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Flexibility and Complexity of Effective Enterprises

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The aim of this research was to give contribution to the efforts that are being made to develop the procedures of structural designing of industrial systems - highly effective enterprises. For that purpose, this paper analyses the conditions and possibilities that would enable those structures to adapt to changes in the surroundings - flexibility and management adequacy of organizational structures - by lowering the degree of complexity. Special focus is given to Mass Customization - tailoring the production to the needs and preferences of the customer. This requires high flexibility of a system as this is what determines the costs in this type of production.

The original contributions of this paper are the definitions and determination of the measures of the two most important characteristics of an enterprise - complexity and flexibility, and establishing their interdependence. While in the great body of literature complexity is measured by size (number of structural elements), this paper observes the complexity degree as comprising a number of interrelationships between the elements of a structure, beside the number of elements. Flexibility of the structures of an enterprise consists of three interdependent components: technological component, capacity component and flexibility of flows.

Keywords: production systems, enterprise system, organizational structure, enterprise flexibility, system complexity

1 INTRODUCTION AND LITERATURE OVERVIEW

Flexibility, structure of a system, complexity and customer-oriented production are terms used when considering trends in the development of the realistic requirements of the market [1] and predicting their further development. Flexibility can be defined as the ability of a system to quickly adapt to new circumstances [2] and [3]. It is the ability of a system to respond to changes as quickly as possible and at minimum cost and effort [4]. It is a well-known fact that production costs are reduced with the increase of products produced all the way to the minimum defined by basic costs [5]. Therefore, the term optimum number of products is introduced as an important parameter in observing the relation between the costs and the capacity of the production structures - the relation that involves the estimate of a system's flexibility. The increase of flexibility degree of a system has a negative effect because of its increased complexity, the result of which are limitations in the effective realization of processes in the system.

During the past twenty years, complexity theory has been regarded as an epitome of a completely new way of understanding nature. It has introduced and delineated adaptive systems (species, animals, plants, viruses etc.) as interactive networks of agents and tried to determine the behaviour within the networks [6] to [8].

A special view on a quality of enterprise's production structures involves approaches for its design by using simulation methods. Corresponding methods and techniques as tools for analyzing key performance indicators of production systems are described in [9] to [13].

As a result of the most recent researches into flexibility, mass customization can be seen as a response of flexible structures of a system to unpredictable changes in the surroundings. A model used here was the one that examines the relationships between the unpredictability of the surroundings, production flexibility and work results. Still, the idea of mass customization cannot give a complete answer to the question of production of a large number of various products which would satisfy the criteria of effectiveness, efficiency, and concerning the customer, the criterion of acceptable price [14] and [15].

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Literature on mass customization has mainly focused on two areas: 1) the factors influencing companies to shift from mass production to mass customization [16] and 2) the implementation of mass customization [17]. Few authors have written about the success of customer-oriented mass production and this within the research of the markets [18] and [19]. Considering the efforts of some authors to determine a favourable relation and methodology and thereby solve the problems of flexible structures with low enough degree of complexity which can offer tailor-made products, it can be concluded that each of the mentioned components should be dealt separately with the introduction of common limit functions [20].

2 FLEXIBILITY AND COMPLEXITY OF ENTERPRISES

2.1. Production Structures' Flexibility

Earlier researches on the production structures of industrial systems conducted at the IISE *(Institute of Industrial Systems Engineering, Novi Sad, Serbia)* [21] formed the basis for the development of (Fig. 1) effective enterprises: 1) change of the flow designing approach - individual to group and 2) change of the structure designing approach - process to product.

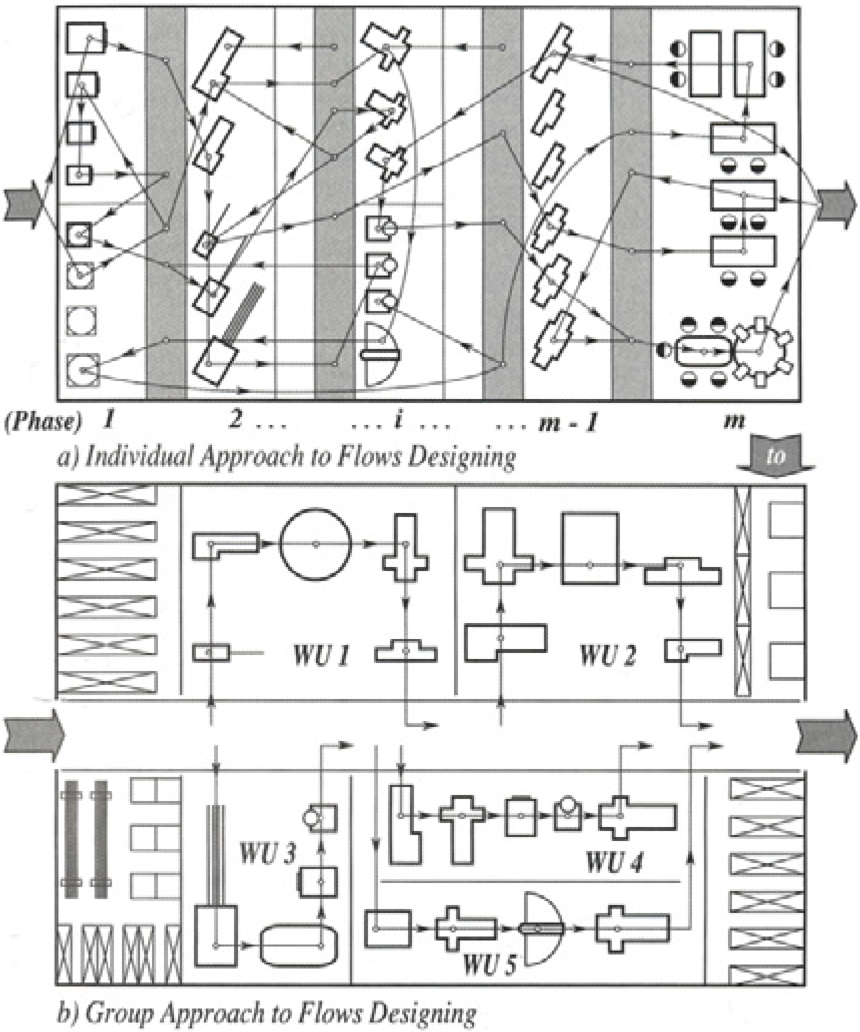


Fig. 1. *The basic changes in approaches for production structures designing*

The result of the mentioned changes in the approach is the creation of the Working Unit, the basic module of an effective enterprise - designated as ***WU*** in Fig. 1. Working Unit is defined as part of the production structure of an enterprise capable to carry out a certain task which is part of the work programme, should conditions of adequate space, technological equipment and the required structure of employees be met. Working Unit has the following characteristics:

- it is independent of the other parts of the system's structure concerning the human resources and technical capacity,
- it is responsible for completion of part of a programme, concerning the amount, quality and deadlines and
- it is suitable for process automation.

