Methodology for Creating a Product Development System Based on Complexity Management Strategy

Ekaterina P. Garina, Elena V. Romanovskaya, Natalia S. Andryashina, Victor P. Kuznetsov, and Sergey D. Tsymbalov

Abstract The article discusses the strategic alternative development of an industry enterprise: the primacy of an engineering idea for a product over the primacy of an engineering idea for production. The object of the study are product development systems, and corporate systems of engineering enterprises. The subject is a set of theoretical and methodological approaches to the formation of product development systems by engineering enterprises. Principles, methods and ways of managing these systems, as well as methodological aspects of their development. The main **objective** is to develop a methodological approach for formation of a system for creating a product of production, based on the management (reduction, retention, increase) of the created complexity. **Methods**. The methodology of design studies was used as a methodological base and heuristic basis of the research process. **The results of the study**. The methodology for creating product development systems is complemented by solutions to manage the emerging complexity due to: a) identify key management complexity challenges faced by the manufacturer; b) formation of a set of guidelines and critical success factors in relation to actions to take into account the complexity of the system; c) complexity management of the product development system in the context of a product life cycle.

Keywords Product development systems · Material product manufacturing · Systems complexity management

E. P. Garina (✉) · E. V. Romanovskaya · N. S. Andryashina · V. P. Kuznetsov · S. D. Tsymbalov
Minin Nizhny Novgorod State Pedagogical University, Nizhny Novgorod, Russia
e-mail: epgarina@mail.ru

E. V. Romanovskaya
e-mail: alenarom@list.ru

N. S. Andryashina
e-mail: natali_andr@bk.ru

V. P. Kuznetsov
e-mail: kuzneczov-vp@mail.ru

S. D. Tsymbalov
e-mail: sergey.cymbalov@mail.ru

E. G. Popkova et al. (eds.), *Socio-economic Systems: Paradigms for the Future*,
Studies in Systems, Decision and Control 314,
https://doi.org/10.1007/978-3-030-56433-9_172

JEL Codes O25 · O32 · O47 · P17

1 Introduction

By methodology we mean a set of principles, methods, tools, strategies for developing systems, as well as procedures and requirements, implementation of which allows to get a result.

Based on the position that a product development system serves as a model in shaping the development strategy of machine-building production, we determine the content of the *methodology for creating product systems at industry enterprises* as the following sequence in the PDP approach or the simultaneous development of a set of processes in the CE concept [1]:

1. PD—product development *(where is the PEP product development process)*;
2. MSP—planning of corporate systems (product development systems, production systems);
3. Production.

The conducted research allowed to reveal relevant practices of the *methodology for formation of product systems by* machine-building enterprises (Fig. 1).

2 Research Results

Considering examples of the product systems formation by industry leaders. We determine that the level of the methodology are issued strategic decisions on product and production. Only then - technical and technological and operational solutions for the design of enterprise systems and manufacture [2]. Proposed solution–control and management of the product development system complexity takes into account the following:

1. Stages of the product life cycle (PLC cycle). Implemented strategies on the phases of "input" and "growth" [3, 4]: (a) Differentiation (customization), (b) Cost leadership, standardization (mass production), (c) Hybrid competitive strategy (mass customization). Implemented strategies on the phases of "maturity" and "recession" [5, 6]: (a) Priority of the system functional complexity (b) Priority of the physical complexity (c) The compromise between functional and physical complexity.

In our opinion, the PLC cycle phase affects the set of guidelines for managing product complexity. The priority value of goals with complexity of the system in each phase is reflected in Fig. 2:

2. Key management tasks:

PD life cycle	product development	enterprise systems planning	production
	product development process (PDP)		
process phases	– product planning – project specification – management requirements – conceptual design, system design – layout, technical design, design specifications – modeling, model analysis – project implementation	– conceptual planning of systems, – system engineering; – designing systems in CAD, documentary support – instrumental design of systems; – prototyping, quality control	– planning, arrangement of equipment, – performance planning, design specifications – actual commissioning – assembly, commissioning, start-up
current approaches	Spiral Design, Stage Gate Concept, Funnel Concept, Product Life Cycle Management (PLM) Model	Funnel concept, Axiomatic design concept, Prototype concept, Computer Aided Design (CAD), PDP process prototyping	Lean manufacturing, Kanban pulling system, protection against the "Bye-yoke" error, heijunk, Djidoka, Just in time (JIT); continuous improvement (Kaizen); Six Sigma project KPI, Losses (Muda); visualization (Visual Factory) and others.
fundamental principles	– innovative PD processes – project management – multi-functionality	– repeatability of PD processes – parallel system design – decomposition in process modeling	– project management – process repeatability – many processes based on product variability and frequency
methods and tools	analytical methods (marketing and patent research, key competencies, risk analysis, cost analysis), deployment of quality functions (QFD), configuration of product options (DFC concept)	simultaneous engineering integrative process, multiple choice concept (DFV), alternative mode and effect analysis (VMEA),	lean, adaptive, flexible manufacturing, product assembly design (DFA), manufacturing design (DFM), diversity reduction program (VRP)
critical success factors	– product positioning – pricing – customer satisfaction – product configuration – performance – product functionality – project team	– efficiency of machines and production processes – processes and quality of execution – core competencies – organizational alignment – project team	– project implementation – logistics – customer feedback
critical points	– functionality – product variability; – product attribute target values – form, configuration and industrial design of the product as a whole, – detailed component design	– deadlines; – project participants; – mechanism of integration interaction; – supply chain – product assembly process – product prototyping	– production plan, launch, – achievement of planned values; – market testing, – launching the product on the market – commercialization

