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Article

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MANAGING THE STABLE DEVELOPMENT OF MANUFACTURING SYSTEMS UNDER DECENTRALIZATION

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Type of manuscript: Research paper.

Abstract: *This article provides an overview of the arguments and counterarguments involved in identifying the state of an enterprise, assessing its functional efficiency, and optimizing its target functions while implementing management tasks. The decentralization of enterprises empowers them to adapt to specific territorial needs. However, it also introduces an element of instability that can be disconcerting. The primary objective of this research is to develop a scientific and methodological approach to modelling the management system of the development of manufacturing enterprises under decentralization. The systematization of literary sources and approaches to the problem of managing the development of manufacturing enterprises reveals that each level of analysis of the state of the enterprise and assessment of its development dynamics and problem situation corresponds to the aggregate set of assessments, which includes both individual indicators and their various groups. At its core lies the crucial recognition of production systems' (PS) state as a pivotal parameter influencing the very fabric of UTC development. The model employs a powerful vector functional approach, allowing for a multi-dimensional assessment of an enterprise's state. The model translates into a tangible metric, empowering informed decision-making and targeted interventions. The relevance of this scientific problem is that the management process of enterprise development under decentralization needs to be more structured and less accidental. There is a need to manage this process to survive and develop in an aggressive market environment. Optimal management of production systems as discrete matrix objects provides an opportunity to consider the functioning of each of them depending on the state of the others at time t of their production to time t+1, which is associated with their further development in a decentralized environment. The results of the research can be helpful for the development of systems for monitoring and strategic management of the development processes of manufacturing enterprises under decentralization.*
Keywords: enterprise; company; functioning; production system; state; united territorial communities.

1. Introduction. International practice uses various management models (systems) at the local level within the corresponding administrative and territorial units. The choice of management model (system) is influenced by various factors: the government, the state and political system, the level of development of production systems, and economic and social development (Durmanov et al., 2019; Lankoski, 2016).

The effective social and economic development of territorial communities heavily relies on administrative and territorial reform, decentralization, and the formation and growth of manufacturing enterprises within the United Territorial Community (UTC). The synergy between manufacturing enterprises and their base territories and the identification of critical areas for development are crucial factors to consider from a practical standpoint (Lozano, 2015; Olszewska & Piwoni-Krzeszowska, 2014).

Managing the stable development of an enterprise as a production system under decentralization is a weakly structured process due to specific characteristics that define it, as observed by (Boadway & Dougherty, 2019; Chen & Groenewold, 2013). These characteristics are as follows: the external environment of UTC, where the enterprise exists, is highly dynamic and subject to frequent changes, as studied by (Baskaran et al., 2016; de Villiers et al., 2016); the process of globalization of the world economy has a significant impact on an individual enterprise; the development of production systems is influenced by both external (exogenous) and internal (endogenous) factors; the link between complex socioeconomic systems within the state and integration into the unified world economy, as studied (Aslim & Neyapti, 2017; Moore & Manring, 2009), has increased influence. Under current market conditions, ensuring economic stability is a critical condition for a company's functioning and is connected with the final results of production and business activities. The steady development of the enterprise's economy ensures economic stability at the macro level. For this purpose, it is essential to investigate the essence of the enterprise's economic stability, study the factors of its maintenance, and, on their basis, select the priority directions of its achievement.

For the above reasons, on the one hand, the development of enterprises is becoming increasingly weakly structured and random. On the other hand, there is a need to manage this process to ensure stable development in an aggressive market environment. Additionally, in today's realities, an essential condition for the functioning of an enterprise is to ensure economic stability through the production and business activities of territories (administrative and territorial units, United Territorial Communities). Moreover, the enterprise's steel development ensures economic stability at the micro and macro levels. For this purpose, it is essential to investigate the essence of the enterprise's economic stability, identify the factors of its security, and select the priority areas for its achievement.

