General principles and search strategy for rational structure types reconfigurable production systems

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Abstract. The article considers selection of rational production system (PS) type. The selection method is described that is based on establishing the structural attributes of an inflow of orders, creation of production system typical structures bank, defining the shared boundaries between typical structures in metric space and development of metrics calculation approaches. The article shows that selection of rational PS type implies the selection of PS technological structure and defining its optimum automation level.

Based on the analysis result of the current PS design methods and main provisions of theoretical and informational approach in terms of PS design, selection method for rational structure types narrows down to solving four tasks:

– establishing the structural attributes of an inflow of orders that ensure optimum technological medium (dominating structural attributes);
– creation of production system typical structures bank according to the current level and forecasted trends of technological systems development;
– defining the shared boundaries between typical structures in metric space reflecting the dominating structural attributes of an inflow of orders (based on equipotential curves or surfaces); and
– development of metrics (indicators, criteria) calculation approaches to reflect the dominating structural attributes of an inflow of orders.

Certain indicators define the main structural attributes of an inflow of orders. On the one hand, they reflect the potential labor input of fabrication and on the other hand, they reflect the potential labor input of reconfiguration of production system (RPS).

Rational PS selection can be divided into two stages:

– selecting the PS technological structure according to the type of inflow of orders; and
– defining the optimum PS automation level.

Technological processes are selected on two levels: local and global. Locally, one searches for an optimum technological medium (for a certain inflow of orders) within a single, usually “traditional”, class of technology in the given industry. For instance, the majority of modern PSs manufacturing car parts do not go beyond machining.
Globally, the selection of optimum technological medium demands a search of brand-new technological solutions based on the analysis of cutting-edge abstract and applied science achievements.

Let us consider the selection of rational PS type within the “set” class of technology. We will show that while the first stage – defining the optimum technological passes set – is completed (e.g., based on typical or group TPs)[1,2], the junction of PS macro-design is a solution on PS elements specializing and optimum correlation of direct and indirect labor necessary to implement all PS connections, which is economically feasible.

Obviously, in the same way as production time used as a point of departure for PS design in heavy production, RPS design demands the use or criteria that can only be defined by the production plan. Such indicators include flexibility and performance. This provision is unbiased as from the very beginning of RPS implementation PS is classified by two criteria not related to the system specification. One of them reflects production diversity (number of different items, number of consignments, etc.). The other attributes to the production scale (annual program, average consignment size, etc.). This method has more of a qualitative and not a quantitative drawback, as “different goods” can be interpreted in the broadest sense[3,4,5]. The same goes for the work pace measured in “items/hour” which becomes biased when the goods type is changed. Such methods can be applied only to very close spectra of goods; thus, they are rarely used practically. In order to make this method universal and viable, you can merely change the number of different goods to the level or scope of diversity (flexibility) \( (F_0) \) and change the annual program to the amount of owned information \( (I_0) \). Flexibility level in goods type defined by Shannon as amount of information establishes the set goods diversity and grows limitlessly from zero (in heavy, mostly, serial production) together with the diversity. Capacity indicator \( I_0/T_0 \) means the output per a time unit and completely complies with the work pace in serial production.

Use of these criteria to define the PS design strategy actually replaces the traditional term of “production type”, as even serial production has inherent flexibility.

Fig. 1 describes an example using the necessary flexibility and capacity to make design decisions. Scheme \( F_0 - I_0 \) provides for the zones of preferable PS types (A for low volume production; B for medium volume production and C for large volume and serial production)[6,7,8]. The recommended software type can be defined by calculating the values for a specific inflow of orders.

![Figure 1. Making design decisions based on necessary flexibility and capacity](image-url)
Preferable PS types will be within a zone limited by $F_0^{\text{max}}, I_0^{\text{min}}, I_0^{\text{max}}$, defining the possibilities of specific technological and economic single and metasystems at a specific technological advance stage. For instance, $I_0$ for bodies of rotation PSs at a production site range at 1...100 Mbit and TM ranges at 0.1...1 Mbit.

As the flexibility and capacity ranges differ for different goods and technical processes, coordinates on scheme $F_0 - I_0$ shall be scaled differentially for different industries and goods with varying purpose[9,10]. A traditional five-type serial goods structure is reflected on the scheme by five relation scales $F_0/I_0$ (I - for individual, II - for low volume production, III - for medium volume production, IV - for large volume production and V - for serial production).

This scheme is a tool for the first step in selection of preferable PS structure type. One defines the rational PS structure type for this inflow of orders by calculating two indicators: flexibility (diversity) range and amount (volume) of owned information of annual (quarterly, monthly) production program.

To define the types of production in the meaning defined above, we can use simpler and more illustrative schemes in $F_0 - n_0$ coordinates (Fig. 2). As not only serial nature but also output (scale) defines the PS content and structure, it is deemed reasonable to consider the range of values $I_0$ or $n_0$ in defining the type of production. By differentiating the flexibility and capacity ranges into small, medium and large ones, we can obtain nine production types.

![Figure 2. Types of production based on output and labor input](image-url)

PS type is also known to depend on production complexity, which, in turn, makes both the term and amount of production types broader.

If we break down the typical products of the industry into three ranges (Fig. 3) based on complexity index, we will get 27 types of production defining the content and structure of PS.
Figure 3. Types of production in view of production complexity

Indicators $I_0$, $K_c$ and $H_0$ directly depend on the number and precision of parts and correlate with the future labor input of processing (within a certain class of technological methods)[11,12]. Thus, universality and flexibility with the average mobility level of PSs similar in purpose and advance level define the labor input of reconfiguration of production system.

The ratio of the necessary flexibility (diversity) range to the necessary capacity is, in fact, the $K_c$ index (in the initial approximation) defining the production type:

$$K_c = \frac{F_0}{n_0 I_0} = \frac{n_0 f_0}{I_0} \leq 1$$

(1)

where $\Pi$ is system capacity; and $f_0$ is flexibility level.

As $K_c$ reaches the maximum level when $F_0 = I_0$ (i.e., when none of the elements of the inflow of products is repeated), $K_c$ actually equals the PS flexibility. When universalism ($m_0$) and number of products ($n_0$) is fixed, the flexibility is defined by the following ratio:

$$K_c = \frac{f_0}{f_0^{\text{max}}} \leq 1$$

(2)

where $f_0^{\text{max}}$ corresponds to the case of equally possible occurrence of different products at PS entry.

Pursuant to equations (1) and (2), $K_c$ value (or set flexibility level) depends on those product’s features that directly impact the production type: diversity and output, product’s repeatability and complexity.

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