Fig. 1 Methodology for the formation of product systems in mechanical engineering

Complexity	Phase
↑	input (market entry) - in the context of complexity management, limiting cost growth is less important than product differentiation
↓	growth — the focus of the company is shifting towards a rapidly growing market share. As a result, efforts to reduce costs (through economies of scale and the experience curve of effects) are becoming increasingly important.
↓	maturity - the desire to maximize profits and competition reinforce the need for further cost reduction. At this point, product differentiation efforts are less important than cost reduction.
↑	recession - as a rule, expenses are carefully monitored, and investments are at a minimum. When you restart the product or extend the PLC cycle, the manufacturer focuses on the functionality

Fig. 2 Summary of guidelines for managing product complexity based on the PLC cycle phase

Task 1: Determining the complexity of systems (products and processes): identification of complexity sources and factors associated with its growth; quantitative assessment of complexity in a manufacturing company due to increased product diversity.

Task 2: Identify the relationship between product complexity and processes: the problem of the relationship between the complexity of products and processes; the impact of change/creation of a new product on production processes in terms of their complexity growth (1 assumption: replacement at the module and component level in the system improves processes; 2 assumption: if it is possible to reuse part of the elements of classical systems in new projects, this determines a significant reduction in the cost of system design).

Task 3: Achieving the "optimal" level of complexity of the systems: classification/grading of products by degree of difficulty; the problem of achieving optimal operational and financial indicators due to the reduction, preservation, and increase in complexity.

In accordance with the idea put forward, a model of the methodology for the formation of the product development system of engineering enterprises based on the complexity management strategy is presented in Fig. 3.

The proposed methodology for creating a product development system for engineering enterprises based on a complexity management strategy includes:

Stage 1. Product development. Assessing the complexity of the product from the position of the system (Fig. 4).

At the considered stage, the critical indicators of complexity growth are [7, 8]:

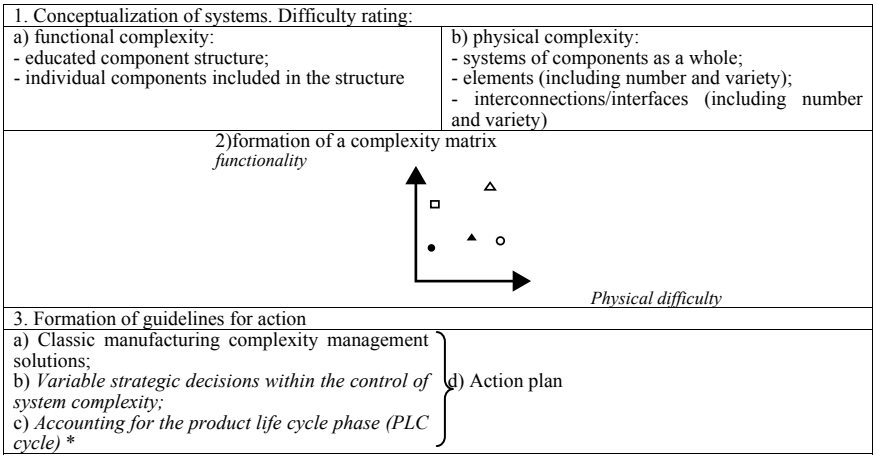

Fig. 3 PD-systems management model in the context of production product complexity control

