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Computer-Aided Techniques as a Tool for the Integration of Industrial Processes

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IIASA Working Paper

WP-74-039

1974

COMPUTER-AIDED TECHNIQUES AS A TOOL FOR THE INTEGRATION OF INDUSTRIAL PROCESSES

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August 1974 WP-74-39

CONTENTS

1. General Remarks

At the IIASA Planning Conference on Integrated Industrial Systems (IIS) and Computer Systems (CS) and in the Survey Report "Computer Aided Design" (CAD) it was emphasised that CAD could be a fruitful field for study at IIASA.

It was recommended that CAD should be supported both by the IIS Project and the CS Project. While the IIS Project deals with problems of rationalization of the design, planning and control of production, the CS Project is concerned with problems of computer networking.

CAD is connected with both the IIS and the CS Projects because CAD is a method for solving problems occurring in industrial systems by the utilization of the computer and its possibilities for man-machine dialogue systems. This is not a definition of CAD but shows its main topic. From this point of view, it would be useful not to restrict the so-called "computer-aided-design-technique" to the design process only but to also include the other processes of industrial systems, i.e. planning processes, control processes and production processes.

In conformity with the principles of IIASA it is recommended that investigations in the field of computer-aided design be extended to all processes relevant to IIS. Therewith the conception of CAD is generalized and goes beyond its original meaning. CAD is considered now as a method for solving problems by utilization of man-computer interaction.

A number of national and international institutions are already working in the field of CAD. A lot of literature, experience and viewpoints are in existence. Our viewpoint is the following:-

- In the investigations and in optimization of the processes, the methods used for problem solving should have the highest priority. This means that it is necessary to find out first of all the methods by which the practical problems are to be solved.
- To support these activities, some general strategies and general methods have to be prepared for developing or analyzing the methods to be used for problem solving in industrial processes.
- Based on these methods for problem solving in industrial processes, efficient means have to be applied and adapted to reach the optimal objectives. One of these means will be any version of the computer.
- These means have to be prepared in such a way that a broad range of utilization can be reached.

Therefore, in accordance with the IIASA strategy, the investigations should be oriented towards finding out how the work in industrial systems is to be done and which methods and means should be prepared to support this work. We are of the opinion that CAD, in its larger sense as a computer-aided technique, could be one of the most powerful means in solving problems in industrial systems. Therefore, it is necessary to combine the investigation of industrial systems' processes with the application and adaptation of the technique which brings these processes to a real optimum.

The main topics of this working paper are:-

1. To roughly characterize the main processes of industrial systems by their essential features.
2. To point out the possibilities of rationalization of the main processes of industrial systems - first of all by utilization of computers.
3. To sketch some methodological aspects of analysis and synthesis of industrial processes.

4. To recommend problems that could be investigated in IIASA in connection with the rationalization of IIS by utilization of computers.

5. To investigate the role of CAD techniques as a tool for the integration of industrial processes.

The main objective of this working paper is to explain the problems and to fix the limits of the area to be discussed at the CAD conference at IIASA in November 1974. We shall not describe here state-of-the-art reports or solutions to the problems but will only point out the direction of possible research and various ideas which will be explained in some papers presented at the conference.

