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INTEGRATED INDUSTRIAL CONTROL
DEVELOPMENTAL CONCEPTS

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Many existing industrial management and control systems are not based on an integrated systems concept. This is largely due to the fact that the production control systems have been developed independently and separately from the management systems. The local control systems aimed at monitoring technological units or transport facilities have virtually no links with the management information systems designed for inventory control, planning and dispatch of production. This failure to exploit the potential power of applied systems analysis is caused, on the one hand, by the complexity of the integrated problem and the lack of general concepts and approaches to its solution. At the same time the people who have developed such limited systems have extremely detailed but narrow experience. To create a process control system, a deep knowledge of the technology is required and these systems are usually designed to make full use of technological equipment. In developing managerial systems, specialists in management, organization, and planning are required, who have a deep understanding of the specific features for the given plant, and experience of its general environment.

The difference in approaches to the problems above, currently results in the organization of production processes being inadequately considered. On-line operational control systems are rarely encountered as a link between production planning systems and local automated process control systems.

At each of these levels control is performed through related models which enable the establishment of a programme of control actions through time. Only in simple cases does the concept of direct feedback appear to be applicable, e.g. for stabilizing process control parameters. In most cases feedback principals are used for adapting the model for management, planning and control purposes.

An enterprise, taken as a plant to be controlled, is a subsystem of a larger and more sophisticated system. If an enterprise is linked to customers through a market, the objectives of its operation will be determined by the product demand forecasting. In most socialist countries, the objectives and criteria of the enterprise operation are established by the Ministry which forms the link with the users of the product and its manufacturers. An enterprise belonging to a large company may find itself in a similar situation. In both cases the environment is a source of uncertainty which may result in breaking delivery promises, changing objectives etc. This type of a disturbance can have a great influence on the outcome of the plant as can other disturbances resulting from deterioration of machine performance, break-down etc. arising from within the enterprise itself.

The features mentioned require a probabilisitc approach to the analysis of both the controlled plant (an enterprise) itself and its links with the environment.
These studies should define:

a. objectives of the plant operation;
b. constraints imposed by the environment;
c. environmental criteria for plant operation
d. the plant structure and the characteristic of interstructual relations as well as boundary conditions of the plant.

The objective of an actual enterprise is to manufacture a defined range of products of a given quality and in a given time. The success in meeting this objective depends on the allocation of resources which basically include technological equipment, transport facilities, materials, power sources tooling, personnel etc.
It is presumed that resources are sufficient to attain the objective if properly organized and managed.

If we assume management and control to be a process of problem identification and decision making, followed by control actions, the organization will determine the way in which this process flows. Organization is considered as a one off process of job specification for each production area and of resource allocation, which ensures that the objective is met. Such organization is characterised by a specific production structure which may be shown in graph form and which reflects the manufacturing capabilities of individual production areas.
When studying a manufacturing enterprise its purpose is not only to describe a production structure but also to estimate productivity statistics for different areas as well as manufacturing costs, quality control and other production statistics. These statistics highlight repetitive situations thus enabling management to pre-determine control strategies.

Optimal performances are frequently judged by multiobjective criteria and the optimization problem can be solved by ranking these criteria using for them priorities or weight coefficients. Initially a solution which satisfies the first criterion is found and if this solution is not unique then a solution satisfying the second criteria is needed constrained by the first solution, and so on.

In some cases the priorities can be changed when the objective function reaches a certain value. For example, the productivity maximising criterion may no longer be top priority if productivity reaches a value at which the production volume reaches a given level. The necessity for changing priorities usually occurs when the production situation changes.

Estimating and adjusting the criterion priorities is an ad hoc procedure and can be carried out by decision making methods simultaneously with the definition of production situations. The scenario written for different situations becomes the basis for their modelling and thus is helpful in selecting priorities. The problem of defining the ranges of weight coefficient can be also solved in a like manner.
By using a production structure for each situation there is a

possibility of breaking down the overall objective identified by the environment into a set of sub-objectives--each for a particular production area--forming an objectives tree. When defining an objectives tree, it is necessary to consider manufacturing capabilities of a production area and the constraints to these areas imposed by the environment (time and resource margins).

