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Finding the Production System in Mechanical Engineering. The Constancy Indicator Method

Organization forms and methods are not imposed to manufacture but, are selected in accordance with production system

The productive process in mechanical engineering is characterized by a number of peculiarities such as, for instance, its heterogeneous, complex, multi-operational and dynamic character, space dispersion and time discontinuity which make its organizational aspect — in view of ensuring a pre-synchronization of the time and space production development in accordance with the planned rate — be one of the main and highly difficult problems.

The number of parameters variable in time intervening in a technological process in this branch is enormous. The combinations allowed by the time and space development of the objects of labour within a given structure with operators can be considered practically unlimited for the highly complex products.

For these reasons, the mathematical simulation and modelling of programming and controlling the production processes in mechanical engineering plants entail outstanding difficulties. This requires that the qualitative sides of the problem should be first referred to, in order to describe an industrial phenomenon or process subject to an organizational action, by finding a set of classifications implying a highly generalizing degree.

In this respect we consider the production system (type) to be the most general concept used for the purpose of organizing production in discontinuous flow plants.

In the most general meaning, the production system is a concurrence of dependent productive factors chiefly conditioned by the time stability, the construction and technological complexity of manufacturing, and the volume of production.

The production system greatly influences the character and proportions of the technical preparation of production, the specialization degree and production structure, the forms and methods of organizing and programming production and the economical character of manufacturing.

CLASSIFICATION CRITERIA FOR PRODUCTION SYSTEMS

According to certain theories, the pertaining to a certain production system depends on the planned volume of production or on the expected rate of manufacturing. However, such criteria only take into account the quantitative aspect of manufacturing, omitting the qualitative aspect, which depends on the construction and technological complexity of the products, as well as the level of technological equipment.

According to some theories, the affiliation to a certain production system depends on the specialization of the work centre, based on the manner in which the objects of labour move (individually or by batches), while other theories assume as a basis the constancy in time of the work to be performed at the work centre. In this respect, the 8 coefficients method has been lately circulated.

Of all these criteria, we think that the method of the manufacturing constancy indicators can be successfully used for finding the production system in which a given industrial process is to be integrated.

A fundamental analysis of this method makes clear that the production system is determined by the degree of homogeneity and stability in time of the work carried out in the various production units (work centre, shop, department, factory).

The homogeneity degree of the work can be measured by means of indicator G, which represents the time constancy of manufacturing a part (λ) at the work centre (i).

The manufacturing constancy is defined as a ratio between the time required for performing operation (i) on part (λ) and the expected rate of manufacturing:

$$G_{i\lambda} = \frac{t_{i\lambda}}{r_\lambda} \tag{1}$$

where:

$G_{i\lambda}$ = indicator of manufacturing constancy at work centre (i);

$t_{i\lambda}$ = time effectively required for performing an operation (i) on part (λ), in minutes/piece;

r_λ = expected annual rate for manufacturing part (λ), in minutes/piece.

The expected rate is calculated by means of formula:

$$r_\lambda = \frac{F_n}{N_\lambda} 60 \times \text{(min/piece)} \tag{2}$$

where:

F_n = nominal annual time stock, in hours/year;
N_λ = annual volume of parts of type (λ), in pieces/year ($\lambda = 1, ..., u$);
u = number of types of different parts manufactured during the plan period.

The rate of manufacturing has a significant value only in case that during a time interval (T) a number of parts (sub-units, products) $N > 1$ of the same type is achieved; in case $N = 1$, the rate cannot have a finite value since, by definition, this notion expresses the time interval between the launching (delivery) of two identical consecutive parts (sub-units, products).

It follows from formulas (1) and (2) that, whereas the volume of products increases, the remaining conditions do not alter, at the work centre (i) the conditions under which production goes on are steady, and the homogeneity degree of the work increases, getting nearer to the maximal value 1 ($G_i = 1$, when $t_{i\lambda} = r_\lambda$).

