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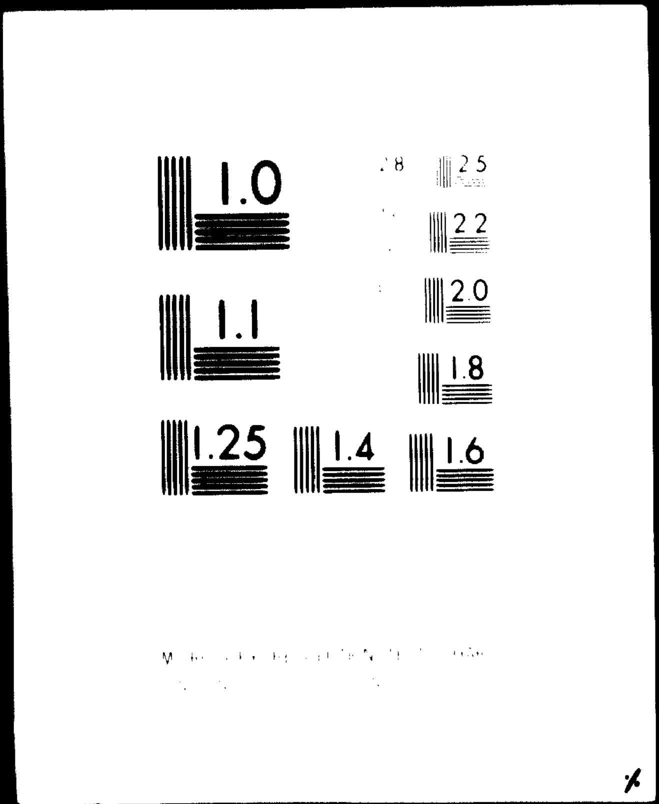
1 OF 1



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D. Zelenović

Yugoslavia.

THE FLEXIBILITY OF PRODUCTION SYSTEMS.

(Examination of Conditions for the Establishment of Flexible Production Systems and Optimization Possibilities)

Project: DP/YUG/73/005/A/01/37

Novi Sad, 1973 – 1978.

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CONTAINS

Abstract,

This paper is concerned with the flexibility of production systems. An examination is made of conditions for the establishment of flexible production systems and of the possibilities for optimisation. The Advantages and Disadvantages of such systems are discussed across the broad spectrum from job to line production. A quantitative model is porposed for the selection of production processes. Consideration is given to the flexibility of material flow with Group Technology. Different aspects of planning, monitoring and control are discussed both at micro and macro levels. Finally, a Methodology id presented for investigating such complex dynamic systems.

Izvod,

Ovo je radni materijal na temu fleksibilnosti proizvodnih sistema. Izvršeno je ispitivanje uslova za postavljanje fleksibilnih proizvodnih sistema i mogućnosti optimiranja. Razmatrane su prednosti i nedostaci različitih tipova proizvodnje u širem spektru od osnovnog radioničkog do maksimalno sinhronizovanog linijskog tipa i razradjeni kvantitativni kriterijumi za izbor tipa toka. Razmatranja su vezana za fleksibilnost tokova materijala i zasnovana na principima grupisanja. Različiti aspekti planiranja, vodjenja i upravljanja proizvodnjom su diskutovani kako sa mikro, tako i sa makro stanovišta. Posebno je razradjena metodologija za ispitivanje složenih i dinamičnim sistema.

1. INTRODUCTION

Production is a basic field of human activity which is necessary to meet the needs of individuals and for the development of society. Without production human society could not exist even for a short period of time, whatever the natural resources of a country. To meet these needs the natural resources have to be transformed by production processes, into useful products. The transformation of resources into products is performed by production plant using developed production methods. Production is therefore a purpose oriented activity designed to obtain useful output values.

Production is limited by a set of elements (input values, production plant and people). They are interrelated in ways determined by the choice of production method. The way in which production is limited by PRODUCTION SYSTEM design is shown by a cause and effect diagram, in Fig.1

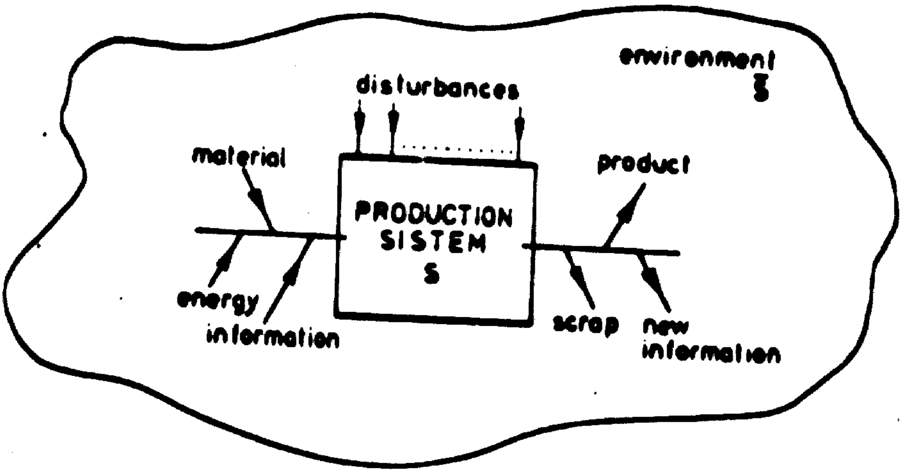


Fig. 1

The Development of Production Systems is limited by:

- The possibility of Forecasting future events
- The Efficiency of production development and of the introduction of new techniques

- The Design of the System elements and by the degree of optimisation of the Relationships between them
- The Quality of decision-making, of organisation and of the control of production flow in relation to time
- Process and Environmental disturbances.

The value of the output is conditioned by the working characteristics of the System and by the Input values. Working characteristics are dependent on the quality of product design, the choice of method, plant layout, organisation of the System and it's Input Values. The output value is limited by Environmental Conditions. The Working Characteristics of a System are the expression of it's Capability to perform work in a given time under given environmental Conditions. At this point we come to the idea of the EFFECTIVENESS of PRODUCTION SYSTEMS, which can be expressed as a probability that the system will start, perform the objective function and adapt itself within the tolerance limits, in a given time and given environmental Conditions. The Effectiveness of the Production System, in that sense, can be expressed as:

$$E_s(t) = A(t) \cdot R(t) \cdot DA$$

where:

A(t) - is the operational readyness of a production system, in terms of the probability that under given environmental conditions, the system will start and move into the field of the tolerated limits of the objective function, in a given time.

R(t) - is the reliability of the system in terms of the probability that under given environmental conditions the system will perform given tasks, within the tolerated limits of the objective function, in a given time.

DA - is the design adequacy of a Production System. It is the capability of the system to adapt itself to the environmental conditions and to the process requirements in a given time.

As a result of the Needs of People and Society and of changes in Environmental Conditions, there are growing requirements for Production Systems to achieve higher Productivity, improved Quality and lower costs. This leads to an increase in the values of the working parameters and to an increase in the Complexity of the Structure of the Production Systems.

Production Systems have typical series related structures. As Complexity increases this leads to a reduction in the Effectiveness of the System.

Changes in the Environmental Conditions require a steady adaptation of the systems which in turn requires a high degree of flexibility in the Systems.

2. FLEXIBILITY OF PRODUCTION SYSTEMS

The pressure on Production Systems to produce more and more output at less expense, leads to a high degree of structural complexity in these Systems. Once designed, the System Structure is constant for a defined time. In practice this means that there are dinamic environmental changes and at the same time there is a very static Structure of the Production System. The level and the Quality of the Output values depend to a great extent, on the quality of the Solution found for this conflicting situation. Bearing this in mind one can postulate the following:

2.1 The Structure of Production Systems

The Structure of a Production System can be presented as a fixed set of technological and plant layout elements, as follows:

$$S = TS, SS \qquad (1)$$

where:

S - is the Structure of the System

TS - is the quantity (number) of Technological elements (machines, handling equipment, measuring equipment, stores equipment and control devices)

SS - is the space structure; or plant layout of the technological elements.

The Structure of a Production System is conditioned by the degree of complexity of the job to be done, by the level of the objective function, by the capacity of the elements of the system and by the type of plant layout used.

2.2 Definition of Flexibility

The Flexibility of a Production System is a measure of it's capability to adapt to changing environmental conditions and process requirements.

A quantitative measure of the flexibility of a production system is given as the value of DESIGN ADEQUACY, which is a probability that the given structure of a production system will adapt itself to the environmental conditions and to the process requirements within the limits of the given design parameters. If the environmental and process requirements exceed the determined limits of the system, the flexibility of the system is not sufficient and the plant and layout will have to be changed to suit new conditions. The degree of utilisation of the system parameters bears a very close relationship to the degree of Design Adequacy. In other works one can design and produce a highly flexible system which can carry out very different tasks but the degree of parameter utilization and the effectiveness of such a system will be very low.

Investigations into the design of flexible production systems therefore, lead to a search for the appropriate ratio between capacity and utilization of the parameters of the production systems.

2.3 Basic Parameters of Production Systems

The Flows of Production Systems (Material Flow, Information Flow and Energy Flow) are the basis for the design and layout of the System. The basic parameters of Production Systems are related to the Flows of material, energy and information and are dependent on:

- The Technological Complexity of the job to be done, where Technological Complexity is given as the sum of the operation times from the first to the last operation, in the form of:

$$\sum_{i=1}^{i=m} t_{ii} \left[\text{time units}\right] \qquad (2)$$

where:

$i = 1,2,3,\ldots,m$ - is the number of operations

- Quantity - The number of product units to be produced in a given period of time (q_j[product units/time period]).
- The Capacity of the system elements which is limited by the selected man-machine data (K_k[time units/time period], or Load/Capacity).

There are two basic Parameters of Production Systems in respect to the Choice of Production Processes, layout planning, flexibility and Effectiveness as follows:

2.3.1 Load-capacity balance

On the basis of inequality in the form of:

$$T_i \gtrless K_{ki} \qquad (3)$$

where:

*T_i time units/time period - is the total production time required for the i-th operation over a determined period of time (usually one year). The value T is obtained from:

$$T_i = Q_{ti} \cdot t_{ii} \qquad (4),$$

where

Q_{ti} [prod.units/time period]

t_i [time units/prod.unit]

$^{*}K_{ki}$ [time units/time per mech.unit] - is the capacity of technological systems in production,

it is possible to create a criterion for the Choice of the Type of Production Processes which is, in this paper, called the DEGREE OF CONTINUITY and is given as the ratio:

$$k_{ser} = \frac{\sum\limits_{i=1}^{i=m} T_i}{K_k} = \frac{\sum\limits_{i=1}^{i=m} (Q_{ti} \cdot t_{ii})_i}{K_k} \gtrless 1 \qquad (5)$$

An increase in the Degree of Continuity leads, as it is shown later, to the choice of more homogeneus processes in the form of Flow production lines and Product layout and on the other hand a decrease of that ratio leads to Job produçtion, and to Fixed and Process layout.

2.3.2 Degree of Universality

The Degree of Universality is the reciprocel value of the Degree of Continuity in the form of:

$$U = \frac{1}{k_{ser}} = \frac{K_k}{\sum\limits_{i=1}^{i=m} T_i} \qquad (6)$$

The degree of universality shows the possibilities for production parts flow through the work stetions of a Production System.

2.4 Components of design adequacy

As can be seen from (5) the structure of Production Systems is limited by the technological complexity (Σt_{ij}) of the job to be done, the quantity (q), the capacity (K_k) and the space/layout parameters of the system flows. This means that Design Adequacy is the result of the technological, capacity and space components described below:

2.4.1 Design adequacy-technological component

This is determined by the possibilities of a given technological system to accept parts from the production programme within the limits of its design parameters.

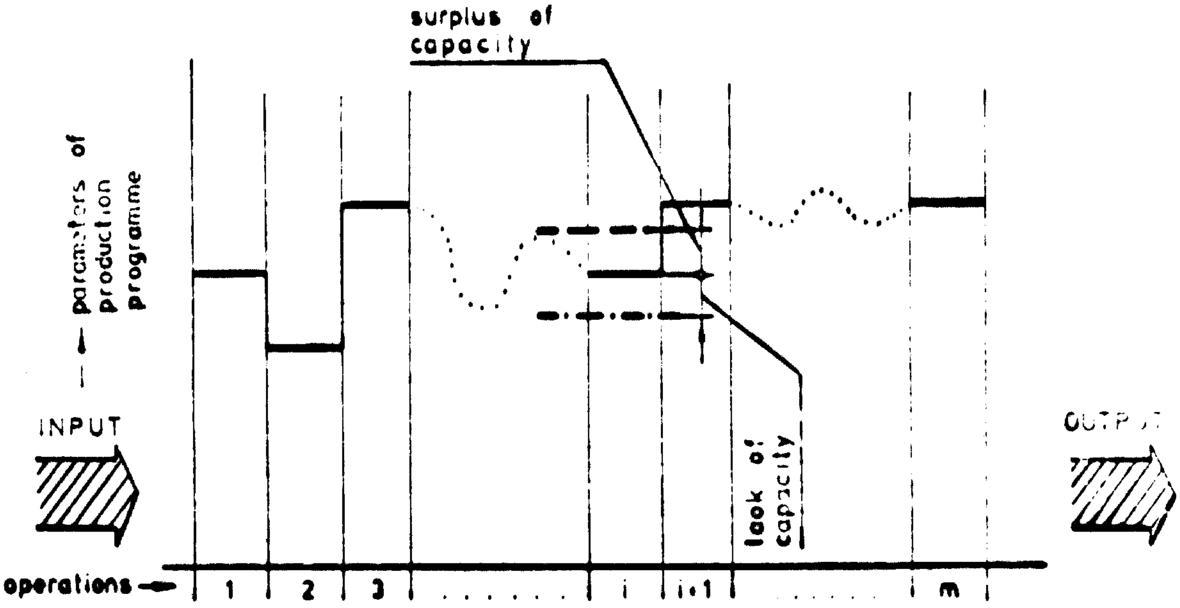
The Technological system, as an element of the Production System, will successfully adapt itself to the environmental conditions and process requirements within the limits of its design parameters, as shown in Fig.2.

On the basis of Fig.2 no conclusions should be drawn on how to get a higher degree of the technological component of design adequacy. Technological systems should not be selected with larger possibilities in terms of the basic parameters because it would lead to lower degree of utilization of such parameters.

In order to explain this we will adopt the following symbols:

p_t - value of a parameter in the technological system, which presents the maximum capability of the system

p_k - the value of the observed parameter which is used. This is limited by the characteristics of the production programme.



—·—·—·—·—·—·—	This selected Technological system for a given operation "i" has not sufficient design adequacy and can not be adopted.
– – – – – – – –	This selected Technological System for a given operation "i" has a surplus of parameter capacity and has a higher degree of flexibility.