2. Literature Review. Numerous scientists delve into the complexities of managing enterprise development and maintaining stability. The practice of deliberately modifying the parameters, structure, and properties of a system in response to changes in the internal and external environment of an enterprise is referred to as the adaptive approach to enterprise development management (Tulder & Mil, 2022). Nelson (1982) introduced the evolutionary approach to development management, which highlights the necessity of new and improved management models to address irreversible and inevitable evolutionary processes worldwide. The innovative approach involves managing industrial enterprise development by stimulating innovative activity scrutinizing and implementing innovative advancements in all aspects of the organization's economic activity (Hamrol, 2018). Leone et al. (2018) showed that an integrated approach to enterprise development management is based on the simultaneous development of many management aspects— technical, environmental, economic, organizational, and psychological aspects—in their interconnection. The definition of *economic stability* of a company as a production system is a comprehensive characteristic of the company for a certain period and indicates the ability to maintain the critical financial, marketing, production, and personnel indicators at the normatively set, with a high degree of probability, level under the influence of the external and internal environment (Taurino, 2018). When implementing the marketing approach to the management of a company's development, more attention needs to be given to the internal aspects of the organization's development. For example, production and personnel needs should be addressed, and changes in the external environment and new challenges in globalized markets should be considered (Fiksel, 2012). Managing a developing industrial enterprise involves a process approach consisting of sequential, continuous, and interdependent actions aimed at achieving the enterprise's goals. According to (Crofton, 2000), one can understand this system approach by examining the object as a whole, where each economic phenomenon is evaluated concerning others. All the elements and processes within an object are interconnected, considering internal and external factors.

To properly analyse an enterprise's state and development dynamics, it is necessary to form a system of situation-oriented indicators and generalize vector-scalar information (Dirks et al., 2009). Each level of analysis and corresponding problem situation requires an aggregated set of assessments that includes various

individual indicators and groups. The general concept of sustainability and sustainable development is essential in studying systems that dynamically evolve: enterprises. From the enterprise's point of view, stability can be seen as the ability of the system to maintain its operating state to achieve the planned results in the presence of various external and internal influences (Navickas & Malakauskaite, 2009). Some fundamental indicators for identifying the state of an enterprise are used to assess its efficiency and optimize its target functions when solving the tasks of managing its development (Van't Wout et al., 2021; Judgment of the Constitutional Court of Ukraine of 13.07.2001 № 11-Rp/2001, n.d.; Onyemelukwe, 2005). To implement the management, the input vector $V = (V_1, V_2, …, V_n)$—which the company possesses during the time t—is based on the current state of the company and retrospective analysis of its activities:

$$V(t) = V_f(t) + V_p(t), \tag{1}$$
where $V_f(t)$ is the functional resource and $V_p(t)$ is the management resource (development).

The task of forming a management system $V(t)$ and ensuring the stable development of an enterprise under decentralization is to determine the orderly state of the enterprise, the vector $X(t) = (x_1(t), x_2(t) \text{ estimate}, …, x_r(t))$ and its change in the performance of functional properties.

3. Methodology and research methods. The development of a scientific and methodological approach to modelling the management of stable dynamic development of production systems under decentralization conditions is the article's objective. The enterprise functions in a particular external environment, so studying stability is impossible in isolation from macroeconomic processes. The enterprise also develops under the influence of the microeconomic environment, reflecting the interests of the production and economic activity subjects. The highest form of sustainability of the economic system (enterprise) is its ability to evolve in a small economic environment (internal and external). It is the dialectic of the study of sustainability. The study of sustainability is dialectical because it reflects both the unity and the intersection of the economic interests of the enterprise and the economy as a whole (Decentralization in Ukraine, n.d.; Freidson & Rist, 2020).

During the development of an enterprise, changes in its elements and structure, including its integrative properties (represented as vectors $Y(t)$), determine its output characteristics. The following generalized mathematical model can be used to manage the dynamic development of a company:

$$\frac{\mathrm{d}X}{\mathrm{d}t} = f(t, x, v, y), \tag{2}$$
where (it) is an n-dimensional phase vector; (it) is a vector for managing the dynamic development of the enterprise; and $y(t)$ is a vector of initial indicators of the functioning enterprise.

Efficient enterprise management requires optimal resource utilization at every production stage, including labour, energy, and information, to achieve the primary objective while adhering to relevant constraints. This type of management task is crucial for achieving optimal productivity and profitability. The conditional optimization of production system management can be expressed by the following formula (Tulder & Mil, 2022):

$$X^o = \arg \text{extr} a\ P(x), \tag{3}$$
where $P(x)$ is a correlation function.

Constraints in the form of nerves are applied to the PS content analysis to establish a set of permissible solutions $X(t)$:

$$h_i\ (x, q_i) \leq 0;\ \ i = \overline{1, \text{n}}, \tag{4}$$

and the equality

$$g_j\ (x, q_j) = 0;\ \ j = \overline{1, \text{r}}, \tag{5}$$
where $X(t)$ is the controlled variable of the PS state space; h_i and g_j are the operators that define the structure of the mathematical model of the corresponding limit; and q_i and q_j are the tuples of the quantized parameters of the corresponding limits.