2. Characterization of the Main Processes in Industrial Systems

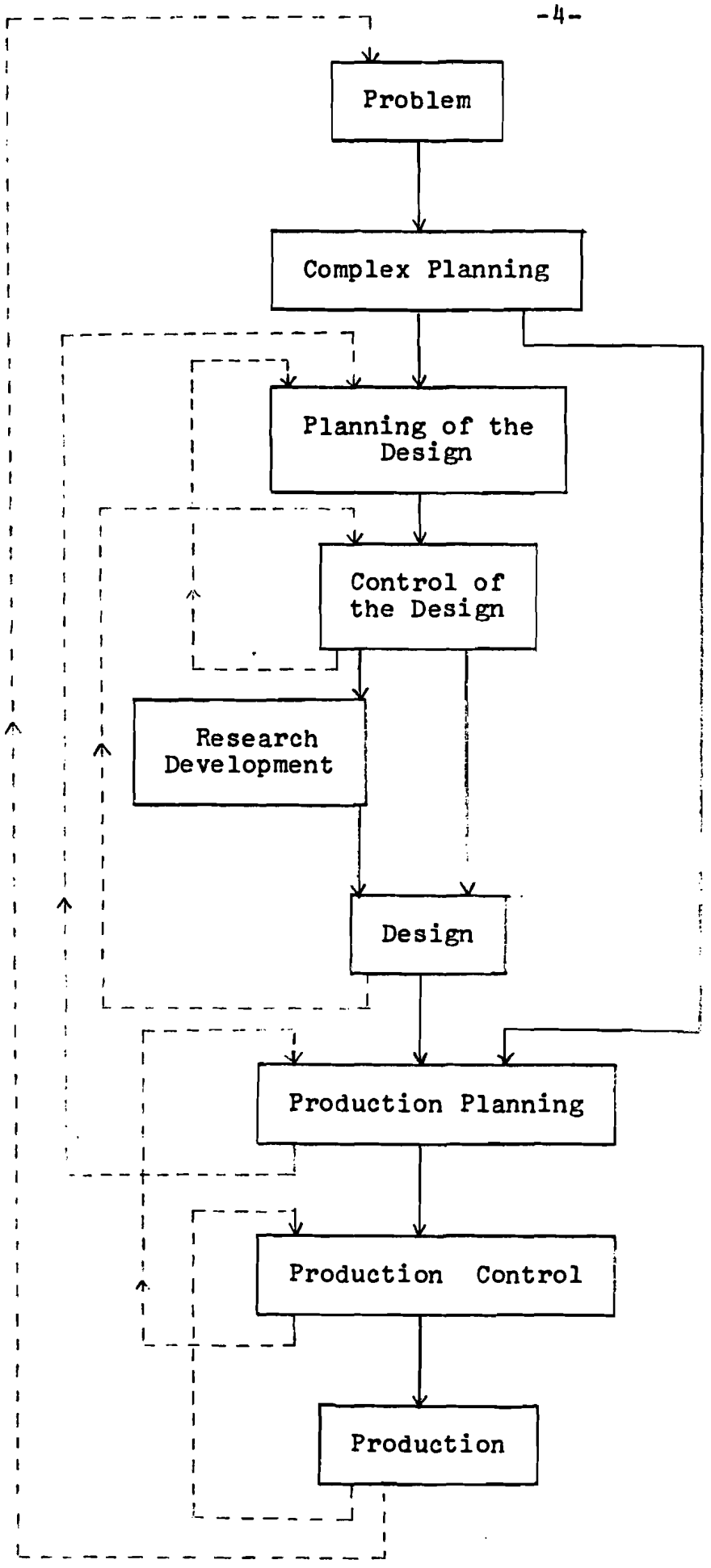
To find a basis for explaining the ideas about an extension of CAD, we first of all have to describe the subject we want to deal with - the processes in industrial systems - in a very simple way. The main processes of industrial systems are:

- Planning processes;
- Realization processes -
  - design processes
  - production processes;
- Control processes.

Fig. 1 shows a very simple version of the relationship that exists between these processes when a certain product is to be manufactured.

In the following sub-chapters the main processes of industrial systems will be roughly characterized by their essential features. In doing this, the main task is to

FIGURE 1


Problem
Complex Planning
Planning of the Design
Control of the Design
Research Development
Design
Production Planning
Production Control
Production

estimate which of the part processes consist essentially of really creative work and how far it is possible to formalize certain of them in order to form a basis for the utilization of computers or other means.

In addition to these main processes some auxiliary processes exist, e.g. transportation processes, the disposition of material, but these will not be considered here.

2.1 Design Processes

A design process is the sequence of all actions taken in inventing a product and in describing the ideas in a form suitable for manufacture.

In designing products the following three problem complexes have to be solved:

(1) Specification of the problem

Within this complex the designer has to define and to specify the problem in cooperation with the employer. From this arises the functional description of the designing problem.

(2) Determination of the solution

Within this complex the following actions have to be carried out depending on the problem to be solved:

- determination or selection of the solution principle;
- carrying out calculations, estimations and evaluations;
- making decisions
  (discussion of solution variants and selection of the optimal solution variant);
- preparation of principal drawings.