In case situation $r_\lambda < t_{i\lambda}$ arises, in order to observe the manufacturing rate in agreement with the proportionality principle, more work will be required. This does not mean that it is necessary to increase $G_{i\lambda}$ above value 1; on the contrary, the creation of several work places leads to a diminution of manufacturing constancy.

Under such conditions, the average per piece time required for performing an operation (i) on part (λ) is defined as a work rate and is calculated by means of formula:

$$r_{t_{i\lambda}} = \frac{t_{i\lambda}}{m_{i\lambda}} \text{ (min/piece)} \tag{3}$$

where:

$m_{i\lambda}$ = number of work centres (machine-tools) of the same type participating simultaneously in performing operation (i) on parts (λ).

The manufacturing constancy is found in this case by means of formula:

$$G_{i\lambda} = \frac{r_{t_{i\lambda}}}{r_\lambda} \tag{4}$$

Starting from the above, it follows that it is possible to use the notion of manufacturing constancy only for the variation interval $0 < G_{i\lambda} \leqslant 1$.

The concept of manufacturing constancy for a time period (T) for which value r_λ is found allows us to asssume that the manufacturing, which is characterized by a certain constancy, has a cyclic character; in other words, it is repeated at certain equal time intervals r_λ. When this constancy is absent, which is the case with the unique products and prototypes where the expected rate cannot have a finite value, the manufacturing has an acyclic character. The acyclic production system, defined as such, is known in the science of production organization under the denomination of "individual production system".

At the same time we should stress that the ratio $\frac{t_{i\lambda}}{r_\lambda}$ divides the cyclic manufacturing into two big systems:

1. The mass production system, in which the objects of labour move in the individual production process if conditions

$$\frac{t_{i\lambda}}{r_\lambda} \geqslant 1 \text{ and } \frac{r_{t_{i\lambda}}}{r_\lambda} \cong 1, \tag{5}$$

are simultaneously met, which means each time that the homogeneity degree of the works being performed at the same work centre is a maximum;

2. The serial production system, in which the objects of labour move associated in batches if

$$\frac{t_{i\lambda}}{r_\lambda} < 1, \tag{6}$$

that is, when the maximum covering of the work centre cannot be ensured by a sole work so that various works are needed, which reduces considerably the homogeneity degree.

In actual practice, since the concept of manufacturing constancy is not amenable for the cases $t_{i\lambda} > r_\lambda$ either, because they have the variation interval $0 < G_{i\lambda} \leqslant 1$, in order to find out the production system the reverse manufacturing constancy $\frac{1}{G_{i\lambda}}$ is used, which is essentially the same, since $G_{i\lambda}$ leads to equivalent considerations.

Coefficient $K_{i\lambda}$ of the production system is found by means of formula:

$$K_{i\lambda} = \frac{r_\lambda}{t_{i\lambda}} \tag{7}$$

The integration of a certain industrial process in one of the two big cyclic production systems shall be in agreement with the value of coefficient $K_{i\lambda}$:

— in the mass production system, for $K_{i\lambda} \leqslant 1$ and $\frac{r_\lambda}{r_{t_{i\lambda}}} \cong 1$;

— in the serial production system, for $K_{i\lambda} > 1$.

In its turn, the serial production system is classified according to certain limits conventionally accepted as follows:

— large series production system, $1 < K_{i\lambda} \leqslant 10$;
— medium series production system, $10 < K_{i\lambda} \leqslant 20$;
— small series production system, $K_{i\lambda} > 20$.

These coefficients of the production system correspond, if we take into account $G_{i\chi}$, to the following limit values:

$0.1 \leqslant G_{i\lambda} < 1$, for the large series production system;
$0.05 \leqslant G_{i\lambda} < 0.1$, for the medium series production system;
$G_{i\lambda} \leqslant 0.05$, for the small series production system.