United territorial communities (UTCs) have a broad spectrum of responsibilities. These include facilitating community development, addressing economic concerns, attracting investments, managing budgets and land resources, issuing construction permits, developing local infrastructure, providing housing and communal services, maintaining streets and roads, managing passenger transportation, and ensuring public safety through municipal police and fire protection. Therefore, administrative and territorial reform, along with decentralization, are critical factors in promoting the social and economic growth of UTCs, which, in turn, affects the establishment and advancement of manufacturing enterprises within these communities.

A viable solution for enhancing the growth potential of communities with limited financial resources and demographic information is to link them with other neighbouring communities, resulting in the formation of larger and more numerous UTCs. Even without immediate economic prospects, this arrangement can yield benefits such as optimizing the local, territorial structure, improving the efficiency of territorial management, boosting investment appeal, and elevating returns on capital investments within the area (Bekabil, 2021).

Monofunctional dependence on a single enterprise can harm a community's economy, while a diversified economy has a greater chance of stable development. The community benefits from the presence of extensive enterprises, especially transnational companies, which contribute to the growth of small and medium-sized businesses that offer them services such as supply, packaging, decoration, design, sales, logistics, transport, catering, advertising, trading, support, and security (Kravchenko et al., 2021). A higher number of profitable enterprises with high labour productivity and added value operating within the community leads to an increased quality of life for its citizens. Defining a metric that compares the quality of solutions with the correlation function's correlation is crucial in optimizing the production system's performance under decentralization. Assessing the state of an enterprise involves a comprehensive evaluation of its financial and economic activities, production, innovation, investments, social functioning, and environmental impact. This comprehensive approach allows for a clear identification of the enterprise's overall state. Achieving strategic goals through the development of a production system is deemed satisfactory when the integrative power of the system changes the direction of improvement, either quantitatively or qualitatively, due to its impact. To optimize development management, it is essential to introduce efficiency indicators as criteria. These indicators should be presented as a maximum function, as suggested by (Kallrath, 2012):

$$J(y) = \int_0^T F(x, y)et, \tag{6}$$

where $x(t)$ and $y(t)$ are the keyed and output changes in the state of the production system.

The function $y(t)$ is restricted:

$$0 \leq y \leq x. \tag{7}$$

An automated management system (AMS) is necessary to provide information support for completing PS development management tasks. However, they are focused on supporting the functioning of the enterprise rather than on the management of development processes. Therefore, the prerequisite for creating a development management subsystem was the composition of the enterprise's automated management system (AMS), the system of development strategizing.

Each set of processes requires a management system that goes through four stages: control, diagnostics, predicting future conditions, and creating actions to control the outcome. The diagram in Fig. 1 shows the relationships between these stages.

The topical theme of the study of management efficiency at present is the evaluation of the performance of the united territorial community, where some enterprises are located within its territory. Among these, there are local employers according to the following indicators: per capita, the community budget's resources, the community's ability to sustain itself economically, the expenses incurred by the community for managing personnel, and the capital expenditures per capita.
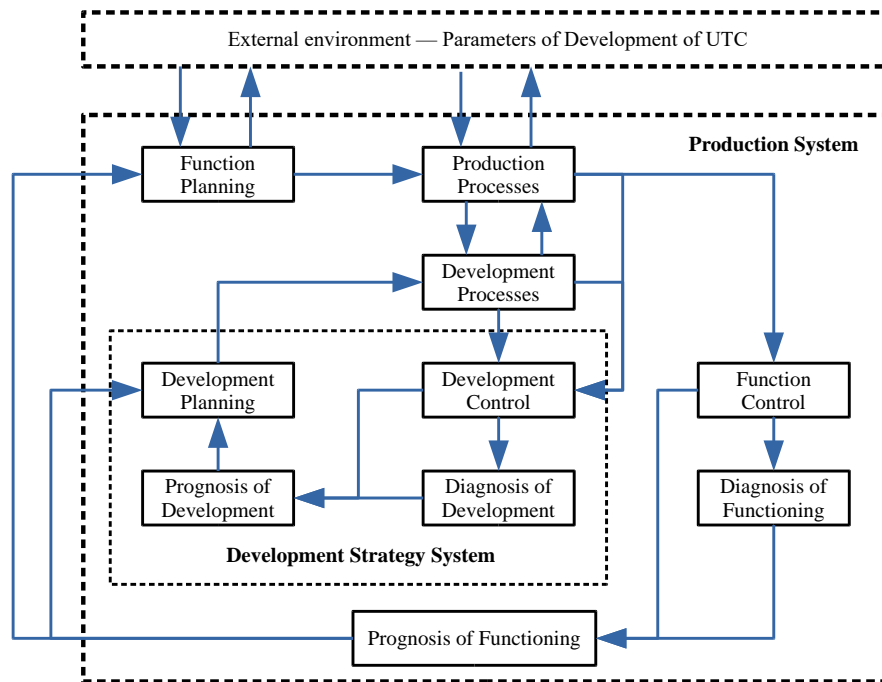
Figure 1. Relationship between the sustainable development and functioning of production systems
Sources: developed by the authors.