Fig. 2

In this case the ratio:

$$\eta_{k,t} = \frac{p_k}{p_t} \qquad (7)$$

presents the degree of utilization of the observed parameter of the technological system for a given set of conditions and the difference:

$$R_p = p_t - p_k \qquad (8)$$

presents the surplus of capability of the observed parameter which allows adaptation to changes in production programme.

On this basis it is possible to conclude that the flexibility of an observed technological system is R_p.

As an example we shall present the results of investigations of a few production programmes and technological system parameters as follows:

.1 The parameter p_u - SPINDLE SPEED - CENTRE LATHE

The technological systems - Centre Lathes - in the sample investigated, all have the same number of 24 different spindle speeds (P_{nt}=24 values).

The requirement of parts "p_{nk}" found [illegible] time study for a number of Production Programmes are shown in Fig. 3.

As it is presented in Fig. 3, the difference $R_{np}=p_{nt}-p_{nk}$ is fairly [illegible] nearly all types of centre lathe which [illegible] they hava a high degree of flexibility, but [illegible] degree of utilization of parameters.

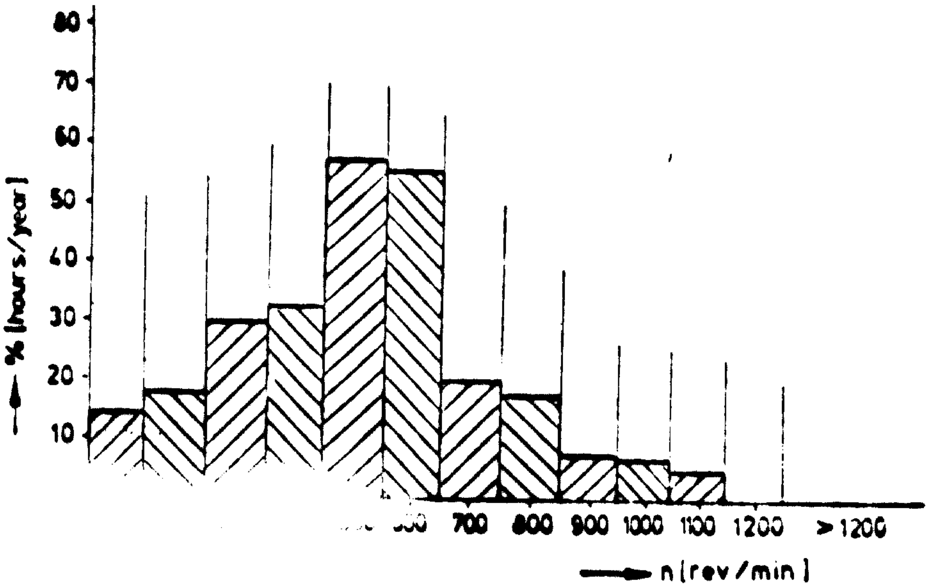


Fig. 3

.2 The parameter p_f - FEED - CENTRE LATHES

In the observed sample of centre lathes there was a total of

$$p_f = 18 \text{ values.} \tag{9}$$

The requirements of the production programme obtained by time study analysis are shown, in Fig.4.

In a given sample of Production Programmes and corresponding sample of centre lathes, the difference:

$$R_{fp} = p_{ft} - p_{fk} \tag{10}$$

was also fairly high which leads to the same conclusions as in the case of the speed.

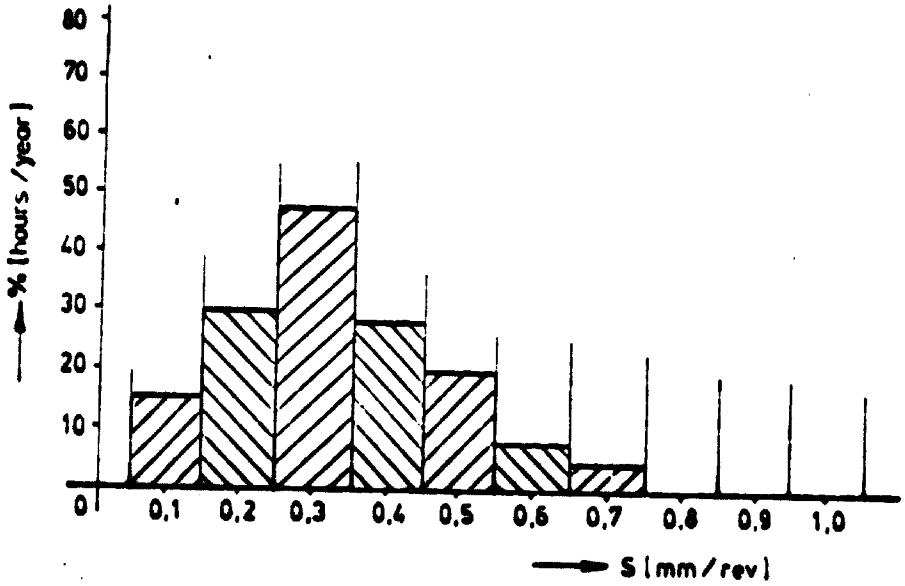


Fig. 4

.3 The Paramtere p_N - POWER - CENTRE LATHES

The Technological System"Centre Lathes" in the observed sample has had two values of power: 10 kw and 15 kw. The Distribution of the Total time needed for the machining of pieces in the Production Programme, on the basis of time study analysis, is shown in Fig. 5. The given Distribution shows the degree of utilization of engine power for a given sample and the possibilities of adoption to the needs of Environmental changes - conditions.

The given Distributions show clearly that R_p difference between available and used parameter values were significant, therefore the technological systems in the given example are flexible enough but with a fairly low degree of utilization of possibilities.

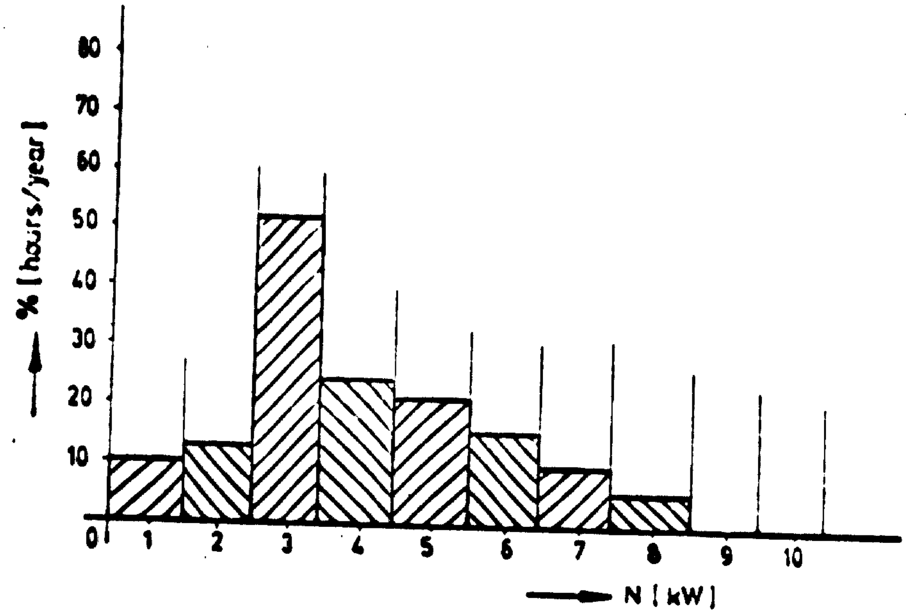


Fig. 5

2.4.2 Design Adequacy - Machine capacity

This is defined by:

.1 The Difference R_c in the form of:

$$R_c = M_{ia} - M_{ic} \qquad (11)$$

where

M_{ia} - is the rounded number of technological Systems (machines) adopted for the given i-th operation

M_{ic} - calculated number of Technological System units needed to perform the i-th operation of work.

The Calculated number of Units is given by

$$M_{ic} = \frac{T_i}{K_k} \text{ [units]} \qquad (12)$$

.2 The Degree of Utilization in the form of:

$$n_i = \frac{M_{ia}}{M_{ic}} \qquad (13)$$

The value of R_c shows that the structure M_i is flexible in proportion to the difference between the adopted and calculated number of units of Technological System needed to perform a determined operation of work to be done.

As the total number of Technological Systems in Production processes is:

$$M = M_1, M_2, M_3, \ldots, M_i, M_n \qquad (14)$$

it is possible to state that the structure M_i is flexible in ration to capacity as much as the difference and degree of utilization of the operation which presents the "bottlenech" of a process. For such operations the difference:

$$R_{ct} = M_{iat} - M_{ict} \qquad (15)$$

and ratio:

$$n_t = \frac{M_{iat}}{M_{ict}} \qquad (16)$$

are as above stated.

The Investigations in the area of capacity have shown that the changes in Production Programmes, in terms of product mix and quantities of parts are not corresponding in most cases, to the changes in total time needed to perform a set of given operations. This means that the flexibility and degree of utilization are changeable in time.

2.4.3 Design adequacy - Plant Layout Component

The space structure of a Production System is defined in terms of the layout of work stations and is probably the greatest problem to the system designer, due to the very high costs of relayout. The Investigations have shown that the degree of effectiveness of plant layout varies in broad limits as shown in Fig.6, due to Changes of product and Production Programme Characteristics.

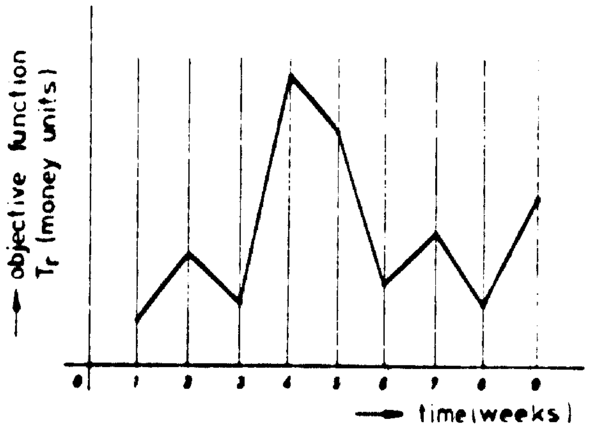


Fig. 6

The space structure can be - according to expressed by the degree of interrelationship between work stations and process characteristics, in the form:

$$\kappa = 2\alpha(\bar{i}-1)\frac{K_{ki}}{\sum\limits_{i=1}^{i=m} T_i} = 2\alpha(\bar{i}-1)\frac{K_{ki}}{\sum\limits_{i=1}^{i=m} Q_{ti}\cdot t_{ii}} \qquad (17)$$

where

$\bar{i}$ - the average number of operations

α - the degree of the similarity of different parts in the Production Programme

Changes of Production Programme are allowable within the limits of reserves of layout capacity space. The reserves of layout capacity are given as a probability that all new requirements, in the sense of work stations and their relationships, conditioned by Environmental Changes, and idle time, will come under one of present - relations.

In the case of functional layout the number of relationships is much larger than with flow line layout, so the reserves in the space structure and the flexibility of such a system are larger and there is, therefore, the possibility for them to adopt to environmental Changes.

2.5 The relationship between Flexibility and the Basic parameters of Production Systems

Consideration of the Components of design adequacy (technological, capacity and plant layout) indicate that the structure of production systems is flexible to the extent of the reserves of the component of design adequacy which allow that the flexibility is conditioned by the type of Production Processes. These are conditioned by the values of basic parameters of Production Systems such as the degree of continuity and the degree of University.

Having that in mind, it is possible to express flexibility as a relationship between the degree of universality, which contains, in a determined way, the components of design adequacy, and the degree of interrelations between work stations and process characteristics in the way of

$$U = \frac{K_{ki}}{\sum_{i=1}^{i=m} T_i} = \frac{K_{ki}}{\sum_{i=1}^{i=m} Q_{ti} \cdot t_{ii}} = \frac{K_{ki}}{2\alpha(\bar{i}-1) \cdot \frac{K_{ki}}{\kappa}} = \frac{\kappa}{2\ (\bar{i}-1)} \quad (13)$$

From this expression it can be concluded that the degree of universality is higher if the value of interrelations is higher and lower if the degree of similarity and number of process stages is higher. The higher degree of universality requires larger flexibility of the systems structure.

As it has become evident that the flexibility of Production Systems is closelx related to the degree of utilisation of the technical capacity and layout parameters, this leads to the need to:

- DESIGN production system flows in order to get a high degree of flexibility and high degree of utilisation of production System parameters.
- SELECTION of technologcial Systems adapted to the needs of designed flows and with a high degree of maintainability.
- DESIGN of space (layout) structure in accordance with a diagram of material flow.
- ORGANIZING of the production elements into a system in accordance with established objectives.

If is possible to meet the given needs by the introduction of:

- Standardization of system elements
- Principles of parts grouping/Group Technology/
- Choice of adaptable technological systems
- Computer aided proccedures in information flows
- Modern methods in the process of decision making.

The Methods of organising Production Flow, based on the principles of parts grouping, will be discussed in more detail later in the paper.

3. THE GENERAL MODEL OF MATERIAL FLOW IN PRODUCTION SYSTEMS

3.1 Basic Approach

Charges in Consumer demand in variety and quantity, environmental Changes and Technological Innovations lead, as mentioned above, to higher pressure on production systems to produce more at less cost.The growth of industrial production systems to meet this demand has gone through evolutionary stages from one-off jobbing, through batch production and further to mass and flow production. The consumer demand in variety of products is still limiting the application of methods of mass and flow line production so that at this stage of industrial evolution, and also in the future, job and batch processing are inherent in most production systems in the metal-manufacturing industry because they are more universal and more flexible. Investigations have shown that in conditions of job and batch processing, the number of parts using each work station is significantly larger that with flow production methods as shown in Fig.7. They have therefore to be more flexible.

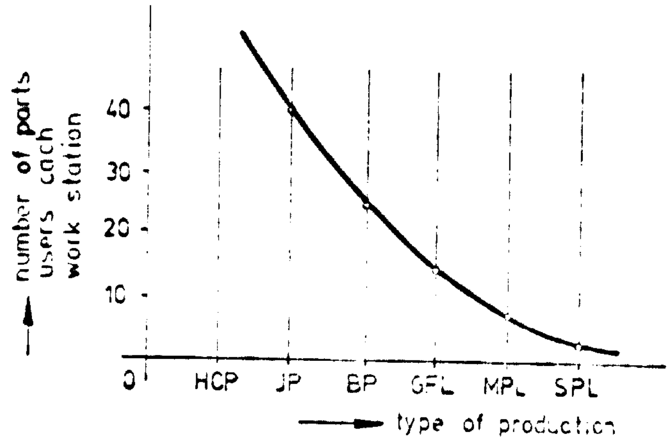


Fig. 7

From another point of view, the degree of utilization and the possibility of application of modern processing methods in conditions of jobbing and batch production, are significantly lower. The profitability of the implementation of modern methods increases with increases in the quantity and similarity of the parts to be made. The QUANTITY - a number of items - - and the SIMILARITY of the parts, become the limiting values in the development of production systems.