FUNDAMENTALS TO BE OBSERVED IN ORDER TO FIND THE PRODUCTION SYSTEM

The peculiarities of the production system in mechanical engineering require the observance of the following fundamentals for setting the production system:

a) the production system is established only for the basic production which is yielded by the basic productive departments (primary processing, mechanical processing, assembling);

b) the production system is established by the part, sub-unit and product, beginning with the lower production units (work centre);

c) taking into account that not all the operations (i) are classified in the same production system for one and the same part (sub-unit, or product), it is required, depending on the frequency with which the value coefficients $K_{i\lambda}$ is included within the limits earlier given, to establish the system prevailing for each type of part (sub-unit or product).

It follows from the above that the constancy indicators method determines in detail the production system, starting with the details, which, in our opinion, is a positive aspect complementing the 8 coefficients methods generally used for products and manufacturing stages. [1])

FACTORS INFLUENCING THE DYNAMICS OF THE PRODUCTION SYSTEM

The production system has a dynamic character and is influenced by technical, organizational and economic factors which are subject to continuous change in time.

The dynamics of the production system depends on the progress in time of the technical level of equipment, on the degree of mechanization and automation of the production processes, on the manufacturing technologies and degree of equipment with tools, contrivances and checking devices, on the products standardization level, on the production organization and on manpower qualification. The change of the volume of production and the work bear particular influence on the production system. However, the dynamics of the production system is differently influenced, at times in a contradictory manner, by these factors.

This shows that, as the volume of production increases, the production system tends to progress towards an upper level (from small series to large and mass series). This trend is, however, counteracted by the new technologies introduced and by the improvement of production organization which accompanies this process, due to the decrease of per piece manpower consumption.

The alteration of the technical and organizational factors bears a predominant influence, on large scale and during short time periods, in opposition

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[1]) The 8 coefficients method was investigated and finished up by the Moscow Orgstankimprom institute and has been unanimously accepted by nine research institutes concerned with production organization in various socialist countries. This method is expounded in references [5] and [6].

with some other factors whose influence, though unnegligible, is by far smaller owing to the long time intervals in which they alter.

Out of this category, the improvement of the production organization forms, such as concentration, specialization and co-operation bears a considerable influence.

The existence of the dynamic character of the production system involves both its periodical determination, with a view to choosing the most adequate organization forms and methods for organizing and programming production, and the probable limits of its progress in time, which is a particularly necessary element for securing a relative stability of the forms and methods of organization adopted during the plan period.

The dependence of the forms and methods of efficacious programming on the production systems is given schematically in Table I.

Table I

Production system (type)	Manner of efficacious planning of production	Order of mechanical working out of parts	Method of correlating the programme between departments
Mass production	According to rate of delivery and standard terms for conveying from a department to another	Continuous	Co-ordination of assembbling with mechanical working out, based on rate (r)
Large series production	By stock	Batches with regular periodicity	Permanent restoration of technological stock in buffer storehouse
Medium series production	Sets based on gaps		Complementary (assortment) gaps in respect of the series delivery terms
Small series production	Sets of sub-units	By batches within the given series	Gap differential diagram in respect of the assembbling term
Individual production	By orders	By sets of parts necessary for a product	Calendar gap in respect of product delivery term

ALGORITHM AND FLOW CHART FOR THE PRODUCTION SYSTEM

Owing to the construction and technological complexity of the products manufactured (great numbers of types of parts and technological operations), the periodical determination of the production system involves an important volume of work. The finding of the production system in which a part (subunit or product) can be integrated is efficaciously achieved by an electronic computer. The use of up-to-date computing technique to this end depends on

the previous working out of an algorithm defining the consecution of the computing and logical operations starting with the input of primary data up to the finding of the final results, of a flow chart and of a working program for the computer.

We subsequently present the computing algorithm for the production system.