For example, in case of a steel plant, an objectives tree based on the plant production structure, identifies the objectives as targets of pig iron production in a blast furnace, production of different grades of steel in open-hearth-furnaces or oxygen convertors, the targets of rolled metal production by rolling mill, etc.

On the basis of the objectives tree analysis performed for different production areas, related objectives trees can be composed for all auxiliary departments, which make up the production areas by corresponding resources. The objectives tree based on the plant production structure may be presented as a graph in a multi-dimensional space. This graph reflects links and sub-ordination of objectives, and functional areas of these objectives.

Some outline of functional areas can be:

- production management and control
- inventory control
- products distribution, etc.

On the basis of the graph under consideration a decomposition of the general criteria of production performance estimate can be achieved. This procedure allows us to correspond to each sub-objective a criterion to be satisfied by a chosen control in order to reach a given sub-objective. The existence of sub-objective and a criterion both assigned to every element of production structure and to the capabilities of each production area, creates a possibility to identify the control function and thus to achieve a functional structure of the management-control system identical to that of graph of objectives.

The solution of the control problems corresponding to the objectives and criteria is determined by means of corresponding areas and auxiliary departments models. These models therefore reflect process dynamics and control as a time-related function having the form of control and decision making actions programme. Since processes in different production areas have a broad dynamic range, the control of these areas is characterized by a broad range of time periods. In order to match the controls of individual production areas over time, the functional structure graph of the system must have a time cordinate and each management and control action must have an execution time. The multidimensional graph so obtained shows not only the links and subordination of controls and functional areas, but also time hierarchy of the control.

The whole complex of local criteria should correspond to general criteria but priorities and/or weight coefficients may vary with the change of a production situation. For example, a production area of two units operating in series given the criteria of maximising productivity and minimising power consumed as the first and the second priorities correspondingly. If attempts to satisfy the first criterion result in the highest available production from one unit, it then becomes a bottleneck. In this case the productivity maximization criterion does not apply to the second unit and the achieved maximum of the first objective function becomes a restriction; the only requirement to be met is to satisfy the second priority criterion. Formulating control problems and developing algorithms for their solution are also ad hoc procedures, very similar to the procedures for decision making. The development of techniques for solving the problems mentioned requires efforts to be made in the following areas:

a) decomposition of the corporative objective for a given production situation and creation of an objectives tree for the production structure of the enterprise;

b) Decomposition of general criteria to the set of local criteria corresponding to the objectives tree;

c) Definition of control problems for each element of the production structure according to the objectives and criteria defined for these elements;

d) Development of algorithms for solving control problems and estimation of the control dynamics for each element considering the probabilistic characteristics of the element's models;

e) Creation of the graph which describes the functional structure of the control system.

It is obvious that the more detailed the graph, the more precise the programme of control actions will be and consequently the better plant performance will be. However, in case of complex plant the definition of the total programme of control actions for a long period is an enormous problem and in most cases a solution is practically impossible. Besides, due to the presence of unpredicted disturbances during implementation there will always be a divergence between the reality and the plan, which usually increases with time. Thus detailed production planning over a long period is quite pointless. One of the possible ways to overcome these obstacles is to subdivide the problem into several smaller problems with different degrees of detail and different time scales.

Thus, the first step in planning the production of an enterprise could be to take into consideration average productivity figures of shops and larger production areas without much detail of the equipment or of productivity variations due to technological variations, etc. Such planning is for a given time duration and the result constitutes the guidelines for the second step - i.e. creation of a plan for each shop. The models used for the second planning step consist of simplified technological models of the equipment reflecting averaged productivity and energy consumption etc. without considering production situations which may occur due to variations in the equipment performance.

The next step is to consider parts of the shop modelled in more detail and the planning problem may then have the form of a job-shop problem over the shorter time scales than previously.

The models for a higher level structure are created by aggregation of the lower level models. The number of modelled levels that can be aggregated depends on the available computer capacity, the complexity of the problems and the probabilistic characteristics of disturbances affecting the production process and resulting its divergency from the planned. The larger the model which is used to solve the planning problem, the more the model parameters will vary and the higher the risk that plant operation will deviate from the optimal. A decrease in risk can be achieved if a more detailed modelling with probabilistic characteristics is considered. These characteristics should include some complex indices defined for a given production situation and "organizational and technological difficulties" in fulfillment of a plan due to plant performance. For example we may consider a shop which should manufacture only one product, and the other shop with many different product items. If both shops are identical, we may find that the probability of divergence will be higher for the second case than for the first one.