Production Programmes in the Engineering industry, and similar industrial branches still generally certain a large variety of products use relatively small batch quantities, even in industrially developed countries. Such a situation limits the application of modern technological, monitoring and control procedures. This points to the next conflict between

- (the need for) SPECIALIZATION in the area of technological methods and systems because of their higher productivity on one side and
- UNPROFITABILITY of implementation of special methods and systems in conditions ehere production programmes call for a large variety of products and small batch quantities on the other.

The Investigations of conditions to solve this conflict, have shown that it is possible by using METHOD OF GROUPING OF similar parts.

The essence of the method of grouping, leads to the selection of the GROUP of similar parts, which are machined by the defined technological systems - (work centre, handling, measuring, stocking or control)-.

Since the given characteristics of the technological system indicates the machine which performs the specific operation the Group of similar parts is called or OPERATIONAL GROUP Q_{op} [pr.units/time period].

Having in mind that each operational group contains parts from the production programme with similar characteristics, then the size of the group is dependent on both the degree of similarity of the parts and on the parameters of the technological systems. In general the total quantity of parts machined in the operational group is:

$$Q_{op} = \sum_{j=1}^{j=k} q_j \ \text{[units/time per.]} \qquad (19)$$

where

q_j units/time per. - quantity of j-th part in production programme

$j = 1,2,3,\ldots,k$ - number of parts in operational group

The size of Operational group is, in general case, changeable along the material flow system and is a function of the technological complexity and the processing parameters.

The set of operational groups in the area of the i-th stage of the production processes is defined as TECHNOLOGICAL GROUP described in the form of:

$$Q_t = \sum_{g=1}^{g=r} Q_{opg} \ \text{[units/time per.]} \qquad (20)$$

where

$g = 1,2,3,\ldots,r$ - the number of operational groups of the same type of processing.

In this way it is possible to design the GENERAL MODEL OF MATERIAL FLOWS of production systems in engineering and similar industries shown in Fig.8.

The general model of material flow in production systems presents the BASIS for research and development of production systems of different types.

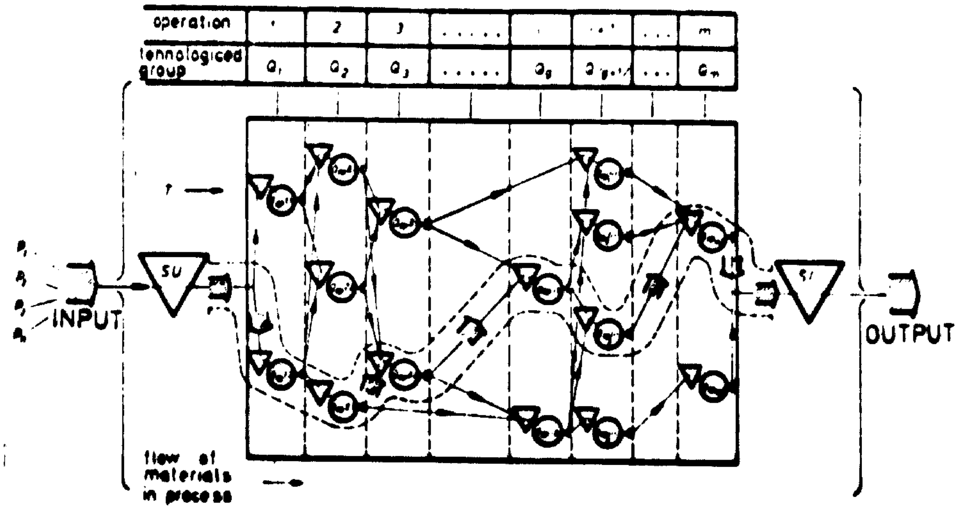


Fig. 8

3.2 Characteristics of general model of material flows in production systems

The total quantity of the parts in a Production Programme for a determined time period is:

$$Q = \sum_{j=1}^{j=u} q_j \ [\text{units/time per.}] \qquad (21)$$

where

$j = 1,2,3,\ldots,n$ - total number of parts in production programme.

Since not all n-parts, in a general case, are passing through all of m-stages in production processes, the number of operational groups is changeable over the stage of production processes depending on the degree of similarity, the parameters of technological systems and the system of calssification.

As each operational group contains similar parts from all the different products in the production programme (Fig.9) it is obvious that

$$Q_{opi} > Q_j \tag{22}$$

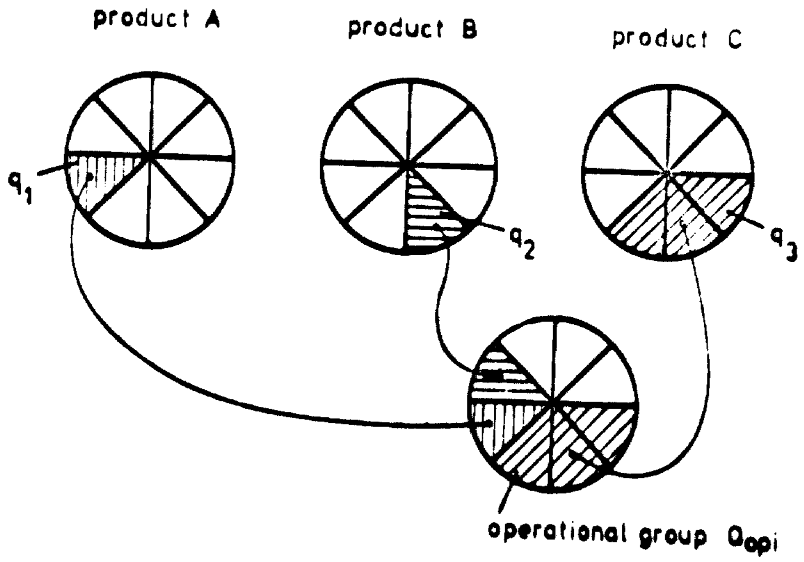


Fig. 9

which means that the quantities of parts are "enlarged" from the point of processing.

In this way a possibility is obtained for use of methods and technological systems of higher class of effectiveness.

Operational group Q_{opi} contains parts of similar parameters (shape, size, material, quality and others) and is shown, on the base of shape parameters in Fig.10.

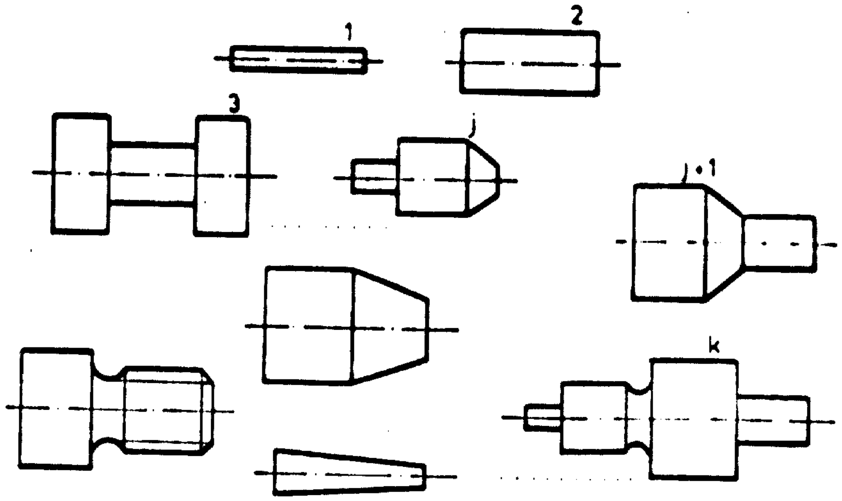


Fig. 10

It is essential to notice two basic characteristics of grouping approach as:

.1 Only components are considered - not assemblies

Since all products, on entering production, are devided into separate groups and are allocated to operational groups on the basis of a classification system, their machining follows throughout the system, disregarding the product to which the parts belong. The parts come together into products when they enter the assembly line as shown in Fig.11.

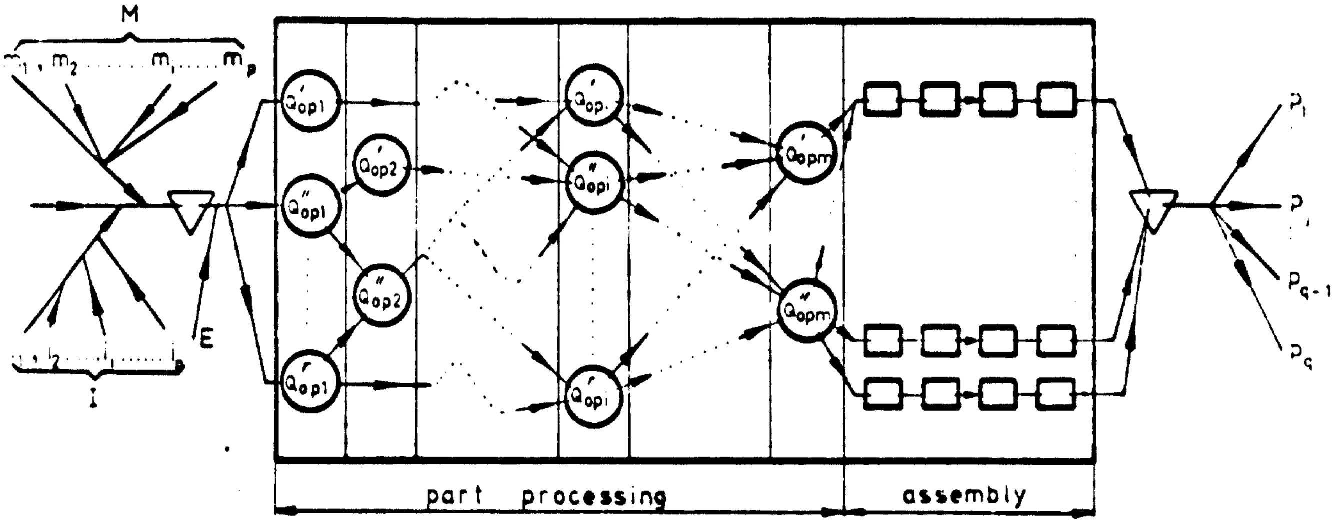


Fig. 11

.2 The effect of the group approach on the designing process and on production planning - coordination of the work of the designer and the production planner on the basis of grouping logic - leads to a further significant increase in the number of parts made in the groups. This is due to the fact that designers and production planners have their own approaches and habits, using different production methods for the same purpose. This happens in spite of attempts at standardization of the design process. It leads to significant differences in geometrical and technological characteristics of the components.

Analysis of the expression:

$$T \gtrless K_k \tag{23}$$

shows that in the development of material flow in production systems, three historical stages can be seen:

-1. Individual approach in production planning and component processing the system.

Individual approach in material flow development can be presented basically by block-diagram according to Fig.12.

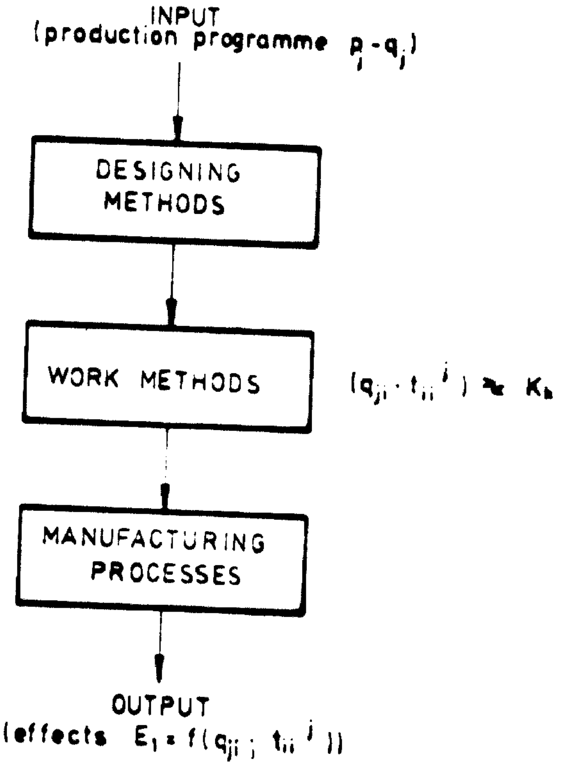


Fig. 12

According to the illustration in Fig. 12 of the individual approach to designing material flow systems, a significant difference in production planning appears in the development of design, solutions and machining of one off jobbing production of q_j quantities and t_{ii}^{j} manufactory complexity on overall operations in the systems of manufacturing processes which gives effects on the E_1 level in dependence on quantity, batch number, discretleness degree and quality degree in the rrganization of production process organization.

-2. Individual approach in design and the grouping approach in production planning and component processing in the system.

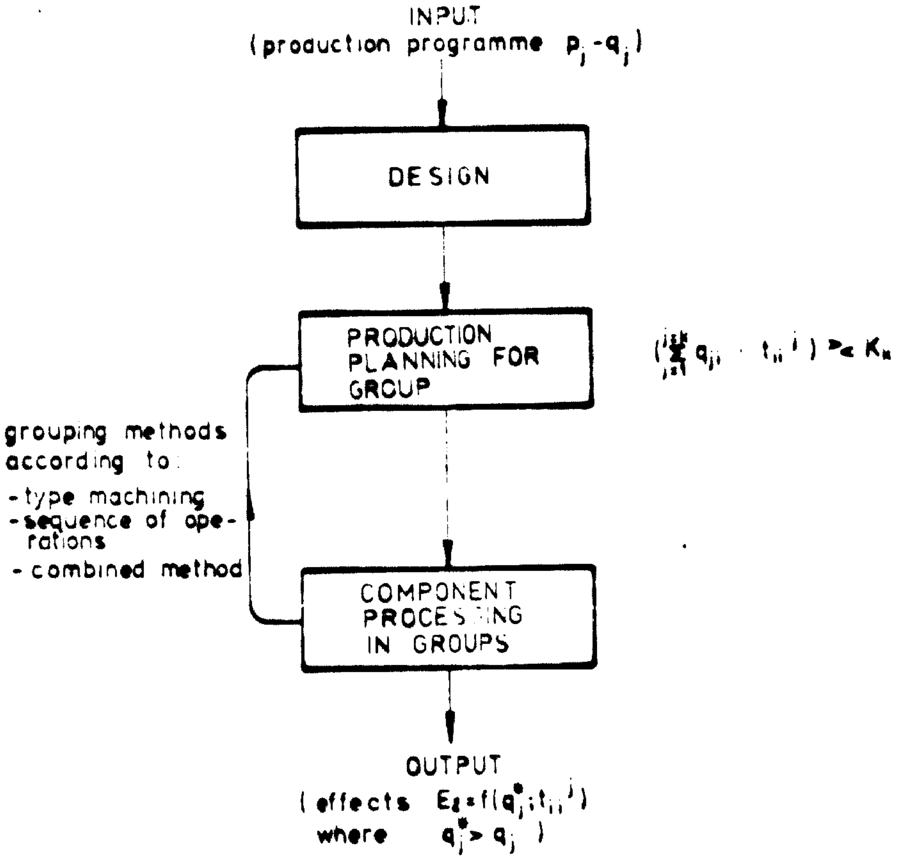


Fig. 13

The group approach to the design of material flow systems can be illustrated by the block diagram in Fig.13. As the result of the group approach there is an increase in the quantity (q_{ji}) with the same component processing complexity t_{ij}

giving the output efeects $E_2>E_1$ for the same other conditions.