Therefore, representing the UTC as an external environment, the model of the enterprise that develops can be represented as the following structural scheme (Fig. 2):
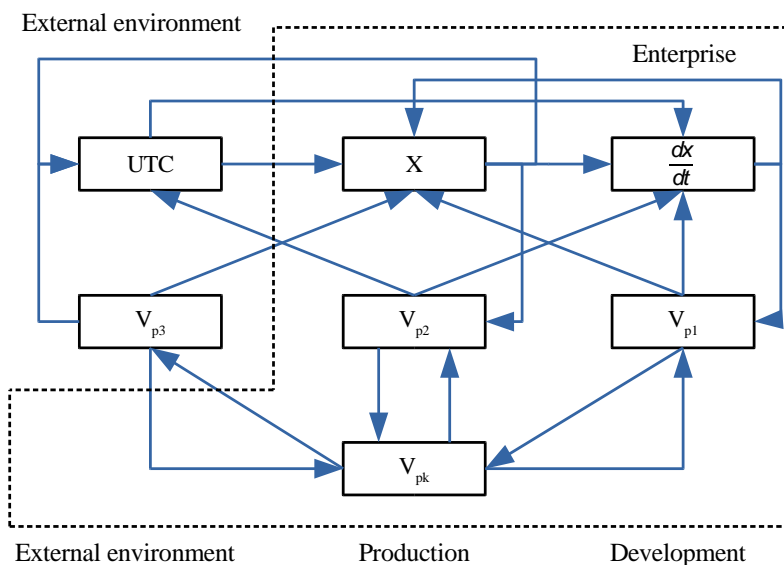
Figure 2. Structural scheme of the management system for the sustainable development of enterprises under decentralization conditions
Sources: developed by the authors.

UTC refers to a territorial community that is united; X represents the vector function of an enterprise's production and technological process; PS operation is denoted by dx/dt; V_{p1} is a system for managing development; V_{p2} is a system for managing production; V_{p3} is a system for managing interaction with UTC; and V_{pk} is a matching system that facilitates interaction between UTC and x(t) dx/dt.

The system of management of stable development of enterprises under decentralization conditions is represented by a high-level management system (V_{pk}), which ensures synergy and interaction with the UTS; a system of production management (V_{p2}); and a system of development management (V_{p1}). The upper-level management system performs management functions and coordinates the lower-level elements. Each of the

lower-level elements has some autonomy in organizing their activities. In this case, the higher-level control system (V_{pk}) manages operational stability and coordinates the system's work.

The following stages can represent the process of coordination and optimization:

• Analysis of the stability of the financial, production, and organizational system (enterprise) Deciding on the necessity of coordinating and optimizing all enterprise activities.

• Coordination and optimization of production, financial, and business activities in the planning period. The indicators of the financial situation are calculated, the system's stability is analysed, and the active elements are determined according to the results of coordination and optimization.

• Comparison of the planned and actual values of the indicators of the state. Depressed conditions should be localized, and decisions about the coordination and optimization of the production program of the enterprise, production, and technological processes should be made.

• The designation of "productive premises." Coordination and optimization of reverse manufacturing and technological processes.

• Development of coordination mechanisms, elements, and information technologies.

The high-level control system (V_{pk}), which ensures coordination and interaction with the UTC, coordinates the local tasks of the control subsystems to ensure that the global task of the system as a whole is fulfilled. Management systems are interconnected. To determine the coordinating influences, the higher-level control system first transforms the global task of the system from the initial state space into the coordination space; for this purpose, the local tasks of the control subsystems are combined, and then the global problem of the whole system in the coordinate space is solved. Finally, changes in the state vector are considered, links with the external environment occur, and the higher-level control system performs the functions of operational stability control and coordinates local control actions (Rodchenko et al., 2019).

The state $q(t)$ of the UTC is reconstructed by utilizing the vector V_{p1} for initiative control. The activities of the PS are transformed from resources to the final product, with resources and products being defined as finances, material goods, and the intellectual and professional abilities of the PS employees.