This algorithm is made up by the total amount of logical relations and operations required to successively find the following values:

a) Annual volume of parts (N) in agreement with formula:

$$N_\lambda = \sum_{j=1}^{p} (q_\lambda \cdot N_j + N_{sch j\lambda} + P_{sig j\lambda}) \left(1 + \frac{\beta}{100}\right) \tag{8}$$

where:

q_λ = number of parts of the same type of product;
N_j = annual volume of products (j);
$N_{sch j\lambda}$ = volume of spare parts required from type (λ) and from assortment (j);
$P_{sig j\lambda}$ = stock of unfinished production of safety devices for parts (λ);
β = tolerable percentage of technological reject.

b) Nominal stock of time (F_n) in agreement with formula:

$$F_n = Z_l \cdot S \cdot h \text{ (hours/year)} \tag{9}$$

where:

Z_l = annual working days (6-month, 3-month, monthly);
S = number of daily working shifts;
h = number of working hours by shift.

c) Expected manufacturing rate (r_λ) with formula (2).

Let us assume that in order to work out part (λ), C operations are required. For each operation (i) one shall calculate:

d) Effective time consumption with formula:

$$t_{i\lambda} = \frac{t_{ni\lambda}}{k_{mi}} \tag{10}$$

where:

$t_{ni\lambda}$ = normalized time for working out part (λ) through operation (i) in minutes/piece;
K_{mi} = medium coefficient for achieving the time rate.

e) Production system coefficient $K_{i\lambda}$ with formula (7).

The value of coefficient $K_{i\lambda}$ requires the integration of operation (i) in a production system. Let us assume that out of the C operations required for working out part λ, a number of C_0 operations are integrated in mass production system having $K_{i\lambda} \leqslant 1$; a number of C_1 operations are integrated in the large series production system having $1 < K_{i\lambda} \leqslant 10$; a number of C_2 operations are integrated in the medium series production system having $10 < K_{i\lambda} \leqslant 20$, and a number of C_3 operations are integrated in the small

series production system having $K_{i\lambda} \geqslant 20$. Obviously, we have the formula $C = C_0 + C_1 + C_2 + C_3$.

The production system prevailing for part (λ) is the one that is in agreement with the number equal to max. $\{C_0, C_1, C_2, C_3\}$.

In case there are two or more prevailling values, close or equal, in counters $C_i (i = 1, 2, 3)$ the production system is established at the lower limit in agreement with the most significant value yielded by the couples of counters $C_i \cup C_{i+1}$, taken in the increasing sense of the order number ($i = 0, 1, 2, 3$).

In the flow chart of production system given in Fig. 1, the values to be computed are found in rectangular cells, and the decisions being made along the algorithm as regards the value of the production system coefficient is met or not, and the course to follow.

With a view to finding the number of operations (i) required for part (λ) and the number of operations pertaining to a production system or another, one should consider counters C, C_0, C_1, C_2, C_3, which initially are zero. For instance, we shall understand by $C_0 := C_0 + 1$ that, for an operation pertaining to the mass production system the value of counter C increases by a unit.

The input data for calculating and identifying detail (λ) are: name of detail; values required to calculate the annual volume of parts; values required to calculate the time stock.

The input data for each operation (i), ($i = 1, 2, ..., C$) on part (λ) are: name of operation (i); normalized time t_{n_i} for working out part (λ) through operation (i); medium coefficient K_{m_i} of meeting the time standards.

For each operation (i) of detail (λ), are printed in a table: name of operation (i); effective time consumption $t_{i\lambda}$; manufacturing system coefficient $K_{i\lambda}$, and the type of adequate (mass, large series, etc.) production system.

After these printings, for detail λ is written:

— number C of operations for detail (λ);

— numbers $C_i (i = 0, 1, 2, 3)$ and what percentage covers C_i in C, in agreement with the production system. The input and output operations in the flow chart are given in the parallelogram-shaped cells (Fig. 1).

The algorithm was programmed for the IBM 360/40 computer at the Centre of Economic Computation and Economic Cybernetics-Bucharest in FORTRAN IV, the input data being punched on cards. When working out and putting the algorithm on the computer, the following was taken into account: to achieve a high precision of results, while the input of initial data, the solving and obtaining the required data are achieved in a very short time. Thanks to its simplicity, the computation algorithm can be programmed also on computers of the type "Olivetti Programa 101" or "Frieden 5610", which renders the suggested method accessible to enterprises.

