DESIGN OF TECHNOLOGY AND ORGANIZATION OF CONSTRUCTION WITH THE AID OF SIMULATION AND EXPERT SYSTEMS /PROBLEMS, EXPERIENCES, PROSPECTS/.

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1. Introduction

Such concepts as scheduling, control and design in construction engineering are computer-assisted to a different degree. The problem can be looked at from various perspectives. One of them is the necessity of defining numerical characteristics about production processes. This in turn is related to the identification and modelling of the said processes.

It follows from the many years experience of the authors that two complementary modelling systems should be distinguished:

technology - model - technology, and

investigations - simulation - investigations.

These two systems combine engineering knowledge with computer methods. The organizing method, based on the induction method, is the basic research method which takes us to modelling (including the control of complex construction processes). It has recently been shown that especially Expert Systems require that the induction method be necessarily used (e.g. when constructing a knowledge base which incorporates a data base).

The induction method combines three groups of methods:

- simulation,
- combined methods (e.g. simulational-analytical and simulational-heuristic) and
- expert systems (ES).

Heuristic rules link combined methods with ES; two groups of rules are distinguished. The first group includes rules applied to, among other things, job-shop scheduling, optimization of resources scheduling and are based on heuristic programming. The second group includes rules based on the logical structure (cause-result) of the IF-THEN type.

All the three groups of methods considerably enrich the engineering knowledge related to the organization of building production.

The paper discusses the authors' experience in the modelling and control of production processes. Special attention is paid to the differences and difficulties encountered when attempting to apply an expert system to the design of the technology and organization of construction. The said difficulties are not encountered in the design and selection of machine parts or in applications in diagnostics.

2. Simulation and combined methods

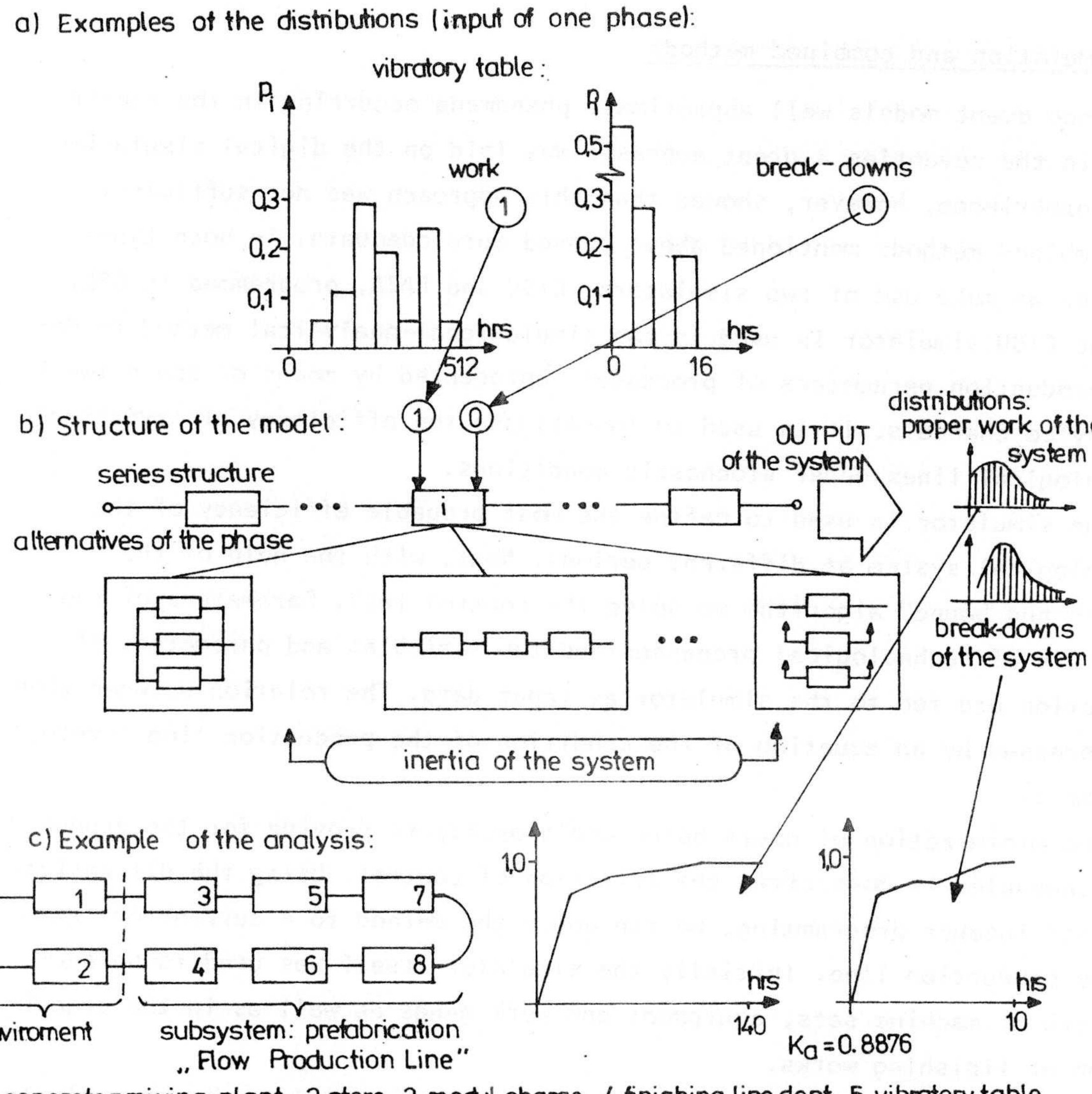
Since event models well approximate phenomena occurring in the construction, in the seventies a great emphasis was laid on the digital simulation. Later experience, however, showed that this approach was not sufficient. The combined methods mentioned above proved more adequate. In both types of cases we make use of two simulators: CIBU and FAZA, programmed in CSL.