PS activity includes various processes to obtain a final product or result. For example, it covers all production functions—planning, development, design, material, technical support, product manufacturing technology, verification, quality assurance, and implementation. The primary activity process and the corresponding technological processes are used in this case. Different types of enterprises located within the territory of the UTC have technologies for the activation process.

In addition to fundamental business activities, enterprises also implement processes of management, communication, and production organization and ensure interaction with the external environment (UTC). Enterprises use the following in their activities:

− Basic processes - $\{P_{1i}\}$;

− Personnel technologies for quality and quantity changes - $\{P_{2i}\}$;

− Organizational technologies such as management, communication, decision-making, and implementation - $\{P_{3i}\}$;

− Interaction with the external environment - $\{P_{4i}\}$;

− Information technology - $\{P_{5i}\}$.

To ensure sustainable development, improved efficiency, and competitiveness, enterprises can achieve this through innovation, products, and technology. Using models that consider state dynamics for analysing the functioning of production systems opens up vast possibilities for the formalized description of such systems and the application of stability criteria. Considering the relative ease of implementing these criteria, the stability of the functioning of production systems will be determined dynamically.

Investigating the stability of the work of an enterprise requires an assessment of dynamic processes under changes in the external and internal parameters of the environment. Therefore, it is of interest to answer the questions of what the area of stability of the monitored indicators is, what actions of risk factors are associated with a loss of stability, how the change in economic indicators of the production system affects the economic environment, and what the indicators of UTC are as a whole. To obtain a complete picture of the impairment of sustainability, a series of experiments revealing the risk factors and the specifics of the economic indicators of the enterprise are carried out. During their implementation, it is possible to visually assess the trajectory of changes in the indicator (or their groups) and set standard or threshold (minimum, maximum) values to calculate the level of stability of the controlled indicators.

If the indicator crosses the threshold level and leaves the permissible range of values, it indicates instability and requires diagnostic of the company's activity. In this situation, the company will fall under the influence

of risk factors, and its adaptive capacity may be inadequate to resist them. For this reason, the diagnostics of the enterprise are carried out in close connection with the assessment and analysis of the stability of the enterprise and the analysis of indicators of the development of UTC.

Let us assume that the UTC consists of n enterprises. The economic condition of each enterprise is characterized by an m-mirror vector: $x_i = (x_{i1}, x_{i2}, \ldots, x_{im})$, $i = \overline{1,n}$ variables that determine the functioning of the i-th enterprise.

It is assumed that any minor incidental effects on the PS can be avoided. All UTC enterprises possess comprehensive knowledge of macroeconomic parameters. Consequently, it is necessary to consider the connections between different enterprises.

As a result, a system exists that links the time and the rate of change in economic indicators (Shin & Xu, 2017):

$$\frac{dx_{ij}}{dt} = qf_{ij}(x_i, y), \tag{8}$$

where $y = (y_1, y_2, \ldots, y_d)$ is the output change in PS and q is the speed at which microeconomic changes are established.

Changes in macroeconomic variables are the main factors that determine an enterprise as a dynamic system. It is essential for UTC, which is home to a city-forming company, to know the conditions for sustainable development management to increase its efficient production. To this end, we will consider the enterprise as a PS with changes that characterize its functional activity. The changes that affect the PS or are related to it can be divided into three groups:

1. Input changes $v_1, v_2, \ldots, v_m$, which characterize the external influences on the system's inputs;

2. The state changes $x_1, x_2, \ldots, x_n$ are the internal changes, the sum of which fully characterize the system properties;

3. Output changes $y_1, y_2, \ldots, y_r$, representing those reactions to external influences and those system properties related to the system efficiency indicators.

All sorts of assets utilized by the system, capital, advancements, implementation of cutting-edge technologies, and modernization of fundamental production methods may serve as inputs $v_1, v_2, \ldots, v_m$. Fixed assets can depreciate, contributing to the changing state of x_i A company's profitability, efficiency of using fixed assets, production capacity, and implementation are also factors that can affect the changing state of x_i. Included in the output variables y_i are PS financial coefficients, which comprise product profitability, turnover, return on assets, market stability and competitiveness indicators. Additionally, social, budgetary, and environmental efficiency indicators are also among the output variables.