-3. The group approcah in design production planning and component processing.

The designs of material flow systems based on grouping methods, aims to increase the quantities for each manjfacturing process making a further development of the idea of grouping in the manner shown in Fig.14.

In the case in Fig.14 the feed back from production planning to design, have the role of directing the designer to reduce the variety of design elements (surface, forms, radii, dimensions etc.) to the necessarc minimum, to realize the conditions for "increasing" the quantities of similar parts in the manufacturing processes and in that way to increase the total output in terms of:

$$E_3 > E_2 > E_1$$

On the basis of a given Act of considerations, it can be concluded that the grouping method provides:

- An increase of the load-capacity index
- An increase in the standardisation of design feature.

For the above reasons, the idea of grouping deserves the greatest attention in the Engineering industry. It presents a way by which the technology of establishing production flow systems can be given a scientific base and a special scientific field.

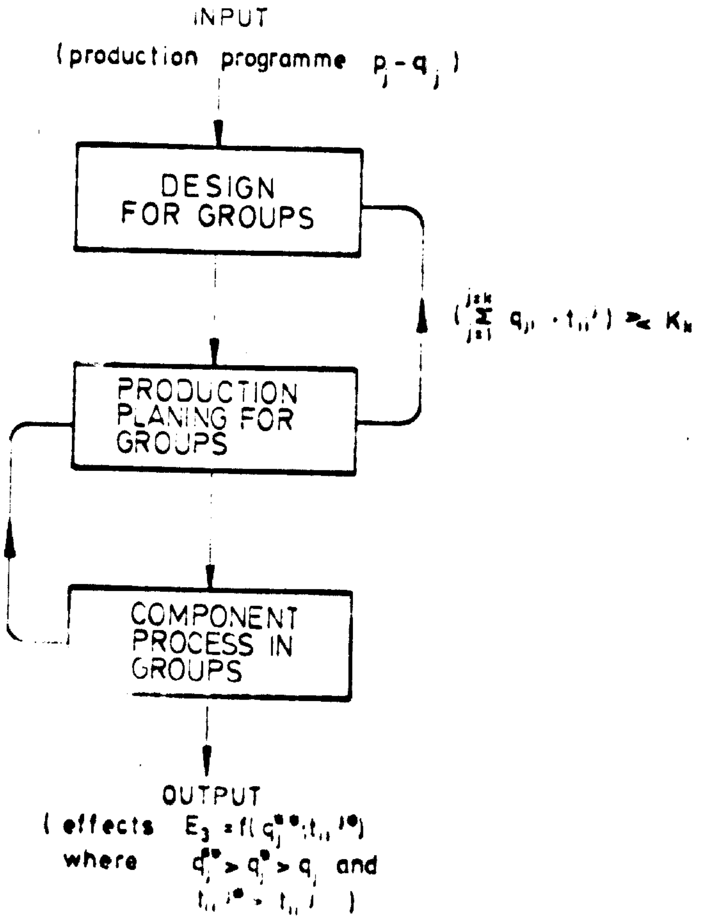


Fig. 14

*** Grouping methods**

Grouping methods have the masic aim of parts classification into OPERATIONAL GROUPS on the basis of similarity of shape, function, materials, setting-up possibilities and similar parameters. In the framework of these objectives there are a number of special aims, including increasing organizational efficiency of the firm, further increase of flexibility, more complete process analyses and similar objectives.

Grouping methods must be based on a TECHNOLOGICAL CLASSIFICATION of the parts produced. On the base of this classification it is possible to establish material flows based on groups in these ways, based on:

- Type of machining process (turning, milling, grinding, drilling, etc.)
- Parts with the same sequence of operations
- Combined methods.

This gives considerable possibilities for the adaptation of material flow system to the production programme requirements. The market makes the production processes more flexible.

GROUPING METHOD BASED ON THE TYPE OF MACHINING PROCESS

Grouping by the Type of machining process, represents the basic development of the grouping idea , which is known in practice as GROUP TECHNOLOGY. This method of classification studies belong to the same TECHNOLOGIC GRUP, which can in other words be machined on the same type of work centre. the technolgic group is broken down into operational groups to which those parts belong which can be machined on a particular work centre with the same set-up, and with the same equipment and tools.

Next comes the regrouping of the parts from groups for one operation, into groups for later operations. This leads to the grouping system scheme, - based on the type of machining process - shown in Fig.15.

It is obvious that the number of parts in each group changes in accordance with the classification conditions. However, in practice the method permits some flow of the steps between groups in order to accumulate economic batches.

It is obvious that parts with technologically similar features fall into the same operational groups. The parts with special features should still be machined in the traditional way.

In the system illustrated in Fig.15 the column headings have the following meanings:

CLASS - group of parts with similar geometrical configuration

SUBCLASS - set of parts inside the class, the dimensions of which are in defined limits, or which are machined from materials with similar characteristics.

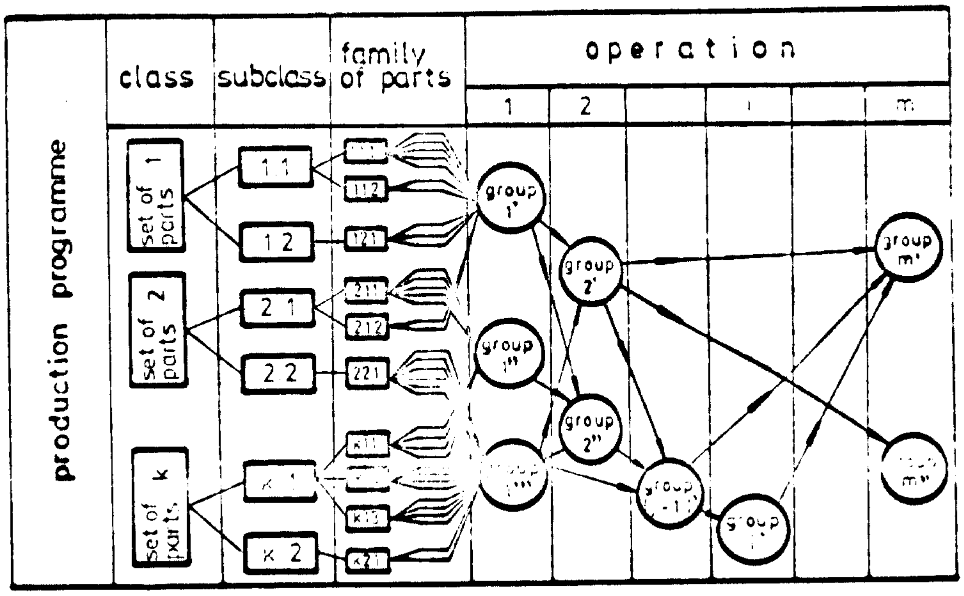


Fig. 15

FAMILY - set of parts inside one subclass, which have similar main functional surfaces or main surfaces for machining

GROUP - set of parts inside one family, which have the same or similar classification numbers and can be machined with the same rolling set-up.

Hence it can be stated that the objective of technologic classification in grouping, is to design part groups, which can be machined on one machine, with one set-up and using the same tools and equipment. The basic characteristics of the grouping system using the methods of type of machining process:

1. Advantages:

The Grouping system based on this principle has the following advantages:

- In Marketing	It is easy to judge if an order is acceptable, based on the previously machining of similar parts.
- Estimating	Estimates can be based on the data for similar parts made previously.
- Design	The Application of the group design system, leads to the adoption of standardized elements and parts.
- Production planning	Operational groups are formed and new processes are designed on the basis of standard methods for composite parts.
- Time study	Time study is simpler and quicker due to the establishment of sanddards and this leads to a significant reduction in setting time.
- Tools design	Design of tools on the basis of group principles.
- Organization	Improvement of work organization on the basis of parts grouping and in Production control.
- Materials handling	Design of handling equipment on the base of group principles.
- Flow analyses	Analysis is simplified as it deals with groups of similar parts.

2. Disadvantages

The basic disadvantages are:

- Need for classification after each operation
- Complexity of classification system

- Organizational difficulties in the case of production programms with high complexity parts.

GROUPING METHOD ACCORDING TO THE SEQUENCE OF OPERATIONS

Grouping of the parts on the principle of operation sequence is sometimes called TYPE TECHNOLOGY. The production planning for groups of parts which have the same operation sequence, is based on the system of classification which is illustrated in the Fig.16.

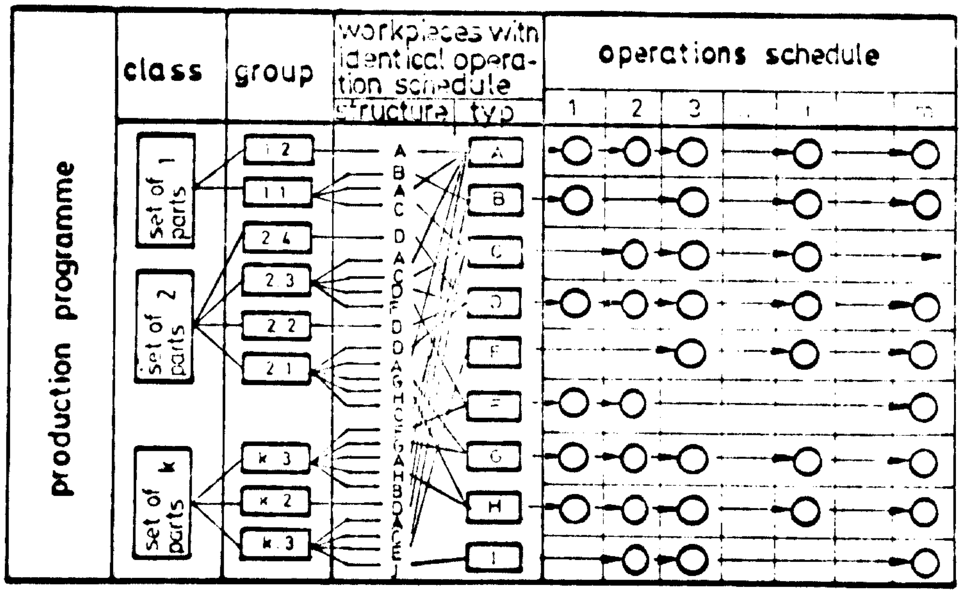


Fig.16

CLASS - is a set of parts requiring the same basic processes

GROUP - is a set of parts inside a class which all have the same characteristics in respect to dimensions, materials, and other parameters.

TYPE - is madeup of parts from different groups which have the same machining plan and the same OPERATIONAL SEQUENCE.

With this grouping system, the objective of system classification is the design of the part TYPE followed by complexity by the production planning job and standardises the machining processes.

The basic principles of the grouping system using the method of sequence of operations,are as follows:

1. Advantages

   - It directs the designer and production planner to more detailed studies of the processing conditions for parts and a greater application of standardised elements in design.
   - The simplified System of classification is carried out only once at the begining of the job.
   - The reduction of a great number of individual procedures to a samll number of standard procedures.
   - Reduction of the number of tools, jigs and fixtures required for operation processing.
   - An increase in the load-capacity ratio which makes it possible to adapt modern machining metnods and to choose machines of more complex type, thus increasing productivity profitability.
   - A saving in the work of production planning.
   - A decrease in manpower skills required.
   - A noticable decrease in set-up time in component processing.

2. Disadvantages

   - Complexity of the system of classification.
   - Insufficient flexibility for changing the production programm.
   - Still requires a large number of different jigs, tools, and fixtures.

GROUPING METHOD ACCORDING TO COMBINED PRINCIPLE

The grouping method according to the combined principle is the result of combining the grouping method according to the machining type and the method of grouping according to the sequence of operations. This eliminates the disadvantages of both the previous methods. The method is presented in Fig.17.

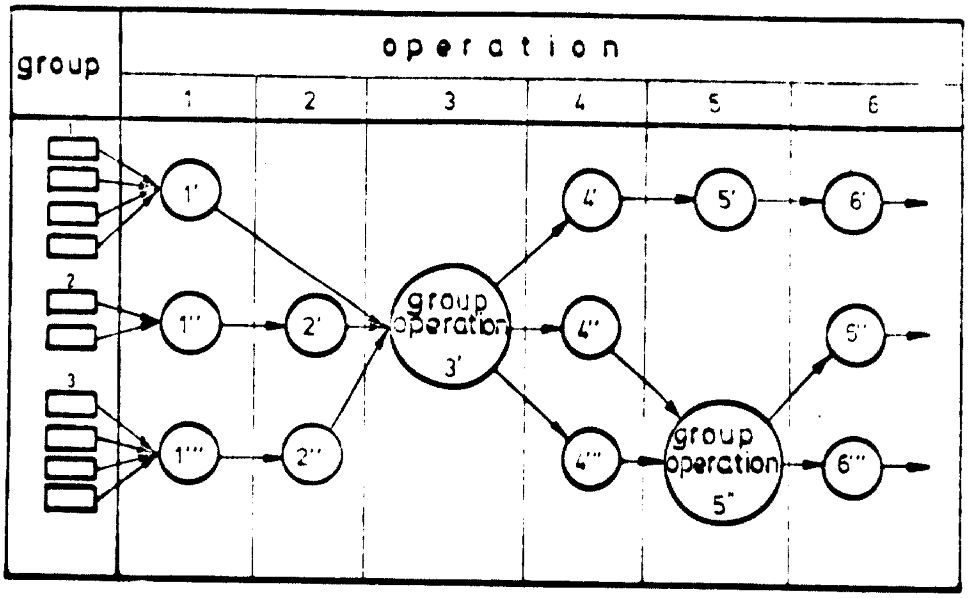


Fig. 17

The grouping methods reduce the time required for Production Planning. It also order and simplifies the material flow and production control, directs product design and makes easier quality control.

Fig.18 ilustrates a part of a certain production programme for which production planning is required.

When production planning is done separately for each part (conventional approach) than as many work method must be designed as there are parts in the programme and special tools and equipment must be designed for each part.

With the traditional approach there is a great expenditure of time on Production Planning. This can be decreased by

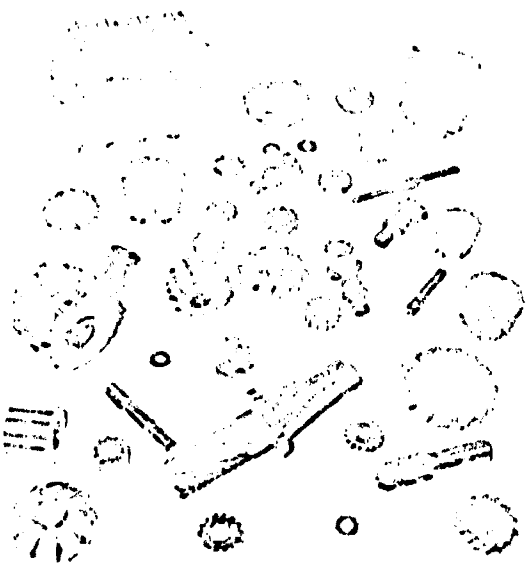


Fig.18

grouping, when each group can be planned as a whole on the basis of COMPOSITE part. It is shown in Fig.19.