The CIBU simulator is used in the simulational-analytical method to define production parameters of processes represented by means of any network of service channels. It is used to investigate the efficiency of asynchronic technological lines under stochastic conditions.

The simulator is used to define the most probable efficiency of the technological system at different periods. Next, with the help of the "branch and bound" algorithm we solve the control task. Parameters of the structure of technological processes and the variables and parameters of production are fed to the simulator as input data. The relation between them is expressed by an equation of the condition of the production line (system) at time t.

The minimization of costs borne additionally to provide for the production scheduled is most often the criterion of control. Using the discretization and integer programming, we can apply the method to a current control of the production line. Initially the simulator itself was used to balance the work of machine sets, equipment and work gangs as well as in the organization of finishing works.

The simulational-heuristic method has been invented in order to evaluate and control the reliability of any production system. Additionally, a genuine methodology of investigation reliability has been outlined. The methodology is based on the decomposition and synthesis of the reliability structure of the entire system as well as on an atypical measure used to evaluate reliability. The measure consists in a distribution of time at which the system works properly. For this purpose the FAZA simulator has been constructed. It permits analysing and evaluating a system with any reliability structure of its individual phases (cf. Fig. 1b). Fig. 1 illustrates a reliability analysis. The simulator is used to control reliability (maintain it a specified level), most often by means of so-called reserves.



1. concrete-mixing plant, 2. store, 3. modul charge, 4. finishing line dept., 5. vibratory table, 6. turn-table, 7. overhead crane, 8. water vaport.

Figure.1. Reliability analysis.

Very interesting results have been obtained in the analysis of the so-called system inertia. The system inertia reflects a phenomenon which permits continuing the operation of the system even when one of the phases breaks down. This is most frequent in concrete prefabrication. A comparison of the reserve method with the inertia method shows the advantage of the latter over the former.

When optimization and control are combined it suffices to find such a number of reserve elements (in a specified phase of the system) which will guarantee the desired level of reliability at minimal costs borne on the formation of the reserve. A linear and integer model is obtained. Since it is very labour-consuming and expensive to determine the reliability of the system and the total cost of reserve formation for the entire set solutions possible by means of simulational experiments, in order to find a solution a heuristic rule is applied.

The procedure of the investigation and evaluation of reliability is expanded, namely it is used as an element of the expert system. Irrespectively of the expert system applications, it is very important to build a data bank and a set of experiences pertaining to functional structures and their mapping onto the reliability structures and to collect information on the kinds of work time and downtime distribution for each phase which represents not only failures (traditional approach) but also the quality of gang work, machines, shortage of materials, personnel, organizational deficiencies, etc.

3. Expert system application to the design of execution of grain silos

The expert system is a method which aids the design of technology and organization of construction and significantly increases engineering knowledge. It has been used to design the manufacture of grain silos. In the five years to come a number of silo batteries will be built in Poland. For example, it is planned that sets of several 9 and 16-chamber silo batteries will be built in six different places.