The sequence of actions to be carried out within this complex depends to a large degree on the design problem to be solved. As a result one gets a structural description of the design problem.

(3) Documentation of the solution

Within this complex the solution determined upon has to be presented in a form suitable as the basis for production, for opening operation and for maintenance. Depending on the problem, the following actions have to be carried out within this complex:

- elaboration of drawings or circuit diagrams;
- elaboration of lists (work sequence lists, parts lists, data carrier for the documentation);
- elaboration of data carrier for manufacturing;
- elaboration of data carrier for starting the operation, maintenance and diagnosis.

The goal of the rationalization of design processes should be to carry out the three problem complexes as far as possible by means of computers. In the first instance this depends on how far it is possible to formalize the single processes, i.e. how big a part of really creative work is in them. Beyond that, the concerned field of application has to be scientifically prepared to a sufficient degree that systematical methods, or at least heuristical methods, are available for the single processes.

The portion of creative and formalizable work is very different in these three complexes. In solving problem complex (1), i.e. in specifying the design problem, the main part of the work has a creative character. Only a small part seems to be formalizable.

In solving problem complex (2), i.e. determination of the solution, one must establish whether the solution principle is known or not. If it is known, then it is possible to largely formalize the actions; if it is not known, then development or research work has to be carried out first. This work consists mainly of creative components.

In principle, the problem complex (3), i.e. documentation of the solution, can also be largely formalized.

The extent to which the work within the three problem complexes can be formalized indeed depends on the degree of scientific processing of the field of application. The aim should be to develop either systematical or heuristic methods, in which certain elements of intuitive approach are combined with systematical methods for partial processes.

2.2 Production Processes

The production process is the sequence of all activities to be carried out in the course of actual manufacture of the technical object which has been invented in the design process.

This means that the production process is represented as a great many technological operations, to be done in the sequence described in the technical documentation. These technical operations are either to be done by human beings themselves or by machines or instruments.

The design process is to be interpreted as an information processing process, i.e. only information (inventions, descriptions, mathematical models, etc.) is to be handled. However, the production process is a material and energy processing process. This is the main difference between the two processes.

In the same way as the design process is supervised by a control process, the production is also controlled by such an information processing process. In this paper we only deal with information processes and their rationalization and not with material or energy processes; therefore, the only possibility of altering this production process is by altering the supervisory information processes which control the production processes.

The production process may be divided into the following classes:

- continuous processes;
- non-continuous processes;
- batch processes.

Another possibility of classifying the production process is the following:

- individual production of one part;
- mass production of a medium number of parts;
- mass production of a large number of parts.

Depending on these different kinds of production processes, different aspects have to be considered in the design, planning and control processes.

2.3 Planning Processes

Planning is the process of preparing a set of decisions for action in the future, directed at achieving goals by optimal means*/. In this sense, planning itself is a decision process.

The aim of the planning is to define an optimal sequence of operations to be carried out in the future. Thereby, the following optimization criteria can be taken into consideration:

- less demand of material;
- less demand of energy;
- less demand of manpower;
- less production time;
- less production costs;
- high quality of the products;
- optimal inventory;
- optimal utilization of the machines.

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*/ F.A. Lyden and E.G. Miller: Planning Programming Budgeting: A Systems Approach to Management.

In this sense, planning is a multi-goal problem. Optimization has to be carried out by ranging the criteria using priorities or weight coefficients and by taking into account certain restrictions, e.g. in resources or manpower. In connection with optimization, a suitable choice of the planning period is of great importance. The longer the period chosen for planning, the higher the rate of optimization. On the other hand, the longer the planning period, the higher the probability of deviation between the planned and actual processes.

Design planning and production planning are of interest in relation to this paper. As the design planning mainly refers to rough estimates, one can only get approximate predictions on the design process itself. The design planning chiefly consists of creative components.

In production planning, roughly speaking the following main steps have to be carried out:

(1) Determination of the objects to be produced and development of a master schedule for their production;

(2) Establishment of the material and manpower requirements implicit in the master schedule;

(3) Schedule of work assignments at the various process locations.