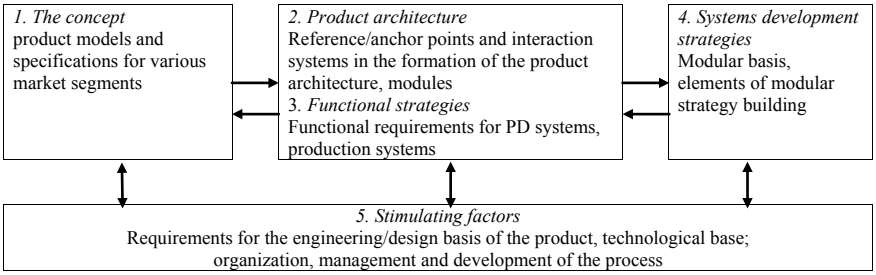

Fig. 4 Content of the product concept

– Unit cost/financial scale of the project;	– The number of alternative components, design, and design approaches;
– Volume of product release;	– The presence of feedback from later to earlier stages;
– The degree of technological novelty;	– The variety of knowledge bases used;
– The degree of IT-support systems;	– A variety of skills and technical resources;
– The number of subsystems and components;	– The intensity of consumer participation;
– The degree of customization of the components;	– Uncertainty due to changing consumer needs;
– The complexity of the choice of product and system architectures;	– – The intensity of the involvement of suppliers in the project

When assessing the complexity are calculated:

- independent components of complexity due to the growth of varieties of products ($C_{product}$), processes ($C_{process}$) and systems (C_{system}).
- dependent components of complexity: $C_{productANDprocess}$ and $C_{productANDsystem}$—complexity of the process and the system, respectively, is due to the growth of diversity at the product level, $C_{processANDproduct}$ and $C_{processANDsystem}$—the problems that arise in the production system due to the growth of process diversity, $C_{systemANDproduct}$ and $C_{systemANDprocess}$—respectively, the level of complexity of the product and the process due introduction of diversity system.

The total complexity is calculated by summing the listed difficulty levels:

$$C_{total} = \sum_{i=1}^{M}\sum_{j=1}^{N} C_{product} + \sum_{i=1}^{K}\sum_{j=1}^{L} C_{process} + \sum_{i=1}^{U}\sum_{j=1}^{V} C_{system}$$

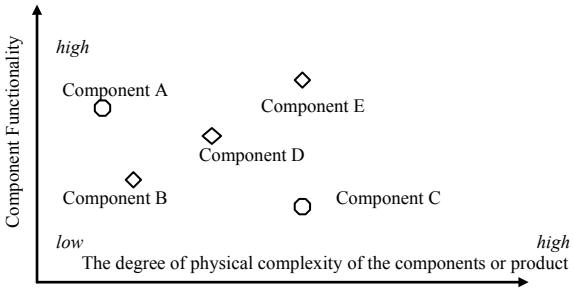

Fig. 5 Schematic representation of the complexity matrix of a product consisting of several components/ elements/ modules * From the picture: components located in the center are more balanced, i.e. their level of physical complexity roughly corresponds to their contribution to functionality

Stage 2. Formation of a complexity matrix (Fig. 5), where:

1. Functional (external) complexity—due to demand, competition and/or technological complexity;
2. Physical (internal) complexity—is determined by: the complexity of the product, determined by a wide variety of raw materials, components, etc.; the complexity of production—the need for a flexible production system; organizational complexity.

The disadvantage of the proposed approach is the impossibility of distinguishing a single functional element for two products, as well as the impossibility of dividing functional elements into two separate functions [9].

Stage 3. Formation of complexity management solutions.

Most manufacturers use classic methods to reduce product complexity, such as [10]:

– replacement of components and product standardization
– inventory management by reducing the number of options stored in stock
– standardization of production processes
– product standardization due to modulation, and standardization strategies.

Based on a complexity matrix and the goal of achieving a balanced system: guidelines for action on managing complexity at the level of production systems and engineering design of a product, in our opinion, can become (Table 1).

At the domestic production level, the strategic options for complexity management can become variable strategic solutions (Table 2):

Research hypothesis requiring further confirmation/refutation: development of product development systems [11, 12] in the context of systems complexity management is possible due to: (1) formation of strategic approaches for the development of production in the context of harmonization of "product-production" systems; (2) simulation of integrated systems and their harmonization—through the integration of production systems and product creation and through the joint development of

Table 1 Set of guidelines for actions to manage complexity of systems

	Guidelines for action	
Product Strategic Decisions	Axis of physical complexity	
	Change in the number of components	– Providing the same functionality with fewer details – Identification and replacement/elimination of individual elements/parts/components
	Changing component diversity	– Determination of the totality of components not conducive to creating customer value for a client – Standardization of individual elements/parts/components
	Fewer interfaces	– Use of several standardized interfaces – Increasing the degree of modularity of the system
	Change the variety of interfaces	– Standardization of interfaces – Increasing the degree of modularity – Input of isolated and/or multifunctional interfaces
	Functionality axis	
	Functionality change	– Adding new features, increasing attractiveness to consumers – Transfer functions between components
	Both axes	
	Combination	– Adding new functions, enhancing the functionality of the system – Shange of product architecture, change of variations in product architecture
	Separation	– Reducing the physical complexity of new components – Enhancing the modularity of the product architecture

(continued)

systems based on: (a) on the primacy of the product model; (b) on the primacy of the process model.