Investigations of a few batteries presently under construction showed that the efficiency obtained is much lower than in the design due to a wrong organization of works. Moreover, a number of technological errors were made.

The silos are made by the slip method. The machine consists of inside and outside slip forms. The forms are raised by hydraulic jacks fixed at

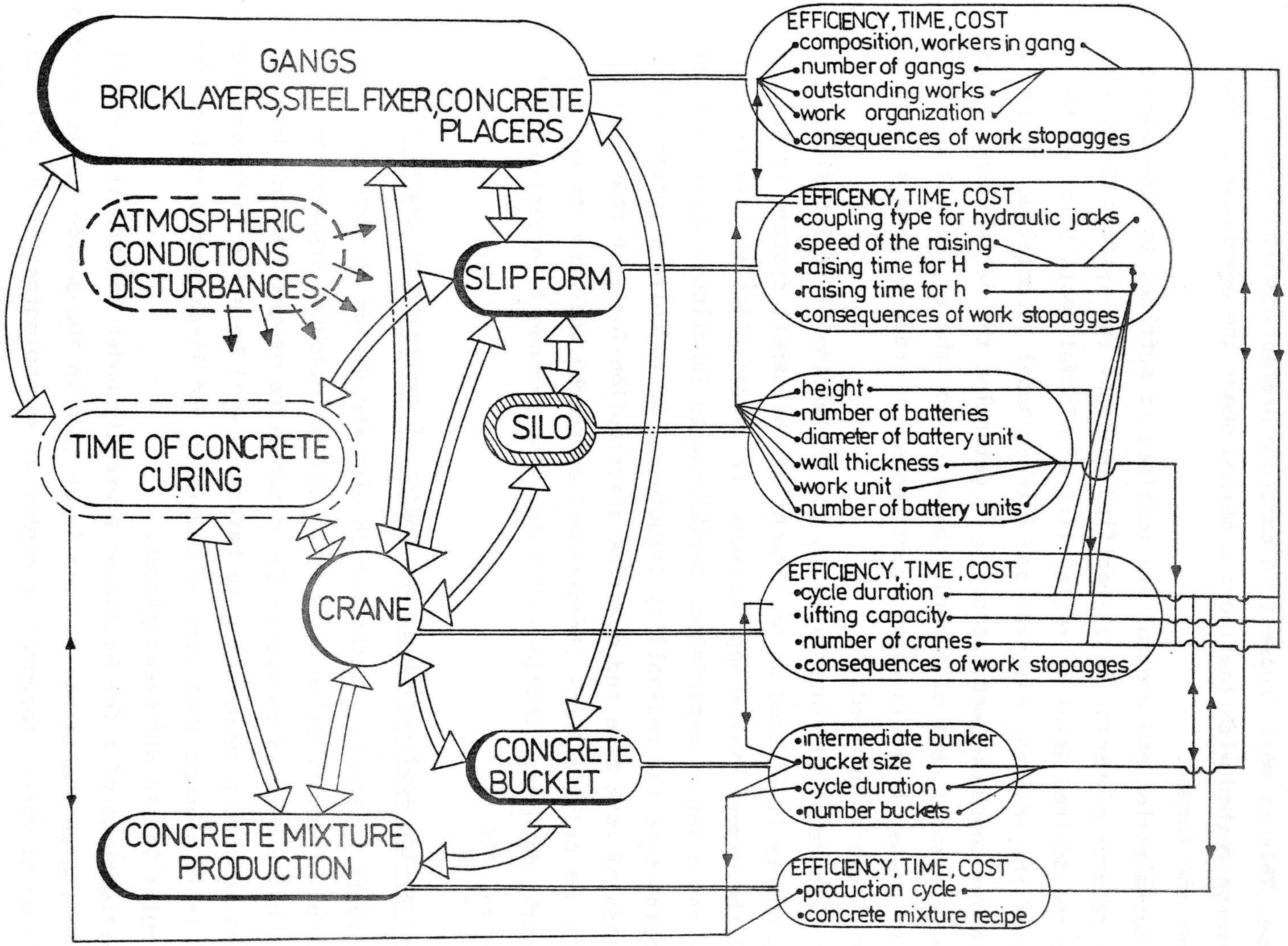


FIGURE. 2. PRODUCTION RECOURCES SUBJECT TO DESIGN AND PARAMETERS CHARACTERIZING PRODUCTION RECOURCES, INCLUSIVE OF EFFICIENCY - EFFECTING RELATIONS.