In order to test the program, the numerical example in Table II was considered.

The following structure has been obtained:

Total number of operations	$C = 38$	100.00%
Mass manufacturing	$C_0 = 1$	2.63%
Large series manufacturing	$C_1 = 34$	89.48%

Medium series manufacturing $C_2 = 2$ 5.26%
Small series manufacturing $C_3 = 1$ 2.63%

Table II

Detail: Injection pump body 65—101
Annual quantity of parts: 36.000 pieces
Average annual rate (minutes/piece): 8.19 *

Item	Name of operation	Time consumption per operation $t_{i\lambda}$ (minutes/piece)	Production system coefficient $k_{i\lambda}$	Characteristic of production system
1	Milling	1.48	5.53	large series
2	Milling	1.44	5.69	large series
3	Boring	0.98	8,35	large series
4	Checking	2.10	3.90	large series
5	Boring	1.11	7.38	large series
6	Boring	1.61	5.08	large series
7	Milling	1.61	5.08	large series
8	Milling	1.10	7.44	large series
9	Boring	15.00	0.55	mass production
10	Checking	0.30	27.29	small series
11	Turning	1.44	5.69	large series
12	Turning	1.08	7.58	large series
13	Reaming	1.98	4.13	large series
14	Boring	2.41	3.40	large series
15	Boring	2.04	4.01	large series
16	Slotting	0.97	8.44	large series
17	Checking	2.10	3.90	large series
18	Boring	2.77	2.96	large series
19	Boring	1.61	5.08	large series
20	Boring	1.34	6.11	large series
21	Milling	1.04	7.87	large series
22	Milling	1.23	6.66	large series
23	Milling	1.26	6.50	large series
24	Milling	1.07	7.65	large series
25	Milling	1.08	7.58	large series
26	Washing	1.05	7.80	large series
27	Checking	2.10	3.90	large series
28	Threading	0.81	10.11	medium series
29	Threading	0.97	8.44	large series
30	Threading	2.03	4.03	large series
31	Threading	1.35	6.06	large series
32	Threading	1.52	5.39	large series
33	Threading	1.10	7.44	learge series
34	Threading	1.11	7.38	large series
35	Threading	2.05	3.99	large series
36	Washing	0.50	16.37	medium series
37	Pressure test	3.10	2.64	large series
38	Final checking	3.10	2.64	large series

* The average manufacturing rate was computed for the following working conditions: $Zl = 307$ annual working days; $S_z = 2$ daily working shifts, and $h = 8$ working hours per shift.