According to above definition, Working Unit (WU) is a concept, in literature well known as *Production Cell*, but with defined differences. It is a part of enterprise's production structure (for machining or assembling) that is maximum independent from all other production structure parts in sense of its ability and capability for making *groups of similar working objects*. Therefore, *Production Cell* holds high flexibility level and it is enabled to all production operations demanded by each group of similar working objects for which it has been previously installed.

Similarity of working objects is providing conditions for high degree or total automation of processes for the *Production Cell*. Working Unit has all characteristics of *Production Cell* but beside its executive (production) independence it has to have an organizational and controlling independence too, which means its total responsibility for quantity, quality, and delivery terms of similar working objects, and also for organizing and managing of processes. So we can say that *Production Cell* can be Working Unit if its competence is not limited just on production functions but also on planning, controlling, and processes improvement.

Flexibility has been defined in specific researches [22] to [24] as one of the basic characteristics of production structures that is of vital importance.

2.2. Organization Structures' Complexity

Functional structure of an enterprise consists of a group of *functions* of the enterprise (Fig. 2) [21] which are determined by the needs of going on a mission and achieving the goals of the enterprise. The project of organizational structures, based on the project of production structures, determines the structure of the other functions of an enterprise: *Top management, marketing, development, commerce, financing, administration* and *logistics*.

3 THE PRODUCTION STRUCTURES FLEXIBILITY - RESPONSE ON CHANGES

The ability of enterprises to adapt to changes in the surroundings and to the disorders in the work process is their extremely important characteristic called *flexibility* [22] to [27].

Fig. 2. *Enterprise's Functional structure*

Considering the characteristics of enterprise structures and the character of changes, three components of flexibility can be defined:

- characteristics of elements - *technological flexibility*,
- capacity of system elements - *capacity flexibility*,
- dependability of system flows - *flexibility of flows*.

The degree of flexibility is a measure of structure flexibility.

It is defined as the likelihood of a system to successfully adapt to changes in the surroundings and to the current needs of the work process. Accordingly, it is possible to determine the components of flexibility [2] and [3] and their measures (Fig. 3).

3.1. Technological Flexibility

Technological flexibility is determined by the parameters of technological system elements and by the characteristics of the work object. The measure of technological flexibility of a system 's structures [28] to [29] (Fig. 3a) is represented by the likelihood with which the given element of a structure, within the certain installed parameters, will accept a group of work objects on which part of the work should be done in accordance with the projected technological procedures.

3.2. Capacity Flexibility

Capacity flexibility is determined by the ability of elements, parts of the structure and the entire system to do that amount of work that is necessary for manufacturing the projected amount of the work object. The measure of capacity flexibility [28] to [30] is determined by (non)existence of capacity reserve as represented in Fig. 3b):

$$f_k^{\,i} = \frac{K_{eu}^{\,i} - K_{ep}^{\,i}}{K_{eu}^{\,i}} = 1 - \frac{K_{ep}^{\,i}}{K_{eu}^{\,i}} \tag{1}$$

where f_k^i is the degree of capacity of flexibility of a workplace *"i"* in the system *(i =1,2...m)*, K_{eu}^i - installed and K_{ep}^i - required capacity of that workplace.

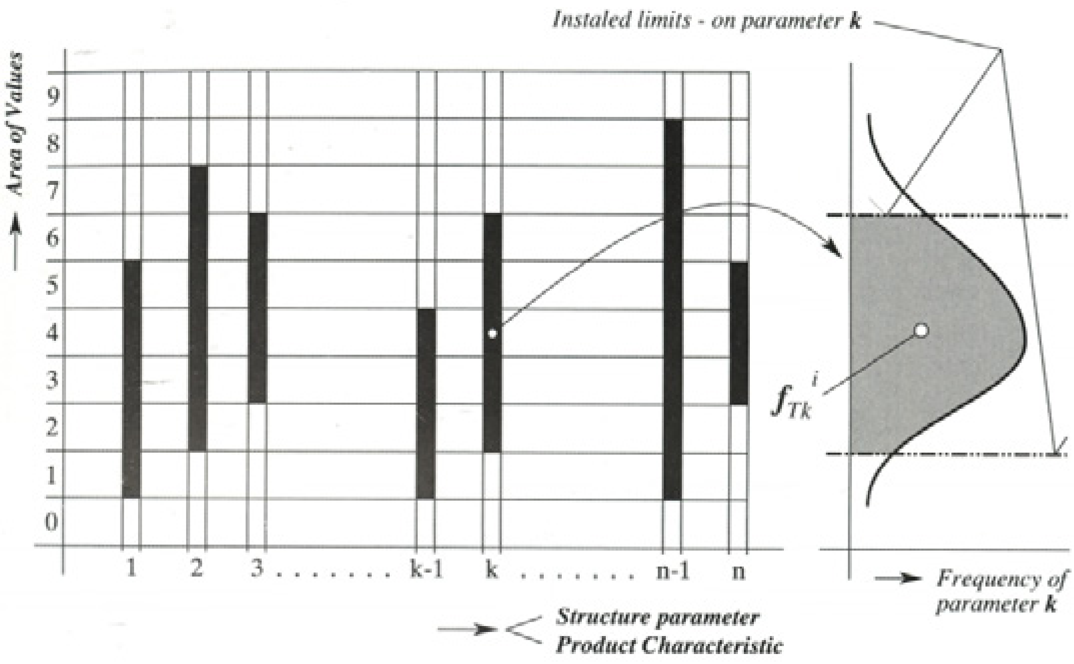


Fig. 3a. *Technological Flexibility*

3.3. Flexibility of Flows

Flows flexibility is determined by flows capacity (Fig. 3c), the relation between structure complexity degree (κ_p) and maximum complexity degree of the structure with a determined number of elements (κ_u):

$$f_p = \frac{\kappa_p}{\kappa_m} \quad (2)$$

Considerations of production structures flexibility indicate the existence of a close relationship between some components of flexibility in a way that:

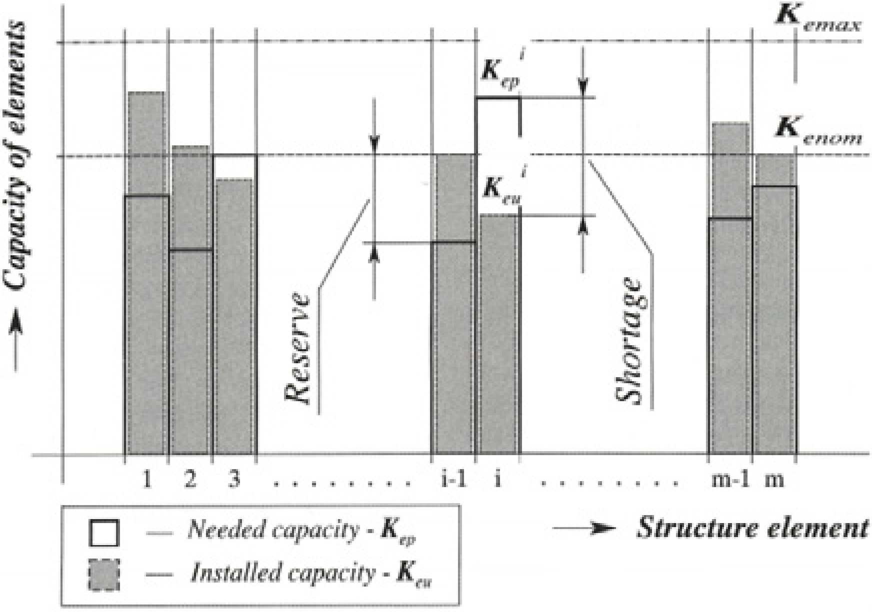


Fig. 3b. *Capacity Flexibility*

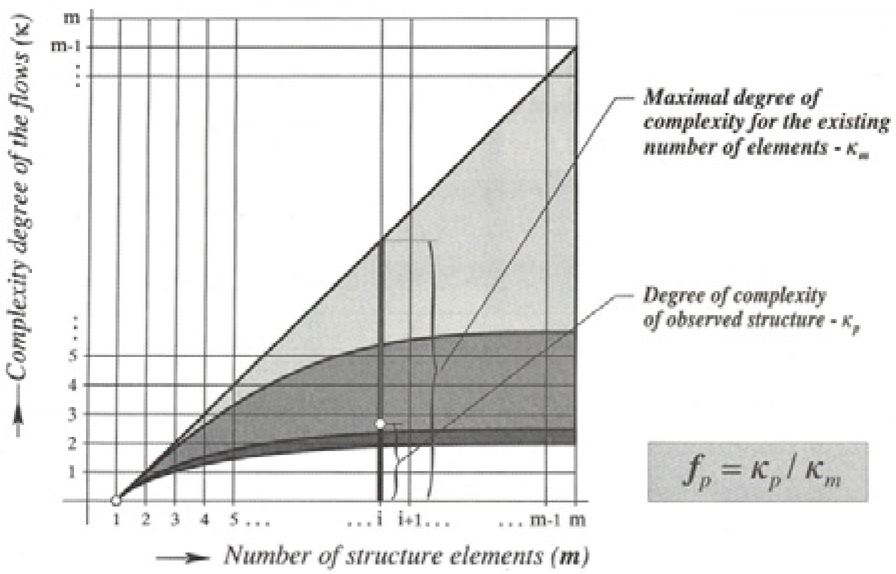


Fig. 3c. *Capacity Flexibility*

- parameters of structure elements, i.e. the value of technological flexibility degree and
- the value of the existing capacity and the reserve of the capacity, i.e. the value of capacity flexibility degree,

in the sense of compatibility between the technological and capacity flexibility in sections of flow, enable relationships between them, i.e. flows flexibility value.

Fig. 3 represents the basic dependability between components:

- *technological component* - on the work object characteristics and on the parameters of technological structures,
- *capacity component* - on the relation load-capacity, achieved in the process of design,
- *flexibility of flows* - on the complexity degree of flows, achieved in the process of design.

3.4. Research on the Technological Component of Production Structures Flexibility

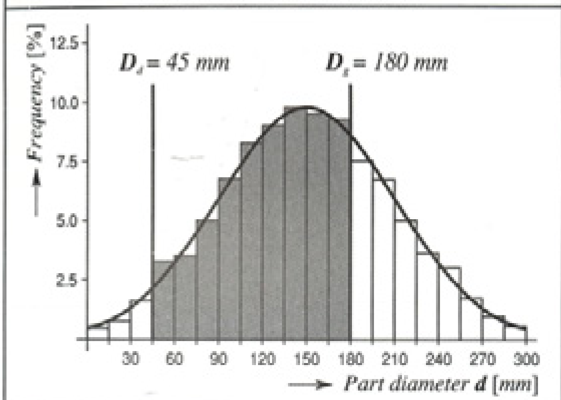
Research into the value of the technological component of a system's structure in the conditions of implementation of the IISE - approach to design of production, organizational and control structures of industrial systems, points to significant possibilities for maintaining certain characteristics on the desired level.