As the number of operational groups is very small in the case illustrated in Fig.19 especially for some of operations (i.e. Turning and Grinding ones-two operational groups) the savings in production planning are very significant.

All production programmes normally include components with widely varying to designing of groups there are following cases (Fig.20):

- Simple machined components with only one operation (Fig.20a)
- Components which can be grouped on the basis of the type of machining process (Fig.20b)
- Components which have the same sequence of operations (Fig.20c)
- Components which can be machined according to the combined principle (Fig. 20d).

Fig. 19

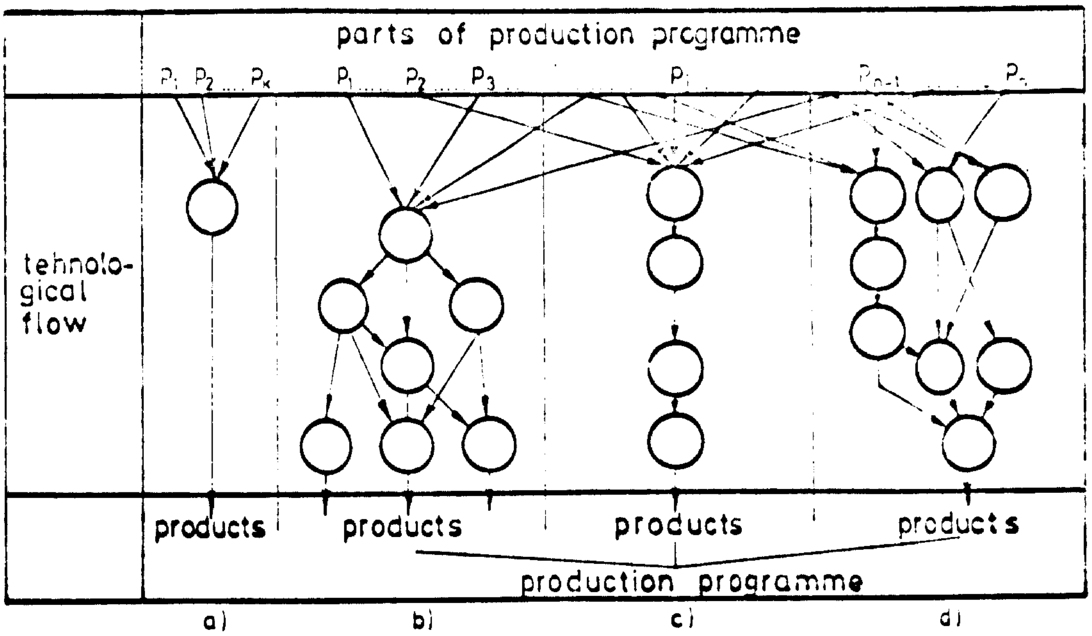


Fig. 20

As it has been shown all the ideas about component grouping according to parametar similarities brought about a new approach in the design of material flow systems and made their further development possible in order to meet needs of output values and changing environmental conditions.

PRODUCTION PLANNING GOR THE COMPONENTS IN THE OPERATIONAL GROUPS

Production Planning for the total of k-components in an operational groups is reduced to planning for one component called COMPOSITE PART. Composite part is chosen so that it contains all the surfaces of all other components in operational group. This can be designed as eather a real or fictive part. Fig.21 illustrates the operational group of k=7 components of which one is of such complexity that it contains all surfaces of the other respectively.

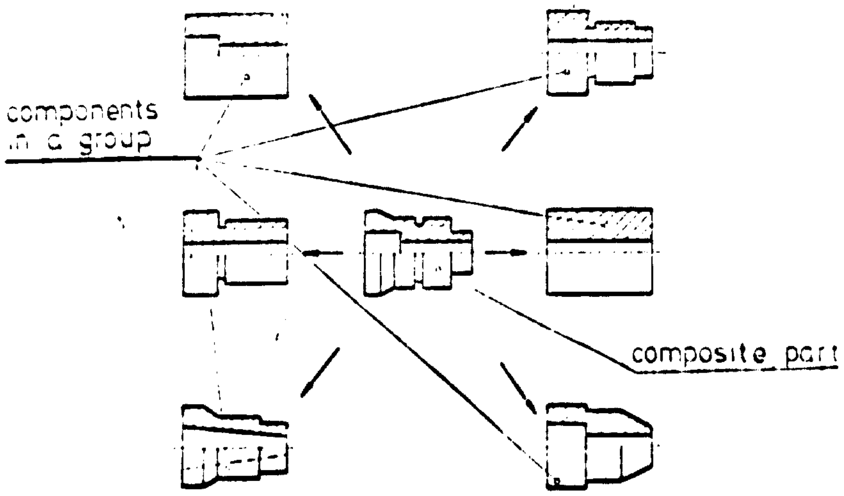


Fig.21

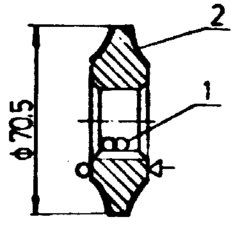
Production Planning of machining operations for the composite part of the operational group is carried out in the nearly same way as for single parts as it is shown in planning chart in Fig.22 in which the elements of machining (speed, feed, depth of cut) and the elements of processing time (setting, operational and idle time) are given in order to obtain objective data about the load/capacity ratio.

3.3 Choice of the Material Flow Type under the conditions of the General Model of Production Systems

The choice of MATERIAL FLOW TYPE for the production systems is the basic problem in the design of production systems. This takes into consideration the fact that the tooling of machines and the total system investments depend on the flow type. The choice is connected with load/capacity ratio given in the form of:

$$\sum_{i=1}^{i=m} T \gtrless k_k \qquad (24)$$

TEHNOLOGICAL SHEET FOR OPERATIONAL GROUP	operational group N°	part sheet		dimension mm	weight N/km	work station	job group	chart of [illegible] for [illegible]		INSTITUTE OF INDUSTRIAL ENGINEERING
		N°	sheet/s	min/max	min/max			N°	sheet/s	

operation			quality	cooling fluid	tool, jigs and fihtures
grasp	sheme	title			
1	2	3	4	5	6
6		1. fixing			
		2. lathing	9✓		18

prepared	date	approved	date

ELEMENTS FOR PARTS GROUP MACHINING	Operational group		Name							INSTITUTE OF INDUSTRIAL ENGINEERING				

part	operation	grasp			tool, jigs and fixtures	cutting conditions				time standard				
		N°	name	dimension		l	v	s	a	t_{pz}		t_i		
						d	n	s_z	i	t_{pzo}	[illegible]	[illegible]	[illegible]	[illegible]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G 500-20	6	1	fixing	ϕ 70,5 x 25								0,10		
G 500-20	6	2	lathing	o 70,5 x 25	18	25 70	150 700	0,4	1			0,082		

where:

T - is the total time needed for machining all the components in operational group

k_k - is the usefull capacity for the observed part of the production system.

The ratio (5) can be, as mentioned before, expressed in the following way:

$$k_{ser} = \frac{\sum_{i=1}^{i=m} T_i}{k_k} \gtrless 1 \qquad (25)$$

In order to determine the total time under the conditions of the GENERAL MODEL OF MATERIAL FLOWS IN PRODUCTION SYSTEMS let us observe a definite operational group composed of a number of different components, in the general case, of different complexity and varying along the material flow.

The operation time for machining each component in an operational group - Q_{opi} is different so it is necessary to introduce an AVERAGE VALUE for operation time for each of the i^{th} operation, where:

$$i = 1,2,3,\ldots,m$$

Thus for operation 1:

$$t_{i1} = \frac{q_{1,1} \cdot t^1_{i1} + q_{2,1} \cdot t^2_{i,1} + \ldots + q_{j1} \cdot t^j_{i,1} + \ldots + q_{h,1} \cdot t^h_{i,1}}{Q_{op,1}} =$$

$$= \frac{\sum_{j=1}^{j=h} q_{j1} \cdot t^j_{i1}}{Q_{op,1}} \quad [\text{time units/comp.units}] \qquad (26)$$

where

$j = 1,2,3,\ldots,h$ - component numbers in the operational group on the first operation

The component complexity changes with the movement along the flow path. This complexity is a function of machining methods and of the number of components in the group. Hence the average operation time value changes too. The following values are obtained in the result for "i" operation:

$$t_{ii} = \frac{q_{1,i}\cdot t_{ii}^{1}+q_{2i}\cdot t_{ii}^{2}+\ldots+q_{ji}\cdot t_{ii}^{j}+\ldots+q_{ki}\cdot t_{ii}^{k}}{Q_{op,i}} =$$

$$= \frac{\sum\limits_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{j}}{Q_{op,i}} \quad [\text{time units/comp.units}] \qquad (27)$$

The average operation time is obtained by the same method for each operation along the flow, thus for the last operation it amounts to:

$$t_{im} = \frac{q_{1,m}\cdot t_{im}^{1}+q_{2m}\cdot t_{im}^{2}+\ldots+q_{jm}\cdot t_{im}^{j}+\ldots+q_{wm}\cdot t_{im}^{w}}{Q_{op,m}} =$$

$$= \frac{\sum\limits_{j=1}^{j=w} q_{jm}\cdot t_{im}^{j}}{Q_{op,m}} \quad [\text{time units/comp.units}] \qquad (28)$$

where, in the general case, is

$$h \gtrless k \gtrless w$$

The total time needed for a certain operation in an operational group with given complexity and given variability of number of components along the flow amounts to:

$$\begin{aligned} T_1 &= Q_{op,1}\cdot\overline{t_{i,1}} \quad [\text{time units/time period}] \\ T_2 &= Q_{op,2}\cdot\overline{t_{i,2}} \quad \text{"} \\ &\vdots \\ T_i &= Q_{op,i}\cdot\overline{t_{i,i}} \quad \text{"} \qquad (29) \\ &\vdots \\ T_m &= Q_{op,m}\cdot\overline{t_{i,m}} \quad \text{"} \end{aligned}$$

By introducing the concept of equivalent quantities Q_{ope} and its corresponding equivalent average operation time t_{ie} in order to eliminate the variability of number of components in the operational group from operation to operation we will get the following:

$$R_e = Q_{ope} \cdot \overline{t_{ie}} \quad [\text{time units/time period}] \qquad (30)$$

where

$$T_e = T_i$$

for each of $i=1,2,3,\dots,m$ operations.
Thus:

$$Q_{ope} \cdot \overline{t_{ie}} = Q_{opi} \cdot \overline{t_{ii}} \qquad (31)$$

from which the following is obtained:

$$\overline{t_{ie}} = \overline{t_{ii}} \, \frac{Q_{opi}}{Q_{ope}} \qquad (32)$$

By substitution the values of t_{ii} from the previous observations the following is obtained:

$$\overline{t_{ie}} = \frac{\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{j}}{Q_{opi}} \cdot \frac{Q_{opi}}{Q_{ope}} = \frac{\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{j}}{Q_{ope}} \quad \left[\frac{\text{time units}}{\text{comp.units}}\right] \qquad (33)$$

By introducting the t_{ie} values in the expression for load/capacity ratio in the condition of equivalent flow the following is obtained

$$k_{ser}^{*} = \frac{\sum_{i=1}^{i=m} T_e}{k_{ke}} = \frac{\sum_{i=1}^{i=m} (Q_{ope} \cdot t_{ie})_i}{k_{ke}} = \frac{\sum_{i=1}^{i=m} \left(Q_{ope} \cdot \frac{\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{j}}{Q_{ope}}\right)_i}{Q_{ope}} =$$

$$= \frac{\sum_{i=1}^{i=m} \left(\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{j} \right)_i}{k_{ke}} = \frac{\sum_{i=1}^{i=m} \left(\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{j} \right)_i}{k_k} \gtrless 1 \qquad (34)$$

as $k_{ke} = k_k$.

The load/capacity ratio given in the form

$$k_{ser}^{*} = \frac{\sum_{i=1}^{i=m} \left(\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{j} \right)}{k_k} \gtrless 1 \qquad (35)$$

contains only values of real flows and thus represents the basis for the choice of material flow type in the conditions of the general model of material flow in production systems in the engineering industry.

By comparing expression (5) with the expression (35) obtained in conditions of single component flow it can be concluded that they are compatible.

The choice of flow type, in agreement with the previous one is made by the following method

Case 1.0:

$$k^{*}_{ser} < 1$$

In the case where the load/capacity ratio is smaller than 1, or more exactly that:

$$\sum_{i=1}^{i=m} \Big(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)} \Big)_i < k_k \qquad (36)$$

the operational group Q_{opi} is not, in a given time period, continuously in work. This indicates the need for the DISCRETE FLOW PROCESS grouping method, based on THE TYPE OF MACHINING PROCESS grouping method, the selection of GENERAL (UNIVERSAL) purpose production equipment and the FIXED LAYOUT of work stations. The case is shown in Fig.1.

Case 2.0:

$$k^{*}_{ser} > 1, \quad (T_i)_{max} \gtrless k_k \qquad (37)$$

For the case where the load/capacity ratio is larger than one, it is necessary to examine the load/capacity ratio on the longest operation:

$$(T_i)_{max} \gtrless k_k \qquad (38)$$

i.e.

$$\Big(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)} \Big)_{max} \gtrless k_k$$

which gives two special cases:

Case 2.1

$$\left(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)}\right)_{max} < k_k \qquad (39)$$

which means that on all operations

$$T_i < k_k \qquad (40)$$

In that case, we have also the DISCRETE FLOW PROCESS. The grouping method based on the TYPE OF MACHINING PROCESS, work stations of UNIVERSAL and SPECIAL (COPYING,NC,CNC) purpose and LAYOUT BY PROCESS. This case is shown in Fig.2.

Case 2.2

In the case where the load/capacity ratio for the longest operation is bigger than one i.e.:

$$\left(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)}\right)_{max} > k_k \qquad (41)$$

it is unknown how many of m-operations have the load/capacity ratio smaller or bigger than one. In such a case the following criteria are recomended:

Case 2.2.1

When the load/capacity ratio at the longest operation is bigger than one i.e.:

$$\left(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)}\right)_{max} > k_k \qquad (42)$$

and the total time T_i, needed for a certain operation, is, on the larger number of m-operations, smaller than capacity k_{ki} of the work station, it is resonable to design the layout of the production processes as a DISCRETE FLOW PROCESS, with the grouping method based on THE SEQUENCE OF OPERATIONS for the family of components, to use work stations of UNIVERSAL AND SPECIAL purpose and to use CELLULAR LAYOUT of work stations. The case is shown in the Fig.3.