While in step (1) much creative work has to be done, the work in steps (2) and (3) is widely formalizable.

If we consider investigating the different types of industrial processes, e.g. continuous, non-continuous and batch processes, different aspects in planning have to be taken into account. The manner in which the planning has to be carried out also depends to a large degree on whether it is individual or mass production.

2.4 Control Processes

The control of industrial processes refers to two aspects:

(1) Giving instructions according to the plan;

(2) Permanent comparison of the operations carried out with the points given in the plan.

If deviations occur between the plan and the operations, then a correction in the process must be made by altering some inputs or process parameters. If the deviations are so big that the optimum support calculated in planning requires too much additional means or resources, then a correction in the plan itself can be necessary. In this sense the control of industrial processes has an adaptive character.

The control of industrial processes includes both management (i.e. control by man) and automated control (i.e. control by technical means, e.g. by control units or computers). Our efforts in the investigation of integrated industrial systems should be directed at replacing as far as possible management by automated control.

In most cases control processes in industrial systems are hierarchically structured (multi-level, multi-goal systems). Mainly in the lower levels the control processes are largely formalizable, whereas in the upper levels creative work dominates. This is the reason why automated control devices can presently be found predominantly in the lower levels.

3. Rationalization, Automation, Computer-Aided Techniques and Integration

3.1 The aims of these activities

To optimize industrial systems, the processes have to be arranged in such a way to obtain at least e.g. a decrease in costs, a decrease in manpower, a decrease in production time, or an improvement in the quality of the products.

There are two main directions we have to consider:

(1) To alter and optimize existing industrial systems. or part processes in these systems. In this case it is necessary to change the running of the process without interrupting the production.

(2) To optimize the design of a new plant before it is built up. Here it is possible to consider and realize all the processes as a unit from the very beginning.

These activities for the optimization of industrial systems can be divided into three classes: rationalization, automation and the use of computer-aided techniques.

(1) Rationalization of industrial systems

As rationalization we will designate the increase of efficiency by improving the structure of a system or the sequence of a process. In rationalizing an industrial system it is not absolutely necessary to utilize a computer or other automatic device.

(2) Automation of industrial systems

Automation is the complete replacement of human work by technical devices, such as control devices, switching circuits or computers. An automated process is self-acting.

(3) Computer-aided techniques in industrial systems

In utilizing computer-aided techniques some parts of a problem-solving process are carried out by a computer, others by a person. A high level form of computer-aided techniques is a dialogue system between man and computer.

In order to rationalize or automatize a process or to utilize computer-aided techniques, it is necessary to have enough information about the process itself and about the theoretical means and methodological methods, which can be used to alter and optimize this process, and to have sufficient knowledge of the possibilities of computer techniques. The

first item is the subject of Chapter 3.2 (Methodology of analysis and synthesis of industrial processes), and Chapter 3.3 (Computer hardware and software) deals with the second one.

Based on these methods and computational means, a derivation of problems to be solved will be possible.

At present, rationalization, automation, and utilization of computer-aided techniques are mostly carried out with respect to one process, i.e. either with respect to the design process, to the planning process or to the control process. In this way several optimization processes are solved independent of each other, so one cannot expect to get the total optimum of the industrial process. To do this, it is necessary to take into account to a larger degree the influence between these processes which is directed to the integration of industrial systems.

Integration in industrial systems requires a unified way of thinking and unified techniques and technologies in computer application (languages, data structures, data banks). In this connection it would be of interest to distinguish the kinds and steps of integration and the factors by which the bounds of useful integration are determined.

3.2 Methodology of Analysis and Synthesis of Industrial Processes

A computer can only carry out actions or operations which are formalizable. If a computer is to be applied in any industrial process, we at first should analyze the process and try to separate the formal logic work from the truly creative work, in order to be able to utilize the computer as much as possible.

The analysis of industrial processes should be carried out in two directions:

(1) Analysis of man's problem solving logic in design processes, planning processes and control processes;

(2) Analysis of the function, structure and properties of the objects of processes in industrial systems, in order to recognize the set of information which has to be worked out through these processes.

Both directions have to be seen as one unit.