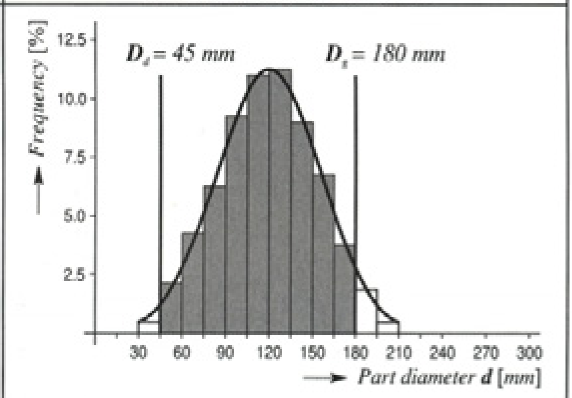
The main result of the research was the following [28] and [29]:

- Using the sample of 30 production programmes of real industrial systems, the technological component of flexibility was determined in the conditions: *STATE - individual approach* to flow designing and *process approach* to structure designing, and *PROJECT - group approach* to flow designing and *product approach* to structure designing. More than 10,000 work objects and 100 technological systems were analysed;
- In accordance with the definition presented in part 3.3 and presentation in Fig. 3, basic dimensions of parts were analysed and technological component of flexibility determined, taking into consideration the possibility of accepting the work object, as shown in Fig. 4.

Technological system: **0250 UNIVERSAL LATHE**
Characteristic: DIAMETER OF PARTS

BEFORE DESIGNING		AFTER DESIGNING	
Size of sample: 120 Interval beginning: 0 Interval end: 300 Iinterval width: 15	Distribution: **NORMAL** $\mu_x(d)$ = 150.000 $\sigma_x(d)$ = 70.863	Size of sample: 75 Interval beginning: 30 Interval end: 210 Iinterval width: 15	Distribution: **NORMAL** $\mu_x(d)$ = 120.000 $\sigma_x(d)$ = 28.336
DISTRIBUTION DIAGRAM		DISTRIBUTION DIAGRAM	





ACCOUNTING OF FLEXIBILITY			ACCOUNTING OF FLEXIBILITY		
$x_g(d)$ = 180 $x_d(d)$ = 45	$P_g(d)$ = 0.6628 $P_d(d)$ = 0.0694	$f_{T,d}$ = **0.5934**	$x_g(d)$ = 180 $x_d(d)$ = 45	$P_g(d)$ = 0.9830 $P_d(d)$ = 0.0040	$f_{T,d}$ = **0.9790**

Fig. 4. *An example of results of Technological Flexibility research*

3.5. The Possibilities of Designing Flexible Production Structures

Research on the flexibility of production structures [29] has shown that when group approach is used in designing flows and object approach in designing production structures - the division of the system's structure into *working units* [21], as a result of the narrowing of the area of work object characteristics divergence in the working unit, variants of structure can be formed in the case of technological flexibility (Fig. 5) in which the technological component does not decrease in relation to state.

On the contrary, elements of structure - technological systems with an increased reserve for accepting and manufacturing the work object - occur in the greatest number of the observed cases.

4. THE DECREASE OF ORGANIZATIONAL STRUCTURES COMPLEXITY - A CONDITION FOR EFFECTIVE ENTERPRISE MANAGEMENT

4.1. Complexity - the Basic Characteristic of the Structure of an Enterprise

The basic goals of the process of enterprise structure development are: the ability to achieve a satisfactory (or set) *effects/investment* ratio and high control adequacy, which are conditioned by the increase of structures complexity - the most important inherent limit to the realization of an enterprise's effects.

4.1.1 The Definition

Complexity degree or variety of an enterprise's organizational structure [28], [29] and [31] denotes a variety of flows network in an enterprise, determined by the basic approach to the definition of structure complexity.

This approach is based on the number of elements and the number of connections ratio, using the equation:

$$S_s = \frac{\sum_{i=1}^{i=m} m_i}{m} \tag{4}$$

where:

m - the total number of organizational structure elements, $\boldsymbol{m_i}$ - number of organizational structure elements with a direct connection to element "***i***".

4.1.2 Connections in Organizational Structure

The structure of an enterprise, the structure of its functions and the basic structure of connections between parts of the organizational structure are determined [21] by the quality of approach and implemented design procedures.

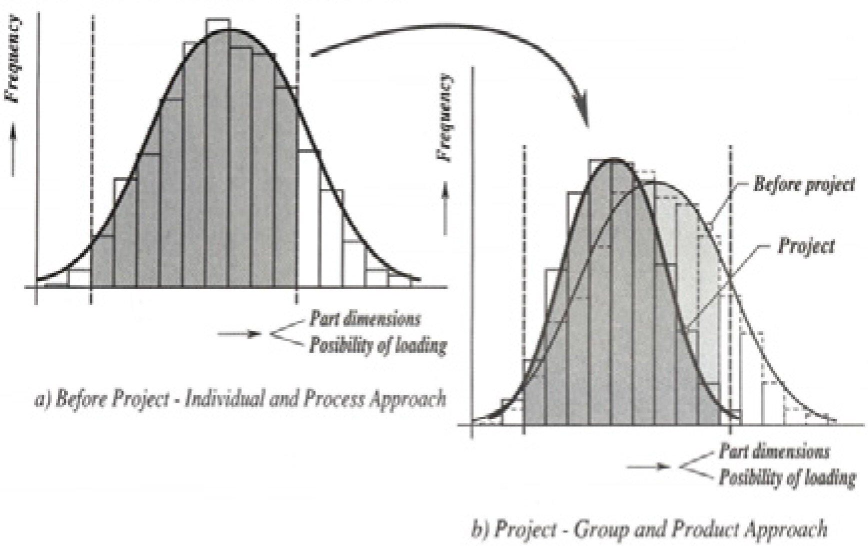


Fig. 5. *Increasing of Technological Flexibility by changing Approach to Structure Designing*

The basic structures of connections between parts of organizational structure are shown in Fig. 6.

4.1.3 The Number of Organizational Connections

Mutual connections are established between parts of organizational structure. These connections (Fig. 7) establish interdependency between the elements. The character of connections may be:

- Connections type: *major* ↔ *minor* and
- Mutual connections type: *minor* ↔ *minor*.

