing, work planning and investment calculations.

3) Classification of steel plate components

Purpose: Standardization, minimization of waste material and grouping of components of similar manufacturing technology.

4) Classification of workpieces

Purpose: Re-use, formation of workpiece families, standardization, lay-out of machines.

5) Classification of jigs and fixtures

Purpose: Quick retrieval of existing designs, application of unified constructions, standardization of planning data.

6) Classification of tools

Purpose: Standardization, simplification of tool organization.

D) <u>Analysis of the Efficiency of Numerically Controlled Machine Tools</u>

Automatic calculation of economic efficiency and comparison of costs and productivity of numerically controlled and conventional machine tools.

Automation in Production Engineering

I. Application of Computer in Production Planning

A) Further developments of NC-programming languages

Combination of the EXACPT1-System for drilling operations and the 2C, L-System for 2 1/2-dimensional milling operations in the EXAPT1-2C, L-System, investigations on a modularized NC-processor for considering specific user's requirements.

B) Standardization of NC-programming languages

Test of existing description methods for computer languages, investigations on the fundamentals for comparing and standardizing the input language and the CLDATA, preparation or recommendations for national and international standardization committers.

C) Use of Display Systems for Workshop-Planning

Methods and procedures for data input, data control and altering of data, needed for automatical systems in workshop planning, menu-technique for the NC iterative programming, combined graphical and alpha-numerical input, graphical control of manufacturing data as tool-motions and drawing information, use of active display systems for a stepwise optimization in operation of workshop-planning.

D) Modules for the automatic production planning

Automatic workplanning and tool selection for turning on the basic of a complete workpiece description, decision logic tables for work-cycles, further investigations in the same field for other machining operations.

E) Information-System of Machining Data

A central information-system for preparation of machining data for workshop-planning, requirements, problems, organization, development of algorithm for tool wear and calculation of machining data for turning, drilling and milling methods of data collection, evaluation and retrieval, methods of information-processing and transport.

F) <u>Machining Equipment Orientated Information-Systems</u>

Methodology of data preparation of machining equipments (e.g. specific data of machines and tools) for interaction between the different automatic workshop planning systems in an integrated production process, development of a system for a flexible description of machining equipments in relation of different user requirements, investigations on the possibilities of an economic use of EDP for these problems.

G) <u>Numerical Representation and Description of Workpieces for the Automatic Production Process</u>

Development of a system for a complete description and numerical representation of any workpiece for the preparation of all geometrical and technological data according to the integration of the production domains design, workshop planning and manufacturing, handling of these data on an active display screen.

H) <u>Determination of Manufacturing Operations on the Basis of Workpiece Formelements</u>

Automatical determination of the manufacturing process on the basis of a complete representation of workpieces, geometrical and technological analysis of the workpiece, definition and systematology of form elements. Assignment of alternative working methods and tools to form elements. Optimizations of the manufacturing process based on all technological requests of the workpiece.

II. <u>Use of Computers for Process Control within Production</u>

A) <u>Direct Numerical Control of Machine Tools Using Computer (DNC)</u>

Development of methods, programs and hard-ware parts for the control of machine tools using process computer. Data collection by means of CRT. Optimization of working conditions (ACO).

Investigations on the possibilities of using machine control units for direct numerical control of machine tools.

B) Use of a Mini Computer for the Control of Machine Tools (CNC)

Analysis of numerical control with respect to the possibility of programming the different control functions for a Mini Computer.
Data collection.

III. Feed Drives for NC-Machines

A) Drive Components

Investigation of drive components of NC-machines (Stepping motor, DC motor, hydraulic motor, torque amplifier)

B) Hydraulic Components

Electrohydraulic servovalves

C) Mechanical Links

Investigation of lead screws and gears with regard to their static and dynamic behaviour. Optimization of their time and transient response.

D) Analysis of Electrical and Electro-Hydraulic Positioning Control Systems

Normalized calculation methods for system layout.

IV. Electronics, Electronic Measuring

LASER

By use of a LASER interferometer as length standard, the error of displacement measuring systems is determined kinematically and with quasi-static output by means of a new digital method.

Using the beam of a He-Ne-Laser stabilized in direction of the reference axis, the kinematic and/or static deviation from straightness of bearings or slide motions is measured continuously and simultaneously for two orthogonal directions with an axially parallel four quadrant photo-diode.