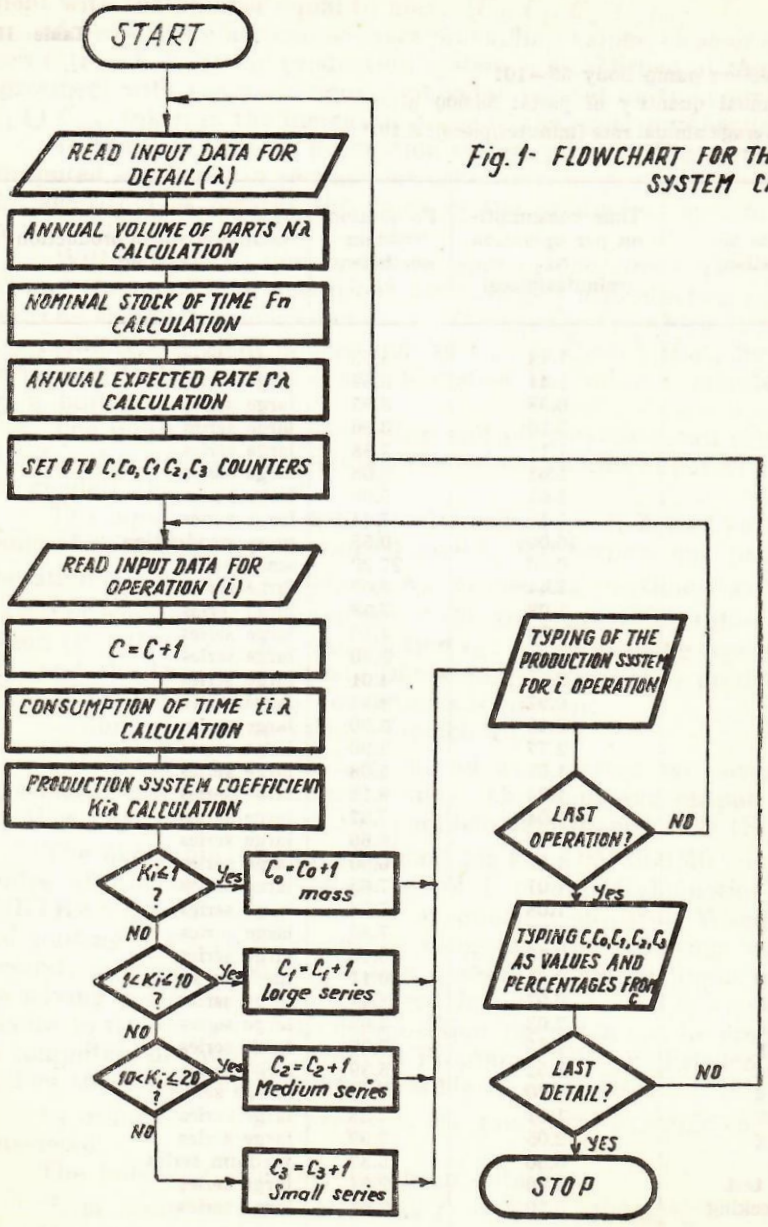

Fig. 1- FLOWCHART FOR THE PRODUCTION SYSTEM CALCULATION

Fig. 1

It follows, then, that the considered detail belongs to a predominantly large series production system.

The total computation for the considered exmple lasted one minute.

An essential condition to be observed when using modern computation techniques in order to find a production system consists in the existence within the entreprise of some files, permanently updated, for details, operations, time standards, material consumption standards, etc.

In this respect we think that the use of the computation algorithm of the production system in an efficacious production programming integrated system is an essential prerequisite for conducting the management and organization of industrial products along scientific criteria.

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ETABLISSEMENT DU SYSTEME DE PRODUCTION DANS LA CONSTRUCTION DES MECANIQUES. METHODES DES INDICES DE CONSTANCE

Bien que la classification des systémes cybernétiques productifs et le modelage mathématique peuvent simplifier considérablement la projection des systèmes de production, traiter ce problème qui est à ses débuts, présente quelques difficultés. On utilise à présent diverses méthodes pour intégrer les systémes cybernétiques productifs à un certain type, auquel on puisse appliquer, vu son grand degré de généralisation, certains critères spécifiques d'organisation en temps et lieu.

Les auteurs présentent la méthode des indices de constance de la fabrication pour établir le système à qui on pourrait intégrer un processus industriel soumis à une action d'organisation.

УСТАНОВЛЕНИЕ СИСТЕМЫ ПРОИЗВОДСТВА В МАШИНОСТРОЕНИИ МЕТОДЫ ПОКАЗАТЕЛЕЙ ПОСТОЯНСТВА ПРОИЗВОДСТВА

Несмотря на то, что классификация производственных кибернетических систем и их математическое моделирование могут значительно упростить проектирование систем производства, рассмотрение этого вопроса только началось. В настоящее время применяются различные методы включения производственных кибернетических систем в определенный тип, к которому на основе большой степени обобщения можно было бы применять определенные специфические критерии организации во времени и в пространстве.

Авторы излагают метод показателей постоянства производства для определения системы, в которую можно включить отдельный промышленный процесс, подлежащий организационному мероприятию.