each yoke which grip the jack rods. The machine moves at fixed rate with all the equipment placed on the working platform and all working units under operation. The realization of monolithic works at different seasons of the year requires that an adequate technology and organization be applied. Component elements of the production system under discussion (henceforth objects) and relations between them are shown in Fig. 2. By objects are meant production resources (machines and equipment, working gangs, etc), which are subject to the design as well as the object of manufacture (a set of silo units - batteries) whose parameters may be given or may be subject to design. Fig. 2 shows also technical-constructional and exploitational (basic and supplementary) parameters which characterize the objects. In order to illustrate the scale of the problem a few relations holding between them have also been shown.

The purpose is to design an optimal set of objects (from among many variants possible) accounting for one or a few of the criteria mentioned (max. efficiency, min. realization time, min. costs, min. losses, max. balancing, etc.) and make a project of the technology and organization of works for the adopted set. All parameters shown in Fig. 2 are subject to the design.

Speaking generally: the problem lies in providing for such resources that it be possible to erect walls at the optimal rate, influenced by a concrete fixing time, which requires a complex mechanization of works (so that the efficiency of machines of working gangs be adjusted to the slip movements).

4. Building of the expert system

The system includes: a data base and an inference rule base which make the system's knowledge base. The system is equipped with the machanisms of verification and supplementation of inference rules. A scheme of the ES is shown in Fig. 3.

When constructing a knowledge base a number of problems have to be solved and a number of questions answered. In the case in question the data base contains knowledge of four kinds (cf. Fig.3). The knowledge contained in the fourth group, obtained directly from experts, practically not recorded anywhere and not described to such an extent, is especially valuable. It comprises data obtained from experience. The inference rule base includes all knowledge pertaining to all technological and organizational conditions