Thus, the topics requiring investigation when selecting the number of levels of model detail are:

a) statistical analysis of the divergency between planned and actual production process courses and estimating complex indexes as a function of the "organizational and technological difficulties";

b) construction of a probabilistic model of production process as a function of "organizational and technological difficulties" for different productions situations.

c) definition of a planning period for a given degree of aggregation providing a given probability of divergency between planned and actual plant operation.

Since planning problems are normally connected with the allocation of limited resources, the "optimization rate" of a plan depends on the time period used. For example, in trying to achieve the best performance over just one shift, it may be that the increase in the resources consumed do achieve the highest performance during that shift but lead to a shortage of resources for the following shifts with a consequent reduction in the overall performance. Thus, the longer the period chosen for planning, the higher the rate of "optimization" may be achieved. But, as it has been shown above, the length of the time period is limited by the probability of divergency between planned and actual. To increase the range of planning with respect to imposed limits it is considered quite reasonable to introduce a "sliding horizon planning". A plan is prepared for a time interval which is longer than was selected after consideration of the tolerated divergency probability. When the chosen interval is over, a procedure of choosing a new interval is prepared for which a new horizon of planning is defined, etc.

As it follows from the above, dividing the problem of planning according to the level of detail leads to a set of models with different time-scales corresponding to each stage of the resultant structure. The difference in time-scales of models involved in different planning stages but representing the same plant necessitates "dual modelling" in which a detailed model is used in solving problems at its own level and also of higher levels when aggregated. Aggregation intended to decrease the dimension of higher stages models should also take into account the difference in time-scales i.e. a higher level model should characterize the behaviour of an area during the whole time interval of a lower stage.

Differing time-scales of models may increase the crudeness of planning problem solutions if the nature of disturbances and the dynamics of those plant areas, have not been considered in these models.

The multilevel character of model aggregation requires a corresponding data base. This data base must contain information varying with the degree of aggregation and structures of models for different production situations. Thus, information belonging to the stage of technological processing must display completely the characteristics of the technological units enabling it to predict their performance during every production cycle. The production area model requires information on average productivity of every technological unit not only the technological process itself. It also requires information about operations and resource allocation in this area. The model of a group of areas, for example a shop, requires more aggregated information in a standard form.

The above mentioned problems are examples of feed forward control used to predict the control action in advance and without considering production errors etc. When the planned performance of the plant is implemented there are always divergencies that arise due to the presence of un-predicted disturbances and the crudeness of the models. Both causes are considered as disturbances and when they occur compensation must be made which can be effected by some extra control actions, not specified by the plan.

All disturbances may be divided into directly or indirectly obvious. For example, the disturbances of a breakdown type are noticed immediately the equipment has stopped, but those of performance changes due to its slow detrioration may usually be revealed in an indirect way by comparing the current production performance with the previously acquired data. Such comparisons of current performance of a technological unit or a production area can be performed by adaptation of corresponding models. Adaptation is a time-consuming process and the time required depends on the dynamic characteristics of the plant being modelled and on the time characterisitcs of disturbances affecting that plant.

Depending on the nature of disturbances being revealed, the compensation for their impact may be achieved by generating extra control-actions without changes in the corporate programme by altering selected controls or by calculating a new programme for the rest of the process. For example, in case of a breakdown of some equipment, the total programme of control actions may have to be revised. If the disturbance may be compensated by extra control actions (i.e. the planned objective can still be met) and the cost of these actions does not change much of the performance plant indices, the programme of actions may need no changes. Only if the "cost" of extra actions is considerable should the programme be revised.

A very complicated problem needing a solution occurs in a multi-level model simulation in which models of a higher level comprise aggregated lower level models operating with different time scales. Since models are created using data stored in the data bank, higher level models require continuous updating of data stored in the bank. Since models of higher level operate on larger time-scales the updating of data for that level is much slower than for lower levels. A corresponding investigation is necessary to define the conditions for data updating used for models of different levels.