The position of elements in the structure, concerning the total numbers of hierarchy levels, the position of the observed element in relation to its minor and major elements, is of great importance when discussing organizational structure complexity.

The *major* ↔ *minor* ratio in organizational structure is determined by a number of hierarchy levels and management range where:

- *Hierarchy level* is part of organizational structure in vertical direction of connections, with one or more elements for defined working area (levels: enterprise, function, department, worker).
- *Management range* - ***r*** is the number of minor elements controlled by one major element.

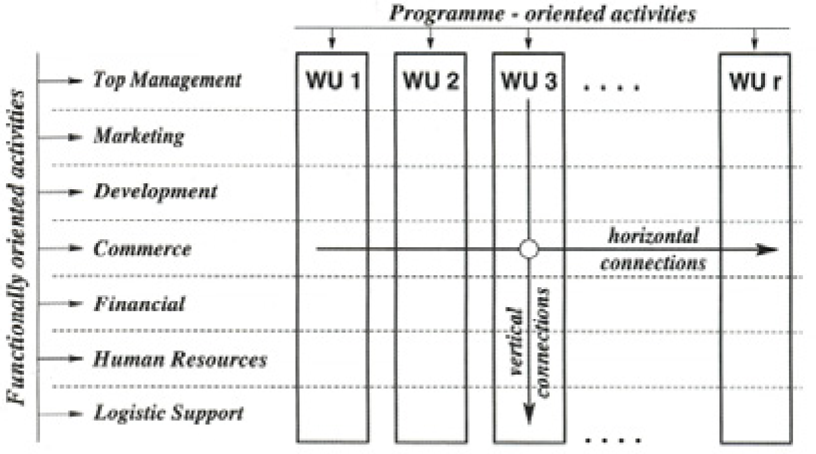


Fig. 6. *The Variety of Connections in Organizational Structure*

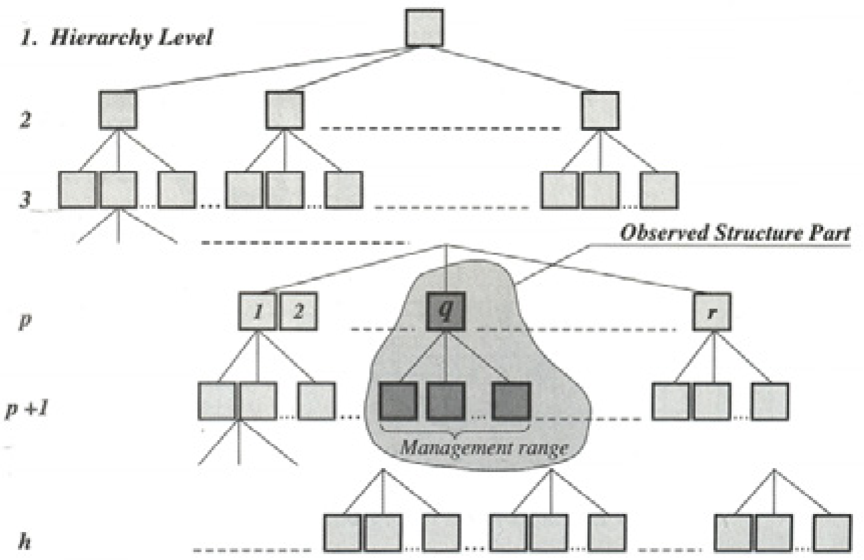


Fig. 7. *Determination of Number of Connections in Structure*

Management range determines the relationship between elements of two contiguous levels. Management range enables [21] the determination of the number of connections between the structure's elements in the observed part of the structure – $\boldsymbol{m}_i^q$, using the equation:

$$m_i^q = r\left(2^{r-1} + r - 1\right) \quad (5)$$

4.2. Complexity of Organizational Forms

With different cases of management range, the number of connections increases:

$\boldsymbol{r}$ = 4 (4 minors) → 44 conn.;
$\boldsymbol{r}$ = 5 (5 minors) → 100 conn.
$\boldsymbol{r}$ = 6 (6 minors) → 222 conn.;
$\boldsymbol{r}$ = 7 (7 minors) → 490 conn.

Using this definition, it is possible to determine the dependence complexity degree for organizational structure part between one major element and its minor elements and management range for different cases of organizational structure types (Fig. 8).

The types of organizational structures in Fig. 8 are the following [21] and [31]:

- *PROCESS TYPE of Organizational Structure* - centralistic, or functional organizational structure (Fig. 8a),
- *PRODUCT TYPE of Organizational Structure* - (non)centralistic, or divisional organizational structure (Fig. 8b),
- *PROJECT TYPE of Organizational Structure* - known as matrix organizational structure (Fig. 8c),
- *"ORCHESTRA" TYPE of Organizational Structure* - a fictitious form of organizational structure taken into consideration for comparison due to the lowest degree of complexity (Fig. 8d).