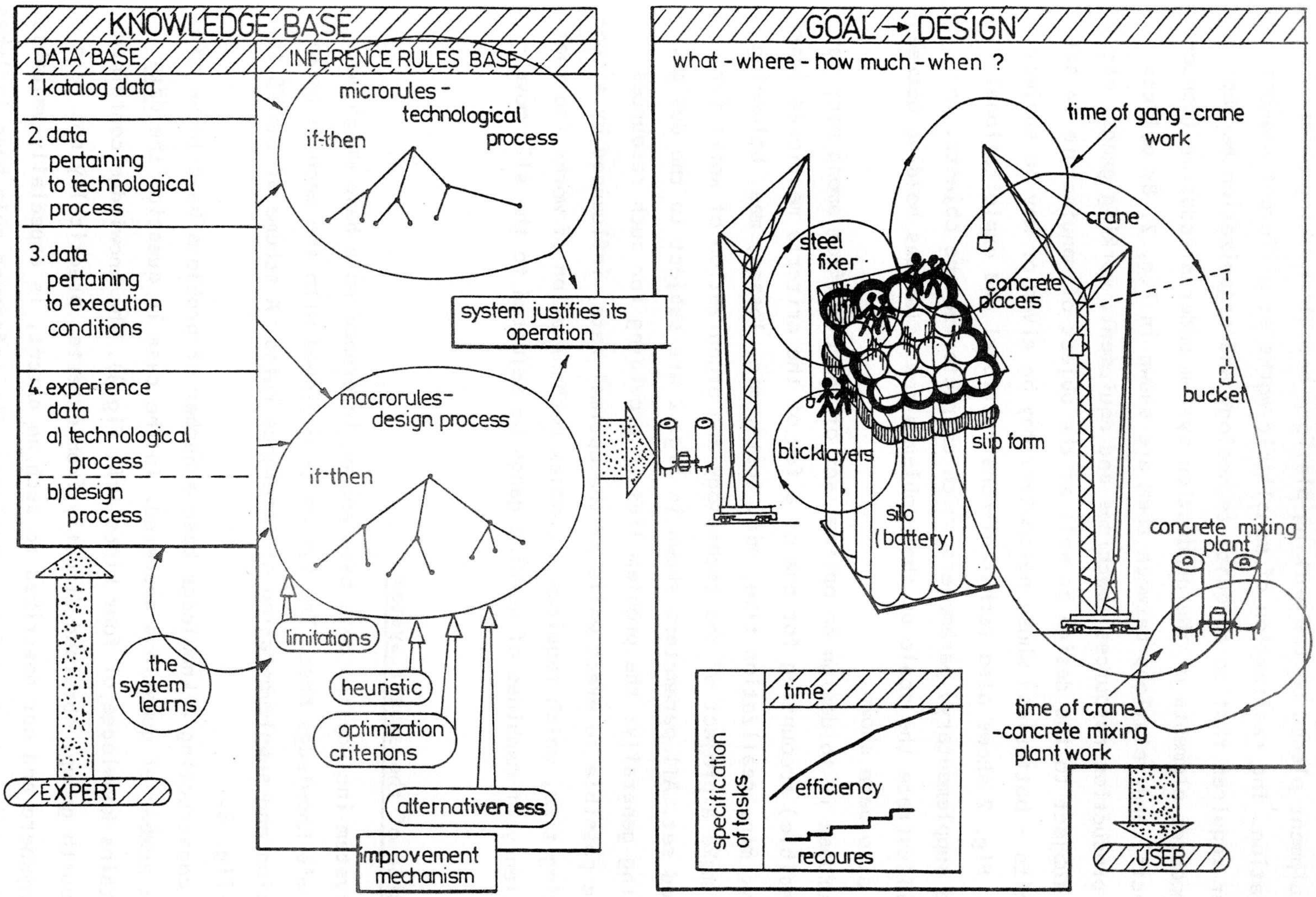


FIGURE. 3 . BASIC STUCTURE OF THE EXPERT SYSTEM.

shown as a dendrite. In this way relations holding between all objects (their parameters) of a complex production process have been established.

The expert system in question pertains to two aspects:

- the art of design
- the technology and organization of monolithic works.

Hence, it appeared necessary to distinguish two rule bases: micro rule base which describes the technological-organizational process and macro rule base which governs the design process.

Micro rule base

Micro rules are the result of a detailed analysis of the technological process which takes into account organizational conditions(e.g. principles defining possibilities and consequences of cooperation between individual machines etc.). Individual parameters subject to design can assume specific values from intervals from which it is possible to eliminate some of the values when relations holding between successive elements are taken into account. E.G. a single concrete layer can be from 5 to 50 cm thick yet because of the vibrator's work (parameters) it must be restricted to 40 cm. A dendrite made of micro rules eliminates some of the data from the data base. Fig.4 shows examples of micro rules. The relations describing individual parameters have been written as functions.

Macro rule base

Macro rules indicate the proper order and hierarchy of the realization of successive design steps, determine the order of extracting knowledge from the micro rule base, inform how to use all the information contained in the knowledge base.

The operation of macro rules is based on successive limitations which eliminate redundant information (factors).

Four stages of reasoning have been distinguished:

a/ the stage of preparation

The most significant exploitation parameters are shown in the same coordinate system (e.g. the efficiency of all elements of the system under design). Types of machines and equipment, etc., which can be applied, have been specified.

b/ the stage of limitations, e.g.