A "black screen" with m inputs and r outputs can depict the PS in the UTC structure. Additionally, each input and output have a corresponding alteration. Let us examine a collection of inputs as a single generalized input, which is affected by a vector $v(v_1, v_2, \ldots, v_m)$. Similarly, we can describe a collection of outputs as a generalized output, with the output vector represented by $y(y_1, y_2, \ldots, y_r)$. Changes in the system's state are connected to the internal characteristics of the system, represented by the vector $x(x_1, x_2, \ldots, x_n)$, and their changes in the production process are indicated by dx/dt. Matrix equations that describe the system's operation must be produced, assuming that the power supply state remains continuous at all time intervals t:

$$\frac{dx(t)}{dt} = F[x(t)]; \quad y(t) = U[x(t), v(t)]. \tag{9}$$

The equation of the PS state is represented by the initial expression (8), and the vector of PS development is obtained when the solution satisfies the conditions of $x_0 = x(t_0)$:

$$x(t) = \psi[x(t_0), v(t)] \tag{10}$$

The output equation is determined by another equation that considers the changes in output based on $x(t)$ and $v(t)$. Equation (8) takes the form shown below under additive production system conditions during UTC development:

$$\frac{dx(t)}{dt} = A(t)x(t) + B(t)v(t); \quad Y(t) = C(t)x(t) + D(t)v(t), \tag{11}$$

where $A(t)$ is the matrix of the system (square of the n-th order); $B(t)$ is the matrix of the size control $(n \times m)$; $C(t)$ is the matrix of the size output $(r \times n)$; and $D(t)$ is the matrix of the size input $(r \times m)$.

The components of matrices A, B, C, and D for fixed production systems are represented by constant numbers that depend on the parameters of the components. A is the primary matrix that defines the production process. B is the connecting matrix that determines how the system input is linked to the different variables in the production process. C is the matrix that connects the variable components of the production system with the output variable vector functions $Y(t)$. D is the matrix that indirectly links the input vector $v(t)$ with the output vector $Y(t)$. The composition of this matrix shows how the input-constraining functions, such as increased indicators of innovative development of the system, affect different outputs $Y(t)$, such as the profitability of produced goods. Matrix $D(t)$ represents the system parameters during transient crises. Therefore, the essential characteristics for constructing deterministic models that study the stability of economic systems are vigilance and attentiveness (Fig. 3).
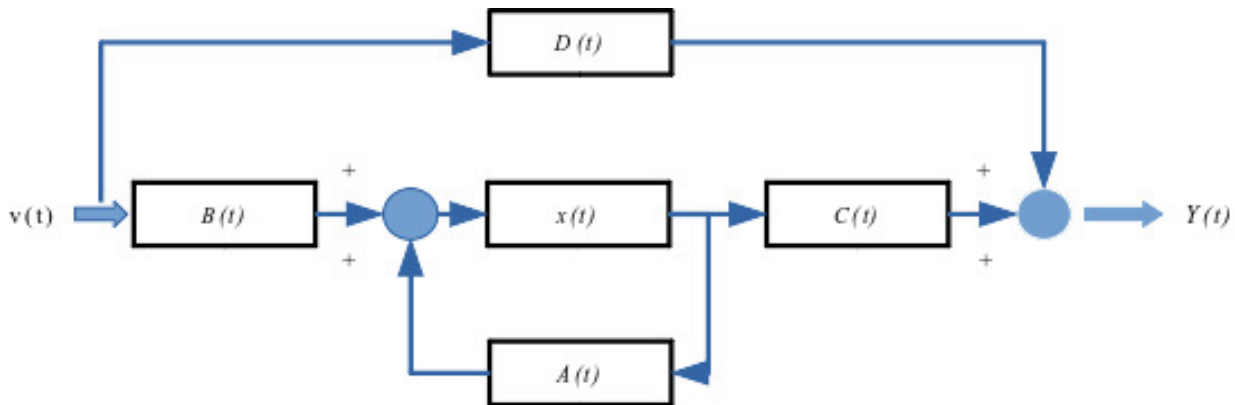
Figure 3. Functional scheme of the production system
Sources: developed by the authors.

PSs with nonlinear dependencies between the input and output variables have complex structures. The equation of state for such PSs can be expressed as (11):

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = Ax(t) + Bv(t) + Fz(t); \quad f[x(t), z(t), v(t)] = 0, \tag{12}$$

where A, B, and F are constant matrices; $f(x, z, v) = 0$ is a nonlinear algebraic equation; and its solution concerning the vector $z(t)$ excludes this vector from the differential equation.