The objects of processes in industrial systems are the results of creation and representation of technical products and/or actions in these systems within different levels of abstraction.

One step in the direction of integration of the different processes in industrial systems can be taken by building up a unified system of representation and description of objects manipulated in the processes and of the processes themselves.

Therefore, it is necessary to analyze the objects and the processes, to find out their structure and function and to investigate their relationship to the environment. In this connection modelling problems play an important role.

The essential theoretical foundation for the analysis and synthesis of objects and processes is given by:-

- systems theory;
- information theory;
- automata theory;
- control theory;
- game theory.

The aims of this investigation of the processes in industrial systems and of the structure and function of objects are:

- to recognize common features in different industrial processes;
- to synthesize new processes;

- to find out new possibilities for rationalization and application of computers
- to find out starting points for integration of part processes
- to support the application of unified mathematical methods for modelling and optimization in this field.

3.3 Computer Hardware and Software

In the same way as the formalization of processes will be possible, so will the application of computers be feasible. In industrial processes the formalization of processes will be possible only to a certain extent. Therefore, it is necessary to link man and computer to a unified system in order to solve the problems in an interactive way, supported by the new kind of man-machine system. Hence it follows that some demands on software, hardware and user-organization of man-machine systems have to be realized. These requirements have to be deduced from the total process in industrial systems (design process, planning process, control process, production process).

Nowadays the application of computers in this area is in general only directed at particular parts of the total process. But we should aim at the application of computer techniques as a means of integrating these partial solutions and of finding out a good way of improving the processes in industrial systems. One way is to use an integrated computer systems.

3.3.1 Structures and features of the hardware

The fundamental requirements of computer hardware have to be derived from the structure and organization of the use of this CAD system. In the field of industrial systems it must be possible to activate and to use the CAD system from different decentralized places. This requires the construction of a network of terminals, connected to the central

computer. The requirements of these terminals have to be derived from the representation and amount of information to be used in the process of communication between man and machine. The level of intelligence this terminal must possess is decided by the necessary information processing.

The realization of such a network for CAD requires a suitable central processor having such properties as time-sharing, multiprocessing, realtime, etc. and a lot of terminals having more or less their own computing capacity.

The peripherals are divided into two categories:

- α-numerical and graphical units for communication between man and computer (planning and control processes use mainly α-numerical units, design processes use graphical units).
- units for communication between computer and direct controlled working systems (NC-machines, supervisor systems in production, etc.).

There are a lot of demands on this computer network, e.g. reliability, minimum error-rate, security against unauthorized changing, manipulating or accessing information, efficiency and economics.

3.3.2 Representation, transportation, processing and storage of information in computer networks

The representation and description of information to be processed in this network depends on the structure and kind of information to be found in the area of application. The algorithms for manipulating the information, for input-output, for transportation, for storage and retrieval of information, have to be based on this representation of the information. There is a complex of basis software and a complex of problem oriented software for solving these problems. The latter is based on the basic software.

Two complexes of problems are of interest:

- elaboration of a unified description system for the problem-related information. There is an internal and external description system closely related to one another;

- elaboration of suitable languages to support the construction of both the system of basic software and the problem-oriented software packages.

The unified description system contains all kinds of objects, in particular:

- functional description of technical objects and processes
- geometric-structural description of technical objects
- description of operations in production processes
- description of operations in planning processes
- description of operations in control processes, etc.

This unified description system comprises both the description of the elements and the hierarchical structure of the objects.

The aim of integration is to create a relationship between the descriptions of the objects of the different partial processes (design, planning, control, production) which enables the exchange of information between these partial processes without translation of the description of the object into another description system.

A main topic is the representation of the geometry of technical objects. To do this, it is necessary to have a special system for description and manipulation of 2- or 3-dimensional objects.

An approach of representing and describing objects on the basis of the systems concept is possible. In connection with computer application it is necessary to extend this concept in order to find a way of describing the detailed information sufficiently. It is also necessary to build up a subroutine library for handling these objects.