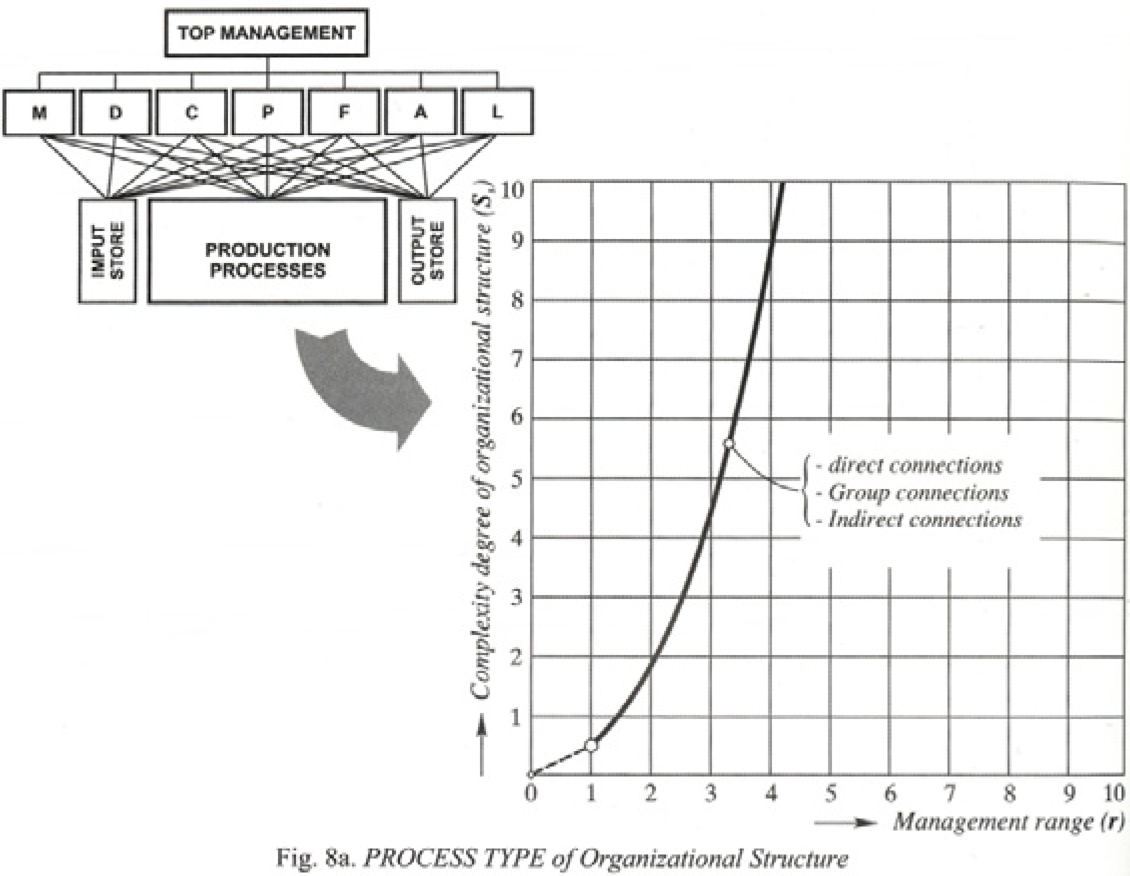


Fig. 8a. *PROCESS TYPE of Organizational Structure*

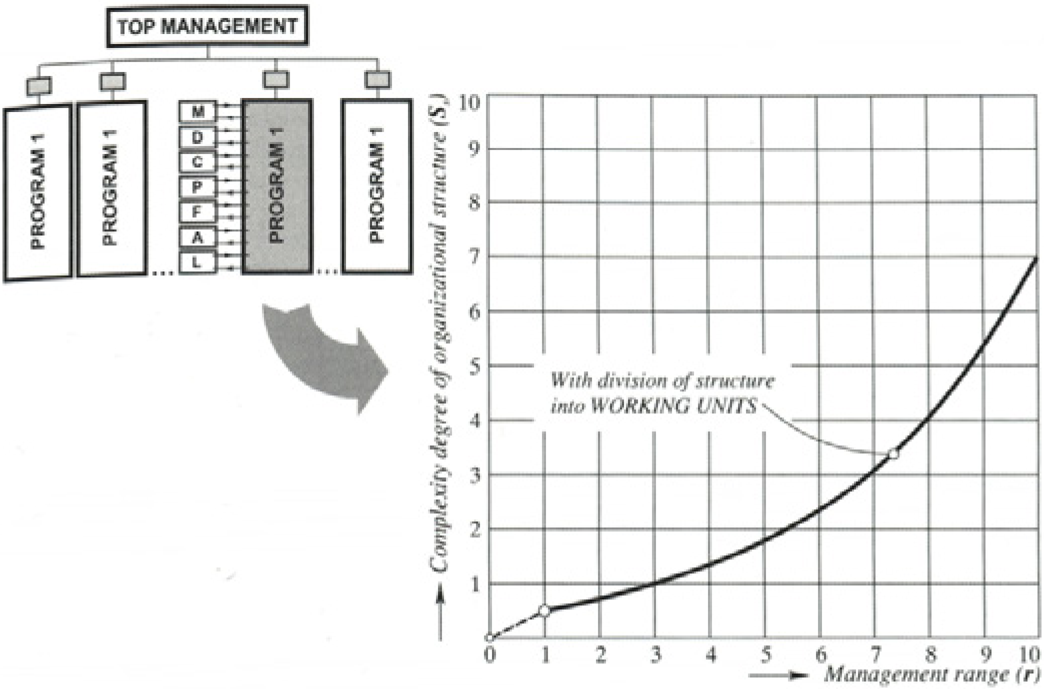


Fig. 8b. *PRODUCT TYPE of Organizational Structure*

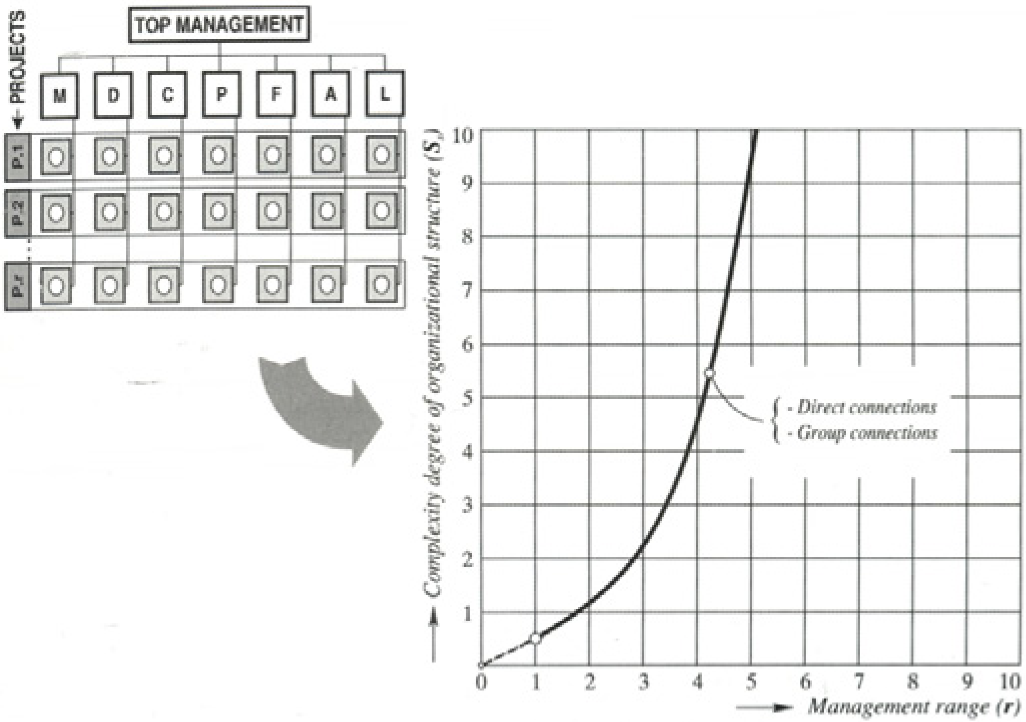


Fig. 8c. *PROJECT TYPE of Organizational Structure*

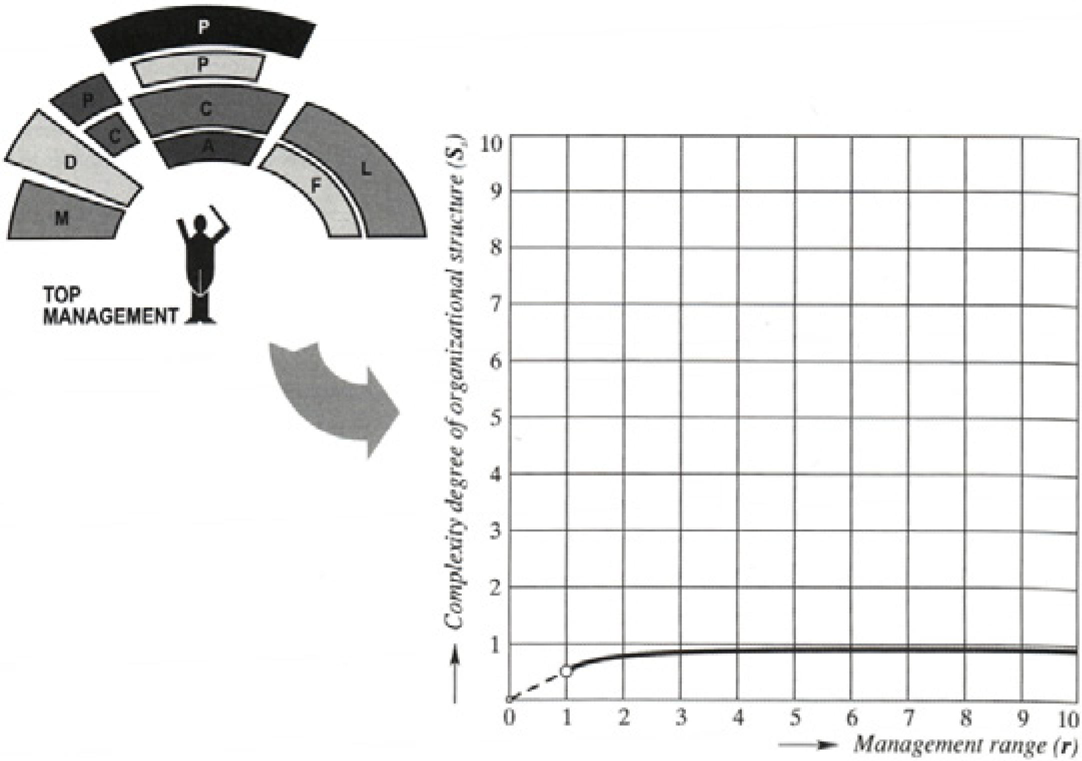


Fig. 8d. *"ORCHESTRA" TYPE of Organizational Structure*

4.3. Needs and Possibilities of Organizational Structures Simplification

Research on organizational structure characteristics in real industrial systems (enterprises) points to the necessity of eliminating all the installed limits for effective management of the work process, especially decreasing the complexity degree [28] and [29].

The possibilities of designing organizational structures with low degree of flows complexity, according to the given definition, various analyses and the presentation in Fig. 9, are reflected in the right choice of structure type. A detailed analysis of variants within a certain structure type is needed, however, with a special emphasis on the number of elements and their interrelations - the number of hierarchy levels and management range.

Research on the complexity degree of an enterprise's organizational structures shows that the complexity degree, beside the basic dependence on the number of elements and connections in a structure, is a consequence of the *quality* of the organizational structure *project*.

The quality of organizational structure project depends on:

a) Type-Variant of the Organizational Structure

The choice of the approach to organizational structure development - process, product, matrix or "orchestra" type results in the total number and specific character of connections between structure elements:

- *Process type* - a variant that demands direct, group and indirect connections between elements and results in high complexity degree,
- *Matrix type* - a variant that demands direct and group connections between elements and also results in high complexity degree,
- *Product type* - a variant that considers the installed principles of team work, demands group connections between elements and results in low complexity degree, and
- *Orchestra" type* - a variant with the lowest complexity degree, a theoretical variant - the goal in the process of organizational structure designing.

b) Management Range

Combined with a number of hierarchy levels, management range is a direct result of the process of organizational structure design because:

- Management range harmonizes the enterprise's functional activities and determines the number of structural parts on the first hierarchy level and their relationships, and
- Management range affects the design of structural parts, the total number of hierarchy levels and relationships between structural elements; most notably, management range makes a compromise between formal and informal organizational structure.

5 MASS CUSTOMIZATION

Mass customization basically refers to applied flexibility of business and production structures towards meeting the customer's requirements. As the demands of the market and development of their trends are more or less predictable (Fig. 10), the need for implementation of intelligent concepts is growing.

The period of value added time and total reconfiguration life cycle are getting shorter in time (Fig. 11). This is the crucial fact that introduces mass customization as a concept and flexibility as an answer in industrial systems.

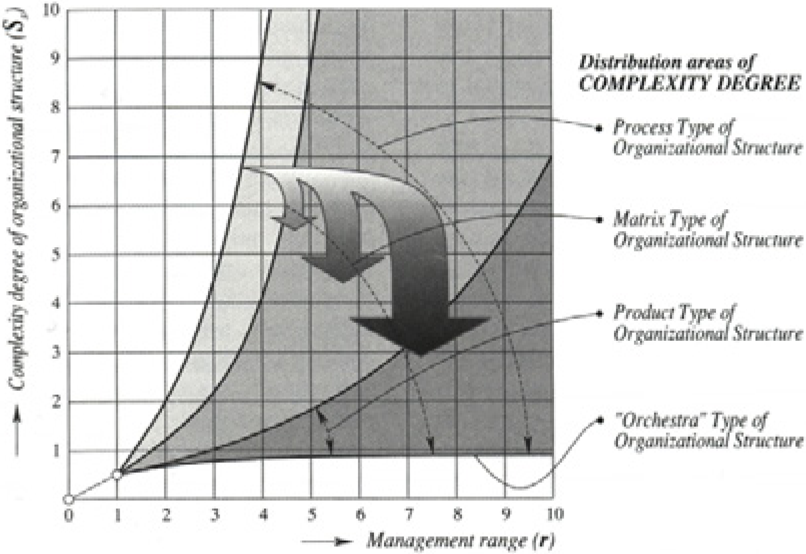


Fig. 9. *Simplification of Organizational Structures - Possibilities*

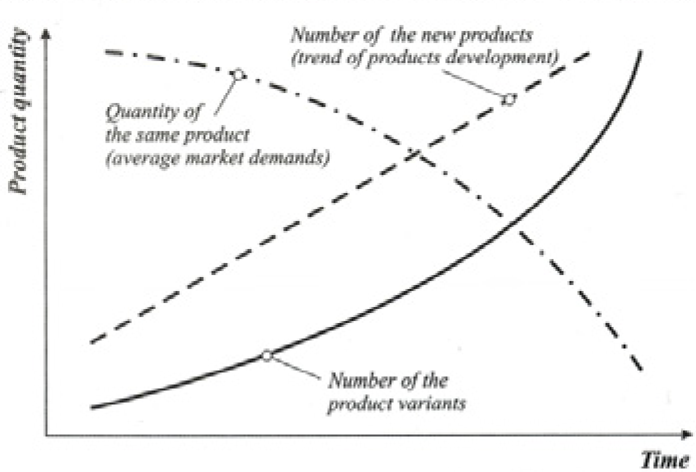


Fig.10. *Trends in market demands*

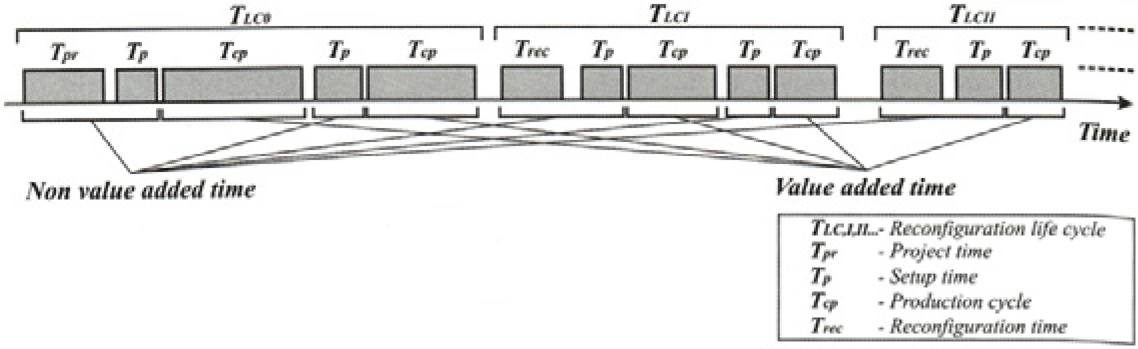


Fig. 11. *Reduction of added time period*

Mass customization is regarded as a strategy for firms to move closer to the customer. It combines elements of mass production and individualization. It can reduce the costs of a firm and increase its productivity. It is estimated that mass customization products have a potential to reach a market share of around 30%.

The implementation of a mass customization strategy requires a shift of the internal organization of a firm irrespective of whether the firm operated in the past as a mass producer or produced tailor-made individual solutions. Every staff member of the future mass customer - not only the staff responsible for production and assembly - must understand the principles of mass customization and their role in the customer-oriented production system. In comparison to the system of mass production, a much higher flow of information has to be processed and shared between the relevant function units. The implementation of a mass customization strategy thus requires, apart from new production equipment and the integration of information technologies, the definition of a new work organization with different roles and routines compared to the old system.

All this leads to a unified direction towards implementing flexibility as the only solution in structure planning and deployment.

6 CONCLUSION

Research on flexibility of production systems based on system approach indicates, as the example of technological component of flexibility shows, that the implementation of ***group approach*** in flow design and ***product approach*** in structure design create the necessary conditions for the design of *effective production structures*.

Systematically based and guided researches on organizational structure characteristics, as shown in this paper, indicate certain possibilities of generalizing the approach to establish the definition and determine *Enterprise's Complexity Degree*.

With this approach, a number of structural elements and a variety of relations between them are the basic parameters which define the complexity degree of organizational structure and simultaneously determine the complexity of an enterprise's information flows. Therefore, the complexity degree of organizational structure determined upon those parameters enables comparison of the designed structure variants using the quality defined as *Control Adequacy*.

The implementation of mass customization requires from industrial firms a reorganization of their internal structures and processes and additionally a more intensive collaboration with suppliers and customers. As the implementation of mass customization depends on the efficient interior communication processes and the willingness of workforce to learn and gain knowledge, as well as on the close collaboration with suppliers, service providers and customers, a cultural proximity between the involved parties smoothens the process of change.

Flexibility and complexity research results helped in defining and measures of key performances which are illustrating quality of enterprise's structure. In this way through different analyses the basics for quality evaluation and real enterprise's structure comparing had been set. However, characteristics of flexibility and complexity of enterprise's structure, how they are defined in this work, in furthers research could be used as criteria for analyzing and choosing the optimal variant in designing procedures of enterprises structure.

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