The state equation $x(t) = Ax + Bv$ represents a system of differential equations with constant coefficients in standard form and describes the PS. The solution of this equation satisfies the initial conditions $x_0 = x(0)$ for the state vector $x(t)$ and the output vector $Y(t)$ and is presented as follows (Usov et al., 2020):

$$x(t) = \phi(t)x(0) + \int_0^t \phi(t-r)Bv(r)\mathrm{d}\tau \ ;$$
$$Y(t) = C\phi(t)x(0) + \int_0^t C\phi(t-\tau)Bv(\tau)\mathrm{d}\tau + Dv(t) \tag{13}$$

The first addition in (12) corresponds to the reaction of PS, which depends on the initial conditions (production functions in the standard model), and other additions, reactions to external influences (e.g., the implementation of investments in the principal capital and the number of advanced technologies in use).

The transition matrix of the PS state, denoted as $\phi(t) = e^{At} = \exp At$, is known as the fundamental matrix. It outlines the state of the enterprise $x(0)$ at a given moment t (when no inputs are applied), i.e., $x(t) = \phi(t)x(0)$.

At the onset of the PS, when the input vector $v(t)$ and the output vector $Y(t)$ and $D = 0$ are unconnected and $x(0) = 0$, the relationship between the input and output responses is described by the following ratio:

$$Y(t) = \int_0^t C\phi(t-\tau)Bv(\tau)\mathrm{d}\tau = \int_0^t g(t-\tau)v(\tau)\mathrm{d}\tau. \tag{14}$$

The matrix $g(t) = C\phi(t)B$ represents a broad characteristic of the PS as it relates to both its inputs and outputs. A reaction to the enterprise's i-th output can be expressed as follows:

$$y_i(t) = \int_0^t [g_{i1}(t-\tau)v_1(\tau) + g_{i2}(t-\tau)v_2(\tau) + \cdots + g_{1m}(t-\tau)v_m(\tau)]\mathrm{d}\tau, \tag{15}$$

where $g_{ij}(t)$ are ij-elements of the $g(t)$ matrix, which describes the influence of the corresponding input parameter and equals the reaction $y_{ij}(t)$ on the i-input relative to the j-input under the condition that all other inputs are zero, i.e.,

$$y_{ij}(t) = \int_0^t g_{ij}(t-\tau)v_j(\tau)\mathrm{d}\tau\,; \quad i = \overline{1,r}; \quad j = \overline{1,m} \tag{16}$$

According to (Usov et al., 2020), the fitting of functions $g(t) \times v(t)$ is the right part of equation (15). There are four different ways to express $y_{ij}(t)$, considering the scalar functions $y_{ij}(t) - y(t)$ and $v_j(t) - v(t)$ reduction while considering the properties of the function set (Usov et al., 2020).

$$y(t) = g(t) * v(t) = \int_0^t g(t-\tau)v(\tau)\mathrm{d}\tau = \int_0^t g(\tau)v(t-\tau)\mathrm{d}\tau = \int_0^t h(t-\tau)v'(\tau)\mathrm{d}\tau = \int_0^t h(\tau)v'(t-\tau)\mathrm{d}\tau, \tag{17}$$

where $h(t)$ is a function similar to that of $g(t)$ according to the following argument:

$$g(t) = \frac{dh(t)}{dt}; \quad g(t-\tau) = \frac{d}{d(t-\tau)}h(t-\tau) \tag{18}$$

The impulse and transient PS characteristics are represented by scalar functions $g(t)$ and $h(t)$, respectively. The economic significance of these functions can be explained as follows: $g(t)$ represents the innovation component in the short term. In contrast, $h(t)$ represents the reaction of the state and its output characteristics during the short-term use of the innovation component.

The $v_p(t)$ for resource development was received at the PS input when τ occurred. The reaction at the output will be presented as follows, based on the power of the average value:

$$Y(t) = \int_0^t g(t-\tau)v_p(\tau)\mathrm{d}\tau = g(t-\theta)\int_0^t v_p(\tau)\mathrm{d}\tau = g(t-\theta) * Su, \tag{19}$$

where $0 < \theta < t$ and Su is the value of $v_p(t)$, the resource of development.

Therefore, $g(t-\tau)$ can be viewed as the PS reaction to the stock $v_p(t) = \delta(t-\tau)$ function applied to the input at the moment τ. If the D-matrix of the connection between the PS input vector $v(t)$ and the output vector $Y(t)$ is not equal to zero, i.e., $D \neq 0$, then the characteristic $g(t-\tau)$ is $v_p(t)$ and is defined by the expression

$$g(t) = Ce^{At}B + D\delta(t); \quad h(t) = C(e^{At} - E)A^{-1}B + D$$

where $\delta(t)$ is the function of short-term income on the input of PS component $v_p(t)$ of the enterprise development management resource and $h(t)$ is the reaction to the initial moment $t = 0$ function $\delta(t)$.