Case 2.2.2

In the case where the load/capacity ratio for the longest operation is bigger than one, which means, more exactly, that:

$$\left(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)}\right)_{max} > k_k \qquad (43)$$

and where the total time T_i, needed for a certain operation, on the larger number of m-operations, is bigger than capacity k_{ki} of the work station, it is reasonable to design the layout of the production processes by the CONTINUOUS FLOW PROCESS groupping method, based on THE SEQUENCE OF OPERATIONS, to use work stations of SPECIAL purpose and to use CELLULAR OR LINE LAYOUT for the work stations. This case is shown in Fig.4.

Case 3.0:

In the case where the load/capacity ratio is bigger than one and the total time needed for the shortest operation $(T_i)_{min}$ is equal to the capacity of that station, - which at the same time means that on the other operations the load is equal (t_o) or greater than the capacity of the stations-, or in other words if:

$$\left(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)}\right)_{min} = k_k \qquad (44)$$

the conditions are appropirate for the design of the layout in the form of a CONTINUOUS FLOW PROCESS, based on the grouping method according to THE SEQUENCE OF OPERATIONS, using work stations of SPECIAL purpose and the LINE LAYOUT of these work stations. This case is shown in Fig.5.

Case 4.0:

In the case where the load/capacity ratio is bigger than one and that the total time needed for the shortest operation $(T_i)_{min}$ is greater than the capacity of that operation, which means that:

$$\left(\sum_{j=1}^{j=k} q_{ji}\cdot t_{ii}^{(j)}\right)_{min} >> k_k \qquad (45)$$

the conditions for deviding the material flow into more flows are satisfied. The process is similar to the process for one product line. The case is shown in Fig.6.

The studies described, make it possible to expend the GENERAL MODEL OF MATERIAL FLOW in production systems, in the way shown in Fig.23.

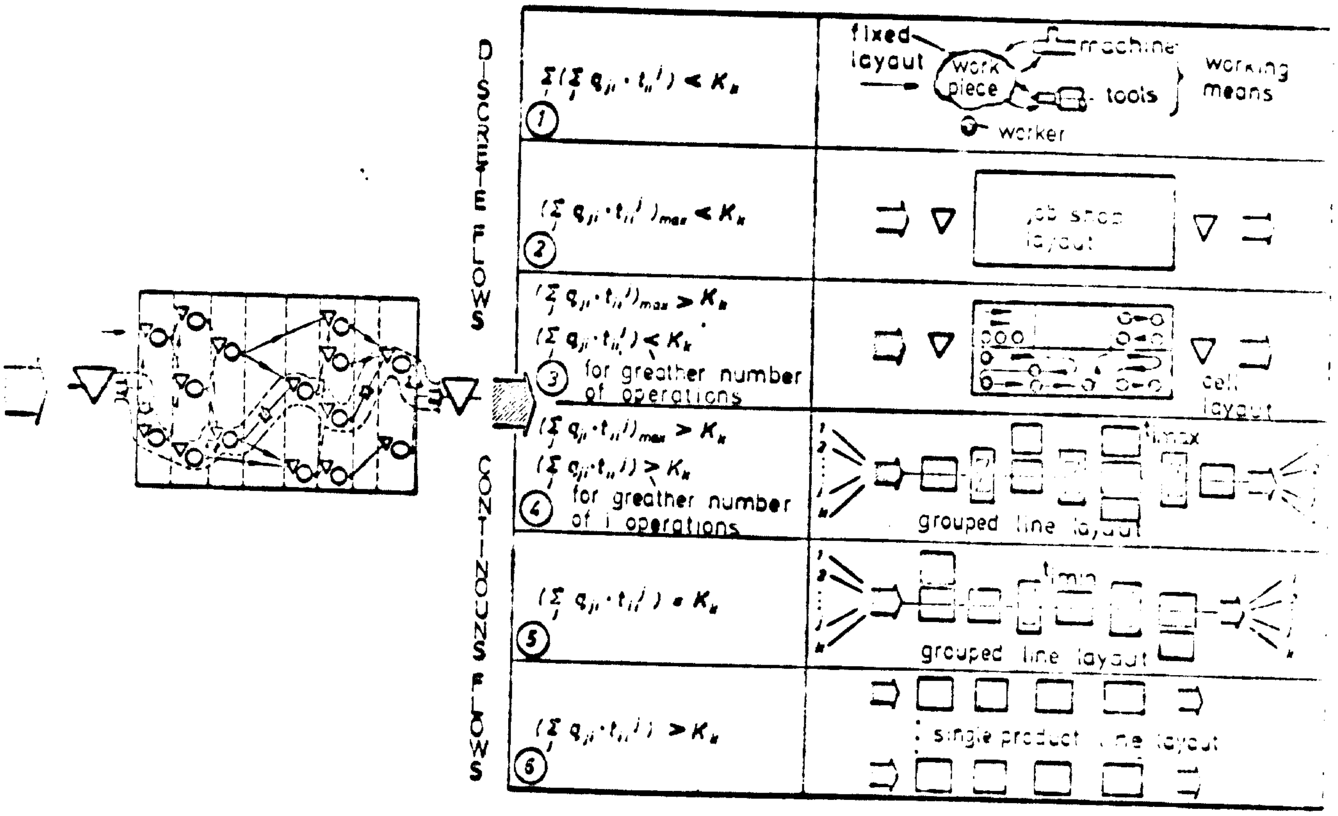


Fig.23

3.4 The basic characteristics of the General Model of Material Flow in Production Systems

Analysis of the developed model shows that the material flows in production systems are basically of two types:

- DISCRETE and
- CONTINUOUS.

The basic qualities of given cases define the conditions governing production system design. Thus there are:

** DISCRETE FLOW PROCESSES

The discrete flows comparise cases 1,2 and sometime 3 as illustrated in Fig. They are characterized by lower load/capacity ratio and by an increased degree of universality - or flexibility of the work system. The basic values of such a system are given as follows:

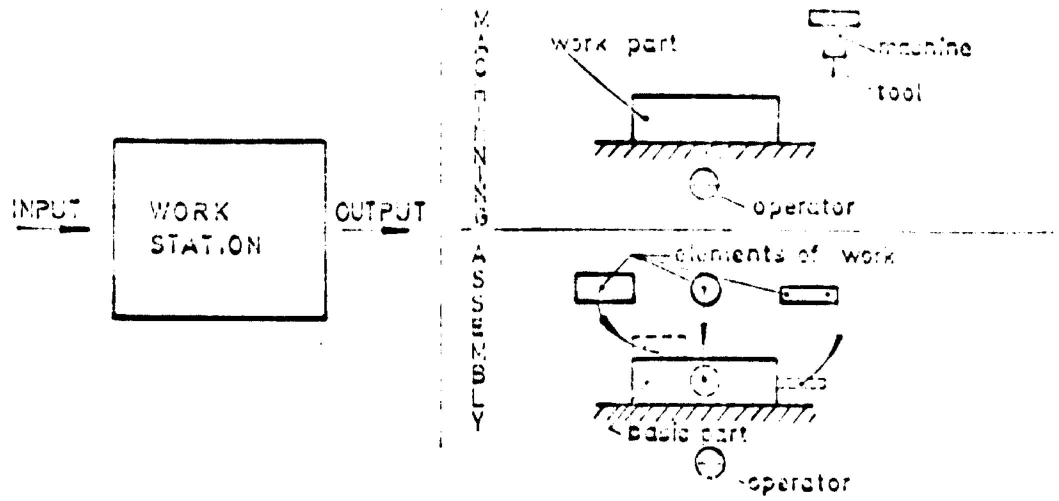
.1 DISCRETE FLOW PROCESSES WITH FIXED LAYOUT OF WORK STATIONS (Case 1 in Fig.23)

The material flow in this case in the general model, is determined by the load/capacity ratio in the form of:

$$k^{*}_{ser} = \frac{\sum_{i=1}^{i=m} \left(\sum_{j=1}^{j=1} q_{ji} \cdot t_{ii}^{(j)} \right)}{k_k} < 1 \qquad (46)$$

and by the work processes which are carried out at one work station, by one or a group of operators whith their equipment. The complexity of such production systems is conditioned by the number of operations "m", work complexity "t_i" and by the capacity and equipment characteristics of the work station (Fig.24).

The work processes of this type are characteristic of the shipbuilding industry, electrical energy generators, large water turbines, special tools, civil engineering industry, handicrafts production and similar production systems.



a) production system b) work processes

Fig. 24

The basic qualities are:

.1.1 Work-in-progress quality

In the flow of this type there is always one work piece which gradually changes in shape, dimensions and quality. To increase output, several flows are used with the same technological and organizational principle.

.1.2 Cycle time (rhythm of the flow)

is determined by the time interval between the output of two concecutive work pieces. It is equal to the throughput time of production T_{cp}. The cycle time will vary from piece to piece according to work complexity shape and different needs for equipment.

.1.3 Universality of system

is the reciprocal value of the load/capacity ratio and should be maximal for this type of production process. The degree of flexibility is related to the degree of universality of such a system. The degree of universality decreases with an increase in the complexity of system structure and is smallest in the case of one product line.

.1.4 The degree of functionality of the process

is given in the form:

$$f = \frac{T_{ct}}{T_{cp}} = \frac{\sum_{i=1}^{i=m} t_{ii}}{T_{ct} + \sum_{i=1}^{i=m} t_{moi}} \qquad (47)$$

where

T_{ct} - technological cycle time

T_{cp} - production cycle time

t_{moi} - time between operations i and i+1

In most cases in this kind of production "f"-values are conditioned by the system of organisation and are generally small.

.1.5 Set-up time

in this type of production has significant value, because it has to be determined for all pieces and all operations. The set-up time in this case causes low effectiveness of such process.

.1.6 Work station equipment

The work stations in production systems of this type, due to wide differences in the work to be done, have to be well equiped with tools, jigs and fietures of high flexibility. The complexity of the work processes requires a skilled labor force.

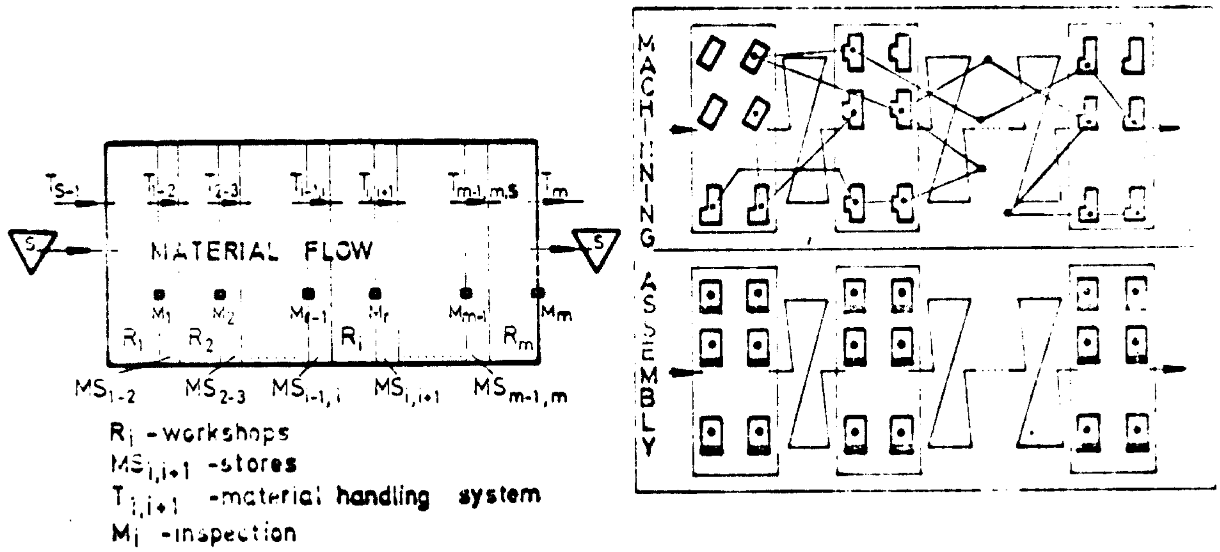
The basic advantages of such types of production system, are low work-in-process, high flexibility and the small amount of production planning needed. The main disadvantages lie in the low degree of equipment utilisation, in difficulties with the organization of materials handling and in the high cost of labour.

.2 Discrete flow processes with process layout of work stations (Case 2 in Fig.23) ("Functional" layout)

The production systems of this type are characterized by a load/capacity ratio in the form of:

$$k^*_{ser} = \frac{\left(\sum\limits_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{(j)}\right)_{max}}{k_k} < 1 \qquad (48)$$

and work processes which take place in workshops specialed according to the type of process (turning, boring, grinding, sharpening, assembly etc.). Such processes are typical to those need for production with many products in small quantities. The basic structure of such systems is given in Fig.25.



a) production system b) work processes

Fig. 25

The basic qualities of this kind of process are:

.2.1 Work-in-progres quantity

The quantity of pieces in a phase "i" of the system is given as:

Q_t [pr.units/time per]

and represents, as has been shown, a technological group which is characterised by the same work method - machining or assembly. The technological group could be divided in the function of work station parameters into more operational groups with quantities

$$Q_{opi} = \sum_{j=1}^{j=k} q_{ji} \quad \text{[pr.units/time per.]} \qquad (49)$$

The material flow system is defined by the routing between operational groups. The sum of the operational groups in the system is the work-in-progress quantity.

The operational groups Q_{opi} have to be divided, on the basis of production plans and production costs, into batches which are characterized by the optimal number of pieces

n_{opt} [pr.units/batch]

The value of "n_{opt}" is conditioned by the quantity of operational group Q_{opi}, by the throughput time and by production costs.

On the basis of "n_{opt}" the number of batches is given as:

$$S = \frac{Q_{opi}}{n_{opt}} \quad \text{[batches/time per.]} \qquad (50)$$

A reduction in the number of batches decreases the set-up costs and increases throughput times and work-in-process costs. And vice versa.

Th work-in-process quantity is in this case equal:

$$Q_n = \sum_{i=1}^{i=m} S = \sum_{i=1}^{i=m} Q_{opi}/n_{opt} \quad \text{[batches]} \qquad (51)$$

.2.2 Cycle time

is in the case of this type of material flow, determined by the time interval between the input or output of two consecutive batches of pieces and is given as:

$$r_p = \frac{k_k}{S} \quad [\text{time units/batch}] \tag{52}$$

.2.3 Universality of system

is determined, as has been shown, by the capacity/load ratio and, with this type of production system, is higher if the value of interrelations between work stations "κ" and similarity coefficeent "α" are higher, and lower if the number of process stages is higher. The higher degree of universality requires larger flexibility of the system structure. The process layout has a high degree of universality.