It is necessary to have special languages, in order to support the process of describing objects and to present and describe algorithms for the manipulation of these object descriptions. In general, extensions of the main programming languages, such as PL/1, FORTRAN and ALGOL, are

used. We have to distinguish between the languages used for constructing and enlarging the CAD system and those used by the engineer in solving problems with the help of this CAD system.

Special consideration has to be paid to the problems of information storage and retrieval. In such a large integrated system there is an extensive quantity of information to be stored, retrieved and distributed to differently located places.

The use of a general data base for the whole system will help to integrate the system. There are data complexes used only in one part of the process, e.g. patents in the design process, but there are also data complexes which are used to connect different parts of the process, e.g. the drawing, which is an output of the design process and input of the production process. This kind of data has to be accessible to more than one process. This access will usually be done by different terminals at different times.

3.3.3 Man-Machine Relations

A main property of such an integrated system is the man-machine relationship in the solution of practical problems. This type of work produces some additional demands both on the hardware and on the supporting programming systems. The organization of the work, the division of the work, and the cooperation between different teams will be influenced by this kind of man-machine relationship.

In particular, problems arising from the division of work between man and computer should be investigated. These are mainly problems of information exchange. The computer indicates the position reached in the process of problem solution, man estimates the results, decides on how to proceed and sends this information back to the machine.

Also in this field the graphical representation of a situation has a special significance; we can control further process by manipulating the graphical representation.

The application of such a CAD system in industrial systems has to be done in such a manner that the user is able to work without having special training in computer techniques. Therefore, we have to elaborate a command language adapted to his way of solving problems in this field. The system will be controlled by the use of this command language.

In the whole field of industrial processes there will be many versions of this command language, e.g. for design, technology, planning and control, and also within the different industrial branches, e.g. civil engineering, machine building, metallurgy, electronic engineering, etc. But all these versions must have a common base.

4. Recommendations for Future Work at IIASA

Computer-aided techniques can be considered as a general method for solving problems in industrial systems. This method should be utilized in design processes as well as in planning, production and control processes. The utilization of this method in different processes would lead to an integration of these processes.

According to principles of IIASA, namely wide utilization of the results of research, it is proposed to enlarge the investigations in the field of CAD (Computer-Aided Design) to all processes relevant to industrial systems.

The integration in industrial systems requires a unified way of thinking, e.g. unified techniques and technologies in computer application.

The aim of this investigation should be to support the integration of industrial processes by application of CAD as a unified method.

The main aspects of the work should be:

(1) Establishment of the general schematics of integrated systems of different industrial areas, keeping in view the modules of which they are composed and the mode in which these are interlinked.

(2) Investigation into the interrelation between industrial processes (design process, planning process, control process, production process), problem solving techniques used in these processes and the required computer techniques.

(3) Investigation into the common features and peculiarities in design processes, planning processes, control processes and production processes in selected branches of industry, e.g. machine building, metallurgy, electronic engineering.

(4) Elaboration of unified computer-aided techniques suitable as a basis for the creation of integrated industrial systems.

In accordance with the planning meetings of the IIS Group of IIASA [1] to [5] the investigations should be started in the following branches of industry:

Processes in the metallurgical industry (steel-making factories);

Processes of machine building (Maschinenbau);

Processes in the chemical industry.

Primarily IIASA should play the role of an initiator, i.e. finding out new problems which are of interest to many countries and which have to be solved for the improvement of industrial processes. Because of IIASA's limited capacity, the majority of the problems picked up should be handed over to institutions in the NMOs for solution in more detail. Particular problems should be worked out by IIASA members themselves, possibly supported by their national institutes. Based on these investigations, a certain part of the work in IIASA should be to produce guidelines for the design and implementation of integrated industrial systems.

Some aspects of the investigations recommended to be carried out in the field of industrial systems could also be of interest to other IIASA projects, e.g. Energy Project, Water Project and Large Organizations Project, because planning and control processes also have to be solved in the generation and distribution of energy, in the allocation of water resources or in the optimization of large organizational systems. The methods used for solving these problems are very similar to those used for optimizing industrial systems. In all these areas the same computer techniques should be applied. Therefore, close cooperation with the other IIASA projects seems to be useful and necessary. As to the methods to be developed for solving problems in industrial systems, support from the Methodology Group would be desirable.

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