- the enterprise has only some types of machines and equipment at its

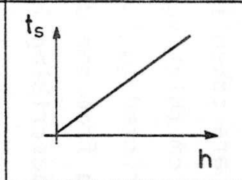
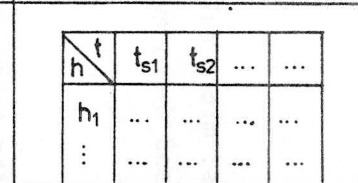
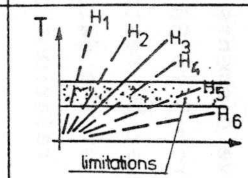
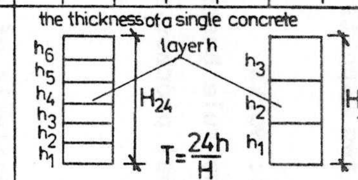
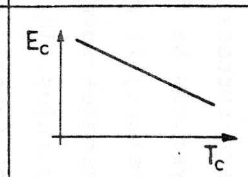
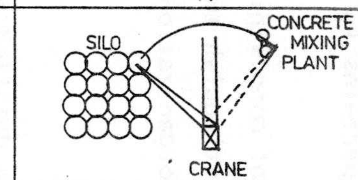
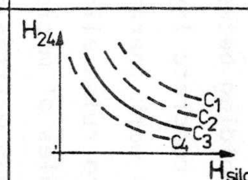
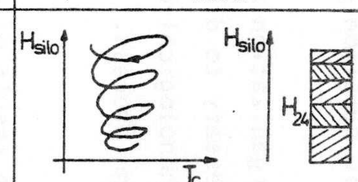
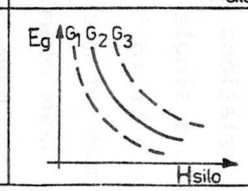
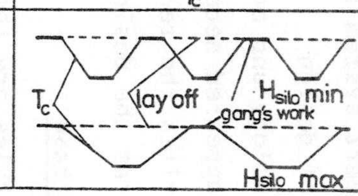
RULE	FUNCTION	DIAGRAM	IF-THEN	MATRIX OR FIGURE OR FLOW CHART
if the thickness of a single concrete layer (h) increases **then** slip raising time (t_s) increases.	$t_s = f(h)$		if h ↗ then t_s ↗	
if the thickness of a single concrete layer (h) increases **and** the 24 hour efficiency (H_{24}) remains constant. **then** the time during which concrete mixture is in the shuttering (T) increases.	$T = f(h, H_{24})$		if h ↗ and H_{24} = const then T ↗	
if the cycle time off crane (T_c) increases **then** the crane efficiency decreases.	$E_c = f(T_c)$		if T_c ↗ then E_c ↘	
if the height of the silo (H_{silo}) rises **and** the production recources (crane C) are constant, **then** the realizaction cycle time (T_c) increases **and** the 24 hour efficiency H_{24} decreases.	T_r, H_{24} = $= f(H_{silo}, C)$		if H ↗ and C = const then T_r ↗ and H_{24} ↘	
if the height of the silo (H_{silo}) rises **and** production recources (gangs G) are constant, **then** the gang efficiency (E_g) decreases.	$E_g = f(H_{silo}, G)$		if H_{silo} ↗ and G = const then E_g ↘	

FIGURE. 4 .MICRORULES – EXAMPLES.

disposal,

- the experts' experience points to the unpracticality of applying specific types of machines,
- conditions in a given area exclude..., etc.

c/ the stage of alternativeness:

if variants of production resources are prepared and limitations taken account then consider rules which permit alternating sets of objects.

As a result, variants of solutions emerge, eg.

A_2 - unalterable basic production resurces, alterable auxiliary production resources ——→ consequence: varying 24 hour efficiency of the slip, decreased losses of efficiency...

d/ the stage of optimization

For particular variants of solutions the function of efficiency losses is defined, costs and times are included, the degree of the system's harmony is determined and an optimal solution chosen. Rules of this type are described by a general relation: if variants of object sets are known then con - sider rules which will permit making a choice. In multi-criteria tasks the ELEKTRA method is used.

The macro rule base is aided by the verification (adjustment) mechanism (cf. Fig. 3). By means of this mechanism inference rules are verified and supplemented and facts whose occurrence in practice is unlikely are eliminated.

As a result an optimal design of technology and organization of works is obtained (an optimal set of objects, situational plan, a schedule illustrating the contribution of all outlays and production resources in time),(cf. Fig. 2).

We have seen that ES can be used in other aspects, eg.

- ES permit not only designing a set of resources for the realization of silos whose sizes are specified but also reversing the problem, i.e. it is possible to investigate the maximal and minimal sizes of the silos with respect to the realization capabilities by means of resources at one's disposal influence of technology on design ,
- ES permit simulating situations which can take place at the building site and introducing appropriate remedy measures.

5. Final remarks

(1) The object of the investigations, including the degree of the complexity of construction processes, their mechanization and recurrence are indispensable if the methods mentioned above are to be advantageous.

(2) The number of solutions pertaining to the sensitivity analysis is insufficient. Moreover, when controlling and optimizing it is important to take into account the intervals of the solutions' stability. The solutions must be expanded to comprise problems of a dynamic and non--stationary character. The latter factor affects especially the efficiency of production systems.

(3) More attention should be paid to so-called combined methods, including heuristic procedures. Combined methods link operational research with business games, case methods and training. All cases of modelling mentioned in the paper can be used in participation simulation.

(4) The problems of the design of technology and organization of works can be modelled and solved by means of ES. Due to the character of ES application in design compared with earlier applications (e.g. in diagnostics) two kinds of rules should be included: micro rules as relations which govern technological processes and macro rules which control the micro rules. The so-called verification mechanism of inference rules also appears to be useful. A module pertaining to the varying realization conditions is often used.

(5) It is envisaged that the influence of stochastic elements on ES will be taken into account through the determination of production parameters by means of the CIBU and FAZA simulators.