.2.4 The degree of functionality of the process

depends with this type of process, on the method of Transfer for the parts from operation to operation, which can be in series in parallel or combined. The degree of functionality is given as:

$$f = \frac{T_{ct}}{T_{cp}} = \frac{T_{ct}}{T_{ct} + \sum_{i=1}^{i=m} t} \tag{53}$$

In the given expression the value T_{ct} is, in a great meassure, different for the series, parallel and combined method of transfer of parts through thessystem. For a given layout of work stations the value "f" is rather small because of significant differences between the T_{cp} and T_{ct} values. The maximal value is equal to one, which is, hypothetical and illustrated the case where the system works without losses of time. The level of functionality degree is the indicator of the quality of the process organization.

.2.5 Set-up time

in this type of material flow, represents the time accorded for setting-up each batch of parts, according to their shape, weig technological complexity, number of dimensions, condition of work and similar characteristics. In the case of individual flows the set-up time is determined for the batches of all part for all operations. In conditions of Group flows set-up-time is calculated for the batch of parts in the limits of operational groups, in the given case, for all of operations. For such conditions, the set-up time falls proportionally or it increases in the number of parts in the operational group.

.2.6 Work station equipment

The equipment of work stations, in this case of material flow, has a high degree of universality with speciall units (NC, work centres, coppying, etc.) at same of the work stations. The tools, jigs and fictures are designed in accordance with the requirements of the operational group.

The production systems of discrete flows with process layout, permit the adjustment of the inputs of batches in production which provides shorter throughput times and increases the total level of flexibility of the production system.

.3 Discrete flow processes with cellular layout of work stations (Case 3 in Fig.23)

The production systems with this type of material flow are defined by load/capacity ratios in the form of:

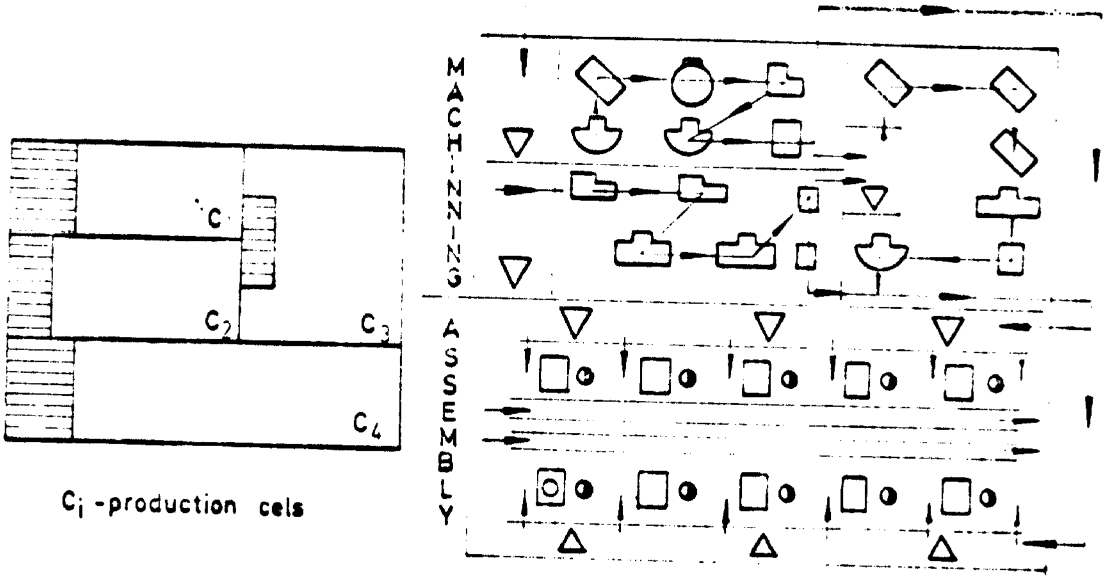
$$k^{*}_{ser} = \frac{\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{(j)})_{max}}{k_k} < 1 \qquad (54)$$

and by the condition that the total time T_i, needed for a certain operation, is on the greater number of m-operations, smaller than capacity k_k of the observed station. In order to get a better degree of utilisation at the work stations where:

$T_i < k_k$ (greater number of m-operations)

The systems of this kind require a layout of work stations known as CELLULAR LAYOUT and is characterized by the performance of all operations on the operational group in the same cell. Layout of this type, based on the principle of minimal distances and minimal backflow routes, allowed an increase in machine capacity, a reduction in the tooling investment, reduction in setting costs and reduction in operation costs.

In contrast to the discrete flow processes with process layout of work stations (Fig.23) in which the components of different operational groups passes through the workshop in discrete flow processes with cellular layout of work stations the component of only one operational group passes through the cell. The basic structure is shown in Fig.26.



C_i -production cels

production system

process of work

Fig. 26

The basic performances of this type of production process are:

.3.1 Work-in-progress quantity

The quantity of peaces in the all of phasses "i" of each cell is given as:

$$Q_j = \sum_{j=1}^{j=p} q_j \ [\text{units}] \qquad (55)$$

where:

p - is a number of position at each work station.

The total work-in-progress quantity in each cell is than:

$$Q_n = \sum_{i=1}^{i=m} Q_j \ [\text{units}] \qquad (56)$$

For the production systems with more than one cells work-in-process quantity is

$$Q_n^N = \sum_{c=1}^{c=N} a_n \ [\text{units}] \qquad (57)$$

.3.2 Cycle time

In the case of this type of material flow cycle time is determined by the time interval between the input or output of two consecutive components as follows:

$$r_c = \frac{k_k \left(\sum_{i=1}^{i=m} t_{ii} \right)_j}{\sum_{j=1}^{j=k} q_j \left(\sum_{i=1}^{i=m} t_{ii} \right)_j} \left[\frac{\text{time units}}{\text{pr. units}} \right] \qquad (58)$$

where

k_k - is the capacity of observed system part

t_{ii} - operation time on the given work station

q_j - quantity of the component "j" in operational group.

Cycle time is changeable with component complexity in operational group.

.3.3 Universality of system

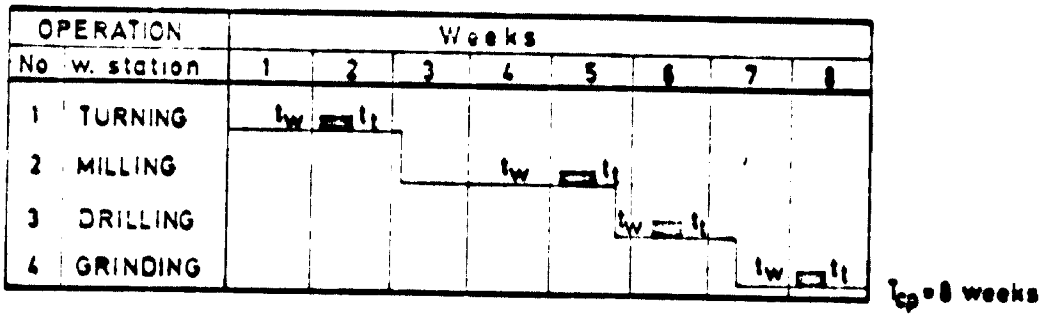
is given as capacity/load ratio and with this type of production system is, for each of cells, lower comparing with process layout of work station.

.3.4 The degree of functionality of the process (operating time/throughput time)

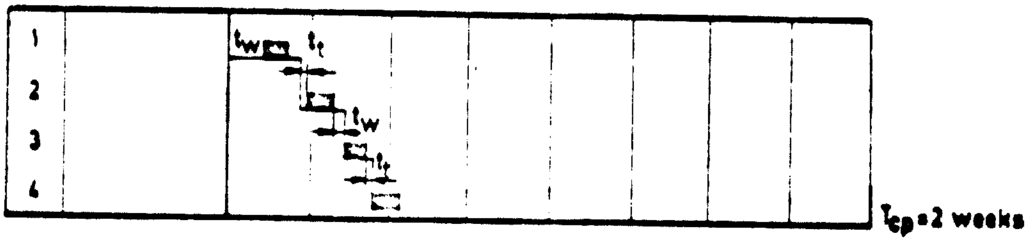
is, as it is shown, given as:

$$f = \frac{T_{ct}}{T_{cp}} = \frac{(\sum_{i}^{m} t_{ij})_j}{T_{ct} + \sum_{i=1}^{i=m} t_{moi}} \qquad (59)$$

As it is obvious the type of layout affects the throughput time as shown in Fig.27.



a) Throughput time with „functional" layout



b) Throughput time with cell layout

LEGEND:

t_{co} - operation time for batch

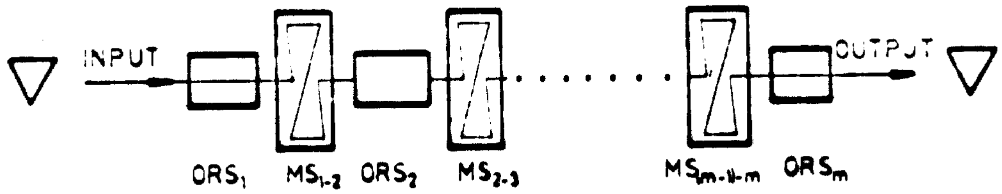
t_t - transportation time

t_w - quening time

Fig. 27

$$k^*_{ser} = \frac{\left(\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{(j)}\right)_{max}}{k_k} > 1 \qquad (60)$$

and by the condition that the total time T_i, needed for a certain operation, is, on the greater number of m-operations, greater than capacity k_k of the observed part of the system. The production systems of this type are flexible enough whcih enabled by the building of interoperational buffers between work stations. The basic illustration is shown in Fig.28.



Legend: ORS_j - work stations
MS_j-(j-1) - buffers

Fig. 28

Continuous flow processes with free cycle time present a general model of material flow in line layout of work places from which the rest of the cases can be derived even to the final case - one product line. In a function of load/capacity ratio of each work stations working place contains, in a general case h-working centers where:

$h = 1,2,3,\ldots,u$ units.

The components are passing in parties through the process from one to the other work station without backflow by which the interoperation buffers enable the increase of flexibility rate of the system. The material handling by the system of free cycle time (unbalanced operation times) is working as:

1. Free handling equipment (Fig.29):
   - manually operated flor type system with two wheeled hand trucks

The cycle time cannot be less than the longest component throughput time. Because group layout brings the work centers used to make each part close together and under the same supervision it reduces throughput times and make possible to work with shorter cycles than it is possible with functional layout. It also makes it possible therefore to work with a much smaller investment in stocks.

.3.5 Set-up time

The group approach in the layout of production systems - cellular type - discovered that long setting-up times are unnecessary. The setting-up time is given only once for all of the parts in operational group because they are suitable for the same tooling, pre-setting of tools and complite rething of improvement possibilities of production processes.

.3.6 Work stations equipment

The basis of group approaches as components similarity in shape, dimensions, quality and quantity of peaces introduces a development of tooling families which reduces the tooling investment. The traditional method of making special tooling for each operation for each component is extremely wasteful of money.

** CONTINUOUS FLOW PROCESSES

Continuous flow processes comprise the cases 4, 5 and 6 of general model of material flows of production systems as illustrated in Fig. 23 . They are characterized by a higher load/ /capacity ratio, lower degree of flexibility and by the same wequence of operations for all of operational groups Q_{opi}. The basic values of such a system are given as follows:

.1 Continuous Flow Processes with Line Layout and Free Cycle Time (Case 4 in Fig.23)

The material flow in this case of production system is determined by load/capacity ratio in the form of:

- different industrial lift trucks.

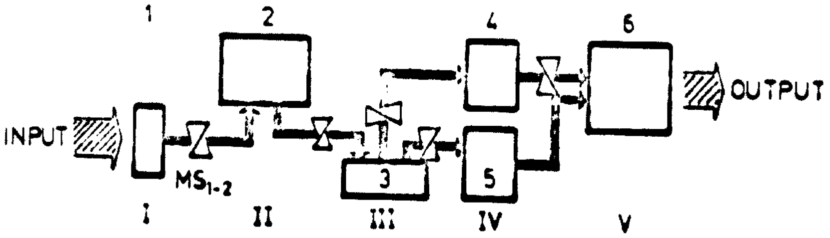


Fig. 29

2. Conveyor handling system (Fig.30) which can be build as:

  - mannually operated flor type railsystem with platforms
  - belt or slat conveyor
  - roller or wheel conveyor
  - monorail and hand operated crane.

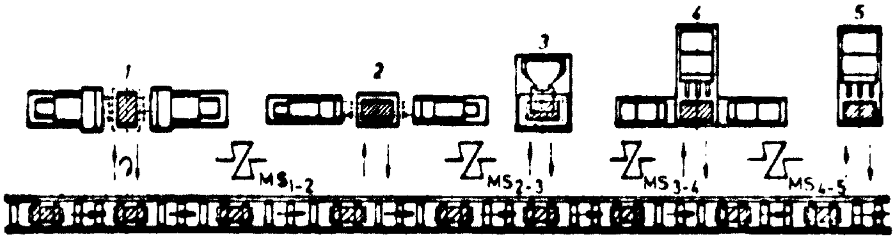


Fig. 30

The basic performances of continuous flow processes of free cycle time are:

.4.1 Work-in-progress quantity

The work-in-progress quantity at one phase of the process is given as:

$$Q_{ji} = \sum_{j=1}^{j=p} q_j \; [\text{pr.units}] \tag{61}$$

where:

p - is a number of position at each work station

The total work-in-progress quantity is than:

$$Q_n = \sum_{i=1}^{i=m} Q_{ji} + {}_{i=1} Q_b \quad [\text{pr.units}] \tag{62}$$

where

Q_b - is the quantity of components at each of interoperational buffers.

.4.2 Cycle time

As it is shown in the previous case the cycle time vary from component to component in a form of:

$$r_c = \frac{k_k \, (\sum_{i=1}^{i=m} t_{ii})_j}{\sum_{j=1}^{j=k} q_j (\sum_{i=1}^{i=m} t_{ii})_j} \quad [\text{time units/pr.units}] \tag{63}$$

.4.3 Universality of system

is given, as it is shown, as capacity/load ratio in a form of:

$$U = \frac{k_k}{T_i} = \frac{k_k}{(\sum_{j=1}^{j=k} q_j \cdot t_{ii}^{j})} \tag{64}$$

The capacity/load ratio presents the possibilities of space structure of the system or possibilities of relations between modes in system's structure. Thanks to the ability of buffer instalation the universality of this type of production system is still rather high.

.4.4 The degree of functionality of the process (Operating time/throughput time ratio)

The degree of functionality is given as:

$$f = \frac{T_{ct}}{T_{cp}} = \frac{T_{ct}}{T_{ct} + \sum_{i} t_{moi}} \tag{65}$$

It is obvious that the method of the crossing of components from operation to operation affects the total throughput time and makes the degree of functionality more or less diferent.

.4.5 Set-up time

presents the amount of time needed for setting job and is given once at the begining of the process. For these reasons it does not present a value of special significance which makes the systems of this type considerably more effective in valuation to the systems of discrete flow.