With this model, we can assess how UTC impulses contribute to the development of PS by analysing the performance of companies and their impact on UTC indicators, all in a single assessment. The criteria for compromise can be applied to the UTC structure depending on the development goals of the company. To ensure the highest output indicators, meeting the specified targets during each development period is crucial, especially in the early stages of system development. The selection and order of criteria depend on the nature of the enterprise's development and operation, as well as the structure of its economic and mathematical models. The primary constraints that govern the development and operation of an enterprise fall into three main categories:

  – Resource constraints (including resources and development funds) and production capacity constraints;
  – Balance constraints that establish the connections between individual components and subsystems;
  – Constraints on the technical and economic parameters that represent different aspects of the system's development and operation.

Assessing sustainability is a crucial step in the PS development process. To model the sustainability of a company, it is essential to consider its production and financial status. This status must ensure the volume of production and product realization, covering all production and business costs and maintaining the financial stability of the enterprise. The enterprise's financial stability should be primarily maintained through its funds. However, the basis for achieving and enhancing the stability of enterprise development under conditions of a dynamically dynamic internal and external environment is constant investment in the development of

production, which can be carried out not only at the expense of resources. By attempting to attract and deposit financial resources, a company must strive to maintain its stability through rational, innovative planning within the Uttawa University (UTC) framework, which must be carried out considering the enterprise's short- and long-term investment needs (Rodchenko et al., 2019).

Managing the sustainable development of economic objects is a complex and diverse problem. The stability analysis theoretical framework developed by Lyapunov is only partially applicable to organizational and technical systems, including PS, because an enterprise's sustainable development comprises functioning and development efficiency components. Moreover, a particular link exists between the analysis of leadership-focused enterprise development modelling results and the stability of this process. Hence, the linear system equation that describes the state of the PS serves this purpose:

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = Ax(t) + Bv(t); \quad y(t) = Cx(t) + Dv(t)$$

We use the Laplace transformation (Shin & Xu, 2017). In the operator form, the PS state looks like this:

$$PX(p) - X(0) = AX(p) + BV(p); \quad Y(p) = CX(p) + DV(p) \tag{20}$$

Therefore, we obtain the solution for the state vector X(p) and the output vector $Y(p)$ in the following equations:

$$X(p) = (PE - A)^{-1}[X(0) + BV(p)];$$
$$Y(p) = C(PE - A)^{-1}X(0) + [C(PE - A)^{-1}B + D]V(p). \tag{21}$$

Here, the matrix $\phi(p) = (PE - A)^{-1}$ represents the transition matrix of the $\phi(t)$ state. It is possible to calculate the transition matrix PS $\phi(t) = \exp(At)$ by converting matrix $F(p) = PE - A$ and reversing the transition from $(PE - A)^{-1}$ to its original form.

When the PS state is initially at $x(0) = 0$, the output vector is in the following format:

$$Y(p) = [C\phi(p)B + D]V(p) = F(p)V(p). \tag{22}$$

The matrix $F(p) = C\phi(p)B + D$ is called the transfer function. The economic sense of this matrix lies in the fact that it forms a link between transforming resources into goods and the output change—the profit from the sale of finished products.

The representation of the i-th output variable is stored:

$$Y_i(p) = \sum_{j=0}^{m} F_{ij}(p)V_j(p) \tag{23}$$

Scalar transfer functions from the i-th input to the j-th output can be observed in the elements $F_{ij}(p)$ of the transfer matrix $F(p)$. If one knows $F_{ij}(p)$, then they have access to this information:

$$F_{ij}(p) = \frac{Y_i(p)}{V_j(p)}. \tag{24}$$

Establishing a connection between investment costs and the transition characteristics of resource management $v_p(t)$ and the output vector $Y(t)$ allows us to estimate the impact of each production system on the development indicators of UTC. The impact can be measured through changes in production profitability, fixed assets value, and the profitability of PS.

Thus, the transfer function $F_{ij}(p)$ represents $g_{ij}(t)$, and the representation of the transient characteristic is $h_{ij}(t) = \frac{F_{ij}(p)}{p}$. To obtain $g_{ij}(t)$ and $h_{ij}(t)$, the Laplace transform is sufficient for passing through the image to the original image. Having determined these characteristics for all pairs, "PS input - PS output", it is possible to write matrices $g(t)$ and $h(t)$.

To control the PS, any changes in the values of $x(t)$ must depend solely on the input influences of $v(t) = (