As it has been mentioned above, disturbances can be compensated for by revised plans or by applying an extra control actions. In both cases, to make a decision of which action to take the corresponding model should be adapted and due to the different models time scales, adaptation to this type of control is a hierarchical in time.

It is obvious that the smaller the gap in time-scales between two models of different levels the less time will be needed for adaptation but the resultant increase in number of levels leads to a significant increase in the problem's dimension. Therefore the number of model levels in the system under design can be defined as a trade-off between probelm dimenstion and

and permissible dispersion of plant performance indices. Thus, problem control solving in an on-line production process requires the following studies:

a) techniques for revealing the disturbance and their time-based characteristics;

b) adaptation of models and their time-based parameters

c) methods of defining the on-line system functional hierarchy;

d) decision making in identifying a form of control to be applied to the plant

e) methods of the number of the system's models levels (i.e. the trade-off between problem dimension and quality of control).

The problem areas discussed above related to feed forward management and control, based on the prediction of plant behaviour. But on-line management and control system's functions contain also problems of production process organization to implement a chosen production plan or schedule. This problem area for a manufacturing plant includes the organization of materials flow between production areas by issuing commands to transport facilities and adjustment of the technological equipment by setting of required technological goals (by setting regulators and programmable controllers). To solve the problems related to the organization of production, models are used which reflect a chosen technological route and which define the relation of quantitative-qualitative characteristics of individual production areas at implementation (not considering its inherent behaviour). These models are built by aggregating those used in process and materials flow controls. Models of both types are adapted simultaneously thus enabling the decrease of the deviation of production process from optimum.

Control actions identified according to the organization of production are agreed with material movements and this movement is monitored by a separate system on the basis of data received from controllers and operator consoles. The data obtained is used to monitor the production process and to compare it with planned data. Such comparisons (in conjunction with on-line prediction of the production process flow based on modelling) make possible the timely detection of errors and to the identification of remedial control actions.

It may be so that the control actions used to eliminate divergency between planned and actual production process flow are not adequate and this divergency nears the danger value before the end of the planning interval. In this case the programme of control action should be revised by the manager for whom the system prepares a list of alternatives. In some cases these changes may affect the sequence of operations performed without any changes in the remaining part of the control action programme. In a like manner a manager intervenes when a production process becomes bottleneck by the breakdown of some units or the lack of materials in case of supply breakdown. In each case of intervention the decisions made should introduce minimal changes in the remaining part of a previously acheduled production process.

The above mentioned problems of planning and management have been considered separately from their implementation. This problem of implementation includes the choice of a proper selection of hardware, (computers, communication channels and peripherals, etc.) and of their interrelation structure. The solution of this problem defines the functional reliability of a system. By the functional reliability we assume the reliability with which the plant performs under control of a given system. An estimate of functional reliability can be made as a reduction of the plant's performance effectiveness caused by errors and failure of the system's operation.

Since functional reliability depends on algorithmical and data redundancy, general methods have to be developed to define the required redundancy on the basis of given hardware and functional reliability values, or to define the required hardware reliability on the basis of given redundancy and functional reliability values.

The choice of systems hardware configuration and structure, should be based on a cost/performance analysis. It relates to the alternatives and decision making review based on the satisfaction of the following requirements:

- minimum capital expenditures on the acquision of the total complex of hardware (including computer cost);
- minimum loss in overall production performance managed by the system
- minimum cost of maintenance and minimum cost of software development;
- minimum time and cost of implementation

The development of methods for choosing the hardware structure and configuration should be based on decision making theory. Though software aspects have been fairly developed (- COPEX and MANPAC systems, etc.) considerable attention should be paid to the improvement of software, especially external software which are closely connected with the algorithmical problems solution.

A specific feature of this area is the necessity to solve problems with different degrees of aggregation and with different time scales. Tasks belonging to different stages should use special languages capable of level to level translation. Taking into account the hierarchical nature of problems and the necessity of solving them in different time scales emphasis should be given to the development of special supervisory programmes.

The priority should be given to the analysis, classification and improvement of the procedures used in models adaptation and problem solving. As a result of this analysis a creation of a library of algorithms and programmes used in problem solving appears to be possible.