.4.6 Equipment of working stations

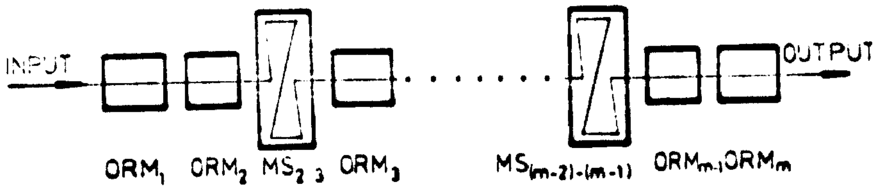
The needs of working stations equipment decreases for this type of production systems because of decreasing of component structure in operational group which enables a higher degree of mechanisation and automations of work stations. The tools are designed according to group principle.

.2 Continuous Flow Processes with Line Layout and combined Free-Forced Cycle Time (Case 5 in Fig.23)

Continuous flows with free-forced cycle time are defined by load/capacity ratio in a form of:

$$k^{*}_{ser} = \frac{\left(\sum_{j=1}^{j=k} q_{ji} \cdot t_{ii}^{(j)}\right)_{min}}{k_k} \geq 1 \qquad (66)$$

and present flows of narrow structure and increased quantities which enables the balance of operation times in considerable higher degree and decreases the need of buffer stations. In that way the speed of material flow is increased and the layout increased and the layout costs are decreased. The illus tration is shown in Fig.31.



Legend: ORM_i - work centers

$MS_j-(j-1)$ - buffers

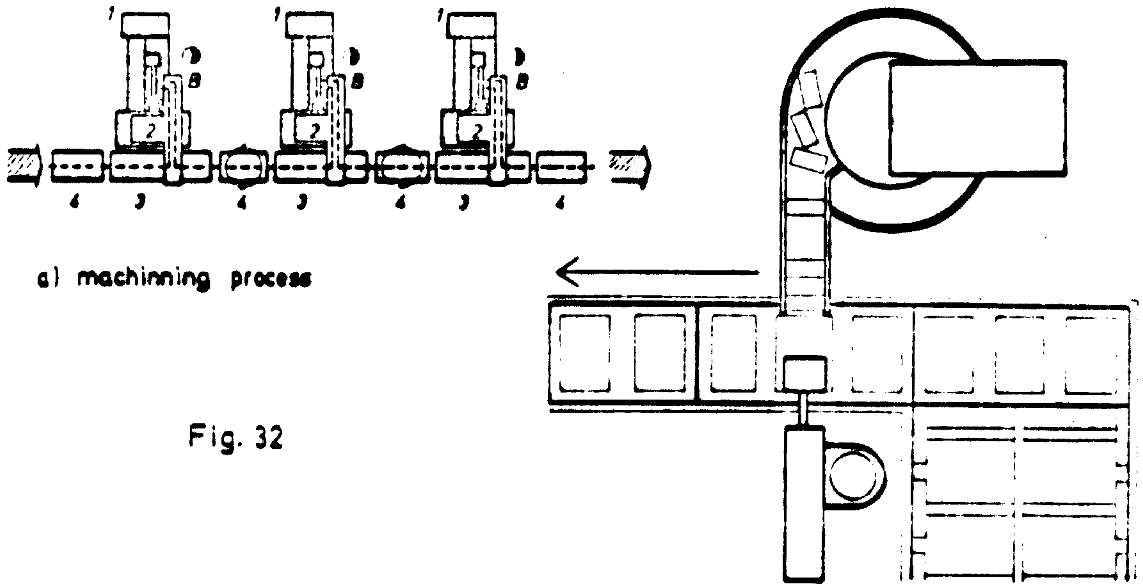
Fig. 31

As it has been shown in a previous case in a function of load/capacity ratio work stations contain h-working centers (units) where:

$$h = 1,2,3,\dots,u \quad [\text{units}]$$

The componetns are passing through the process without backflow. At the places of a higher unbalanced times the inter-operation buffers are established. The cycle time is forced for the parts of the process where the operation times are balanced and free where the operation times are unbalanced.

The material handling system is built as adjustable handling system which has the roll of material transfer without function of fixture during machining operations. The ilustrations are given in Fig.32.



a) machinning process

b) assembly process

Fig. 32

The basic parameters of continuous flow with free-forced cycle time are given as follows:

.5.1 Work-in-progress quantity

is determined by the structure and quantities of components in operational group and by the number of process phases. The parts of operational group enter the process one after another in accordance with cycle time which is, as shown, adjusted for each components. In accordance with the environmental requirements the line has to be adopted in the sense of finishing a certain quantity of one and the starting next component. The work-in-process quantity, as shown previously, is:

$$Q_u = \sum_{i=1}^{i=m} Q_{ji} + \sum_{i=1} Q_b \quad [\text{pr.units}] \qquad (67)$$

.5.2 Cycle time

The cycle time is given as:

$$r_c = \frac{k_k \quad (\sum_{i=1}^{i=m} t_{ii})_j}{\sum_{j=1}^{j=k} q_j (\sum_{i=1}^{i=m} t_{ii})_j} \quad [\text{time units/pr.units}] \quad (68)$$

The cycle time is by this type of the process in a greater measure balanced than in previous case due to the more homogeneous operational group.

.5.3 Universality of system

The degree of universality of the system of this type is lower than one of the system of continuous flow with free cycle time.

.5.4 The degree of functionality of the process (operating time/throughput time ratio)

is given as

$$f = \frac{T_{ct}}{T_{cp}} = \frac{T_{ct}}{T_{cp} + \sum_{i=1}^{i=m} t_{moi}} \qquad (69)$$

Because of increasing similarity in shape, dimensions and quality the degree of functionality is more close to one than in previous case.

.5.5 Set-up time

is decreased compared with the processes with free cycle time on the bases of greater similarity.

.5.6 Equipment of work stations

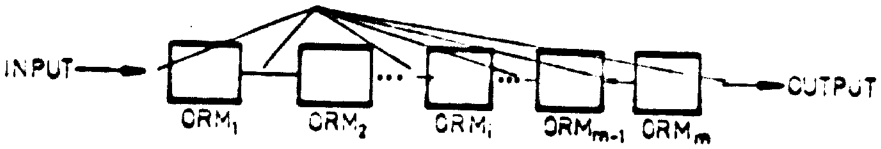
The work centers of this type of the process are adjusted to the requirements of component characteristics and present to the certain extent integrated system of increased degree of automation.

.3 Continuous Flow Processes with Line Layout and Forces Cycle Time (Case 6 in Fig.23)

The production systems of continuous flow processes with line layout and forced cycle time are defined by load/capacity ratio as follows:

$$k^{*}_{ser} = \frac{\left(\sum_{j=1}^{j=k} Q_{ji} \cdot t^{(j)}_{ii} \right)_{min}}{k_k} >> 1 \qquad (70)$$

where "k" is a small number of components and in extrem case can be equal 1. In that case system is getting layout in a form of one product line. The operation times are completely balanced which means that system can be established without interoperational buffers. The basic structure of the system of this type is given in Fig.33.



Legend: ORM$_i$ - work center

Fig.33

In a given system the components are passing through the process fixed on tooling system (jigs and fixtures) which presents the integrated part with transportation system themselves. Cycle time is, due to balanced operation times, closely equal to all of components and on all of working stations. The structure of production system of this type is characterized by maximal efficiency, low flexibility, and integration of system elements.

The production system of this type is given in Fig.34.

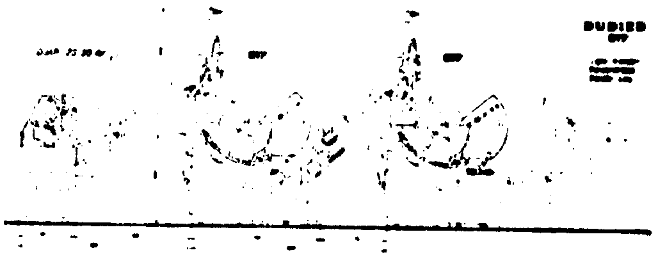


Fig. 34

The basic parameters of one product line production systems are given as follows:

.6.1 Work-in-progress quantity

Work-in-progress quantity includes all of components which are in the process of mashining. The total value of work--in-process quantity contains:

.1 Components in the process of machining

This type of stock is determined by the nimber of:

- work stations
- work centers (units) on each work station and
- positions on each work center

and can be calculated on the bases of expression:

$$Q_u = \sum_{i=1}^{i=m} M_i \cdot p_i \qquad [pr.units] \qquad (71)$$

where

M_i - number of work center units at each work station

p_i - number of positions at each work center

i - number of process operations.

.2 Components in the process of transportation

The amount of components is conditioned by the material handling system capacity and can be determined by:

$$Q_h = \frac{L}{l} p \text{ [units/batch]} \qquad (72)$$

where

L - the lenght of material handling system

l - the distance between components or batches on the system

p - the batch size. For the situation that:

$$p=1$$

components are passing separately through the System.

.3 Spare components

are determined in the function of the probability of appearance of down time. Spare components are needed to prevent distrubance of cycle time and failure of work process.

.6.2 Cycle time

The cycle time of one-product line is given as:

$$r_c = \frac{k_k}{q_j} \text{ [time units/pr.units]} \qquad (73)$$

and is equal to the operation times in a sense of:

$$r_c = t_1 = t_2 = ,\ldots,= t_k = \ldots,=t_m.$$

.6.3 Universality of system

is given as capacity/load ratio in a form of:

$$U = \frac{k_k}{\sum\limits_{i=1}^{i=m} T_i} = \frac{k_k}{\sum\limits_{i=1}^{i=n} q_j \cdot t_{ii}} = \frac{k_k}{q_j \cdot m \cdot t_{ii}} = \frac{1}{m}\,\frac{k_k}{q_j \cdot t_{ii}} = \frac{1}{m} \qquad (74)$$

where

m - the number of operations.

The degree of universality is, in a given case, extremely low.

.6.4 The degree of functionality of the process (operating time/throughput time ratio)

The degree of functionality is given as:

$$f = \frac{T_{ct}}{T_{cp}} = \frac{\sum\limits_{i=1}^{i=n} t_{ii}}{T_{cp}} = \frac{m \cdot t_{ii}}{T_{cp}} \qquad (75)$$

and is as close as possible to the value of one.

.6.5 Set-up-time

includes the time needed to get line into production. Hence, it is minimal in comparing to all other cases from 1 to 6.

.6.6 Equipment of work stations can

can be classified into three basic categories:

- manual
- mechanized
- automatic.

There are lines that utilize only one type of machine while by other lines these three categories of work centers exist side by side.

4. CONCLUSIONS

In this paper an attempt has been made to introduce the idea of the flexibility of production systems based on the princicle of group technology.

Dynamic changes in environmental conditions require a constant effort to develop production systems with higher degree fo flexibility in order to meet the demand for an constant increase in output values such as productivity, quality and profitability.

The introduction of Group Technology could be a good base for increasing of flexibility and output values of production systems. It brings many advantages and more effective approach based on analyses of component processing needs and then designing of material flow structure, work centers, tooling for group production and finally it looks forward to higher degree of automation of batch production. On the basis of carried studies it is clear that the effective planning of technological development is impossible without knowing the characteristics of components of production programme. Ideally technological development schould also follow nationalization of products and parts to avoid making tools which are not needed after rationalization on the way shown in Fig.14.

In a shown way Group Technology is an usefull new philosophy based on the simplification of material flow which can increase the flexibility of production systems.

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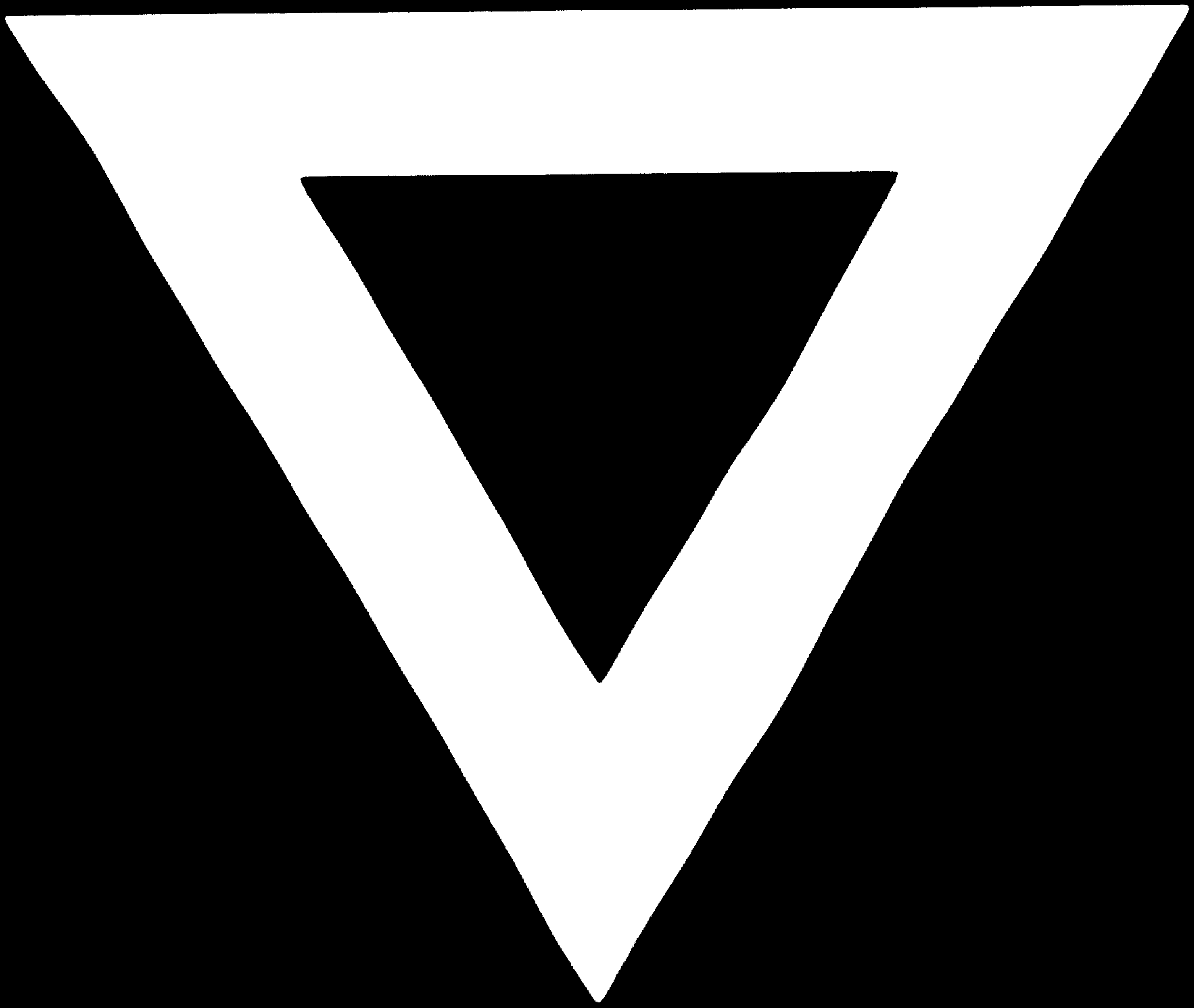

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