Table 1 (continued)

	Guidelines for action	
Strategic decisions on production, assembly	Change in production strategy	– Product setup (mass customization, customization) – Reconfiguration of the supply chain (in order to increase productivity) – Synthesis of production systems through the use of a joint platform – Joint development of production and product development systems; integration of production and product development systems
	Modifying system specifications	– Improving the technical characteristics of systems through the use of association rules – Formation of a unified product platform and production strategy for production systems
	Changing system configuration	– Multivariate design – Increasing the flexibility of systems, production processes

Table 2 Methods for improving PD systems in comparison with complexity management

Indicator	Production system, engineering design	Operational management, marketing
Strategies for complexity management	– Changing product complexity by replacing product components; changing the architecture of a product, its structure through strategies, modulation, use of platforms – Harmonization of product-production systems – Joint development of production and product development systems; integration of production and product development systems – Formation of a unified product platform and production strategy for production systems – Improvement of technical characteristics of systems	– Identification of the effectiveness of used development strategy – Change, segmentation of production processes (CTO, MTO and ETO) – Change the system configuration network systems; system standardization – The formation of highly effective multivariance of variables of the product architecture – Shange in production strategy

[a]copyright decisions in italics

3 Conclusion

The proposed methodology allows to ensure:

- gradation of difficulty to "good" and "bad", where: first determines the cost increase for both producers and consumers, with increased product diversity, and the second—an increase in the cost of production while reducing the level of diversity;
- acquisition by the manufacturer of structural and functional product diversity in the context of a compromise between a unique product/differentiated product range with relatively high production costs and a unified/standardized product with a minimum product range, but also with minimal production costs.

References

1. Garina, E.P., Kuznetsov, V.P., Garin, A.P.: Concepts of creating a high-tech product. Allowed UMO on education in the field of production management as a training tool for students of higher educational institutions. p. 229. Minin University, Nizhny Novgorod (2015)
2. Garina, E.P., Andryashina, N.S.: Integrated product development in the context of its parallel design and production. Econ. Ind. **10**(2), 98–106 (2017)
3. Andryashina, N.S.: Analysis of the best development practices of domestic engineering enterprises. Bull. Saratov State Socio-Econ. Univ. **1**(50), 24–27 (2014)
4. Vdovin, S.M., Guskova, N.D., Neretina, E.A.: Conceptual approaches to sustainable development of socio-economic systems. Regionology **3**(76), 32–39 (2011)
5. Shipshova, O.A. et al.: The innovative component of the formation of competitive advantages in production systems in a changing technological environment: monograph, pp. 142. Moscow (2017)
6. Parshina, A.A., Levchuk, V.V., et al.: The study of modern approaches to development of economic systems through managing their complexity. In: The Future of the Global Financial System: Downfall or Harmony. ISC 2018. Lecture Notes in Networks and Systems, vol. 57, pp. 726–733 (2019)
7. Tolstykh, T.O., Shkarupeta, E.V., et al.: Algorithm for assessing the efficiency of innovational technologies of industrial enterprises. In: Emergence Changes and Future Perspectives. Lecture Notes in Networks and Systems, vol. 73, pp. 463–471 (2020)
8. Romanovskaya, E.V., Kuznetsov, V.P., Andryashina, N.S. et al.: Development of the system of operational and production planning in the conditions of complex industrial production. In: Popkova, E., Sergi, B. (eds.) Digital Economy: Complexity and Variety versus. Rationality. ISC 2019. Lecture Notes in Networks and Systems, vol. 87, Springer, Cham (2020)
9. Shushkin, M.A., Aleksandrovsky, S.V., Fomenkov, D.A.: Research of implementation practices in catching up strategy of innovative development by companies: monograph. National Research University Higher School of Economics, p. 187. Nizhny Novgorod (2016)
10. Kuznetsov, V.P. et al.: Product development systems in industry and their development: monograph. N. Novgorod: NGPU named after K. Minin, pp. 176. (2014)
11. Revunov, S.E., Kuznetsov, S.I., Barkhatova, O.M., Revunova, E.A.: The problem of connection of observer's mind with quantum-mechanical description of physical reality. Vestn. Minin Univ. **7**(3), 14 (2019)
12. Smirnova, ZhV, Krasikova, O.G.: Modern tools and techniques of learning achievement evaluation. Vestnik Minin Univ. **6**(3), 9 (2018). https://doi.org/10.26795/2307-1281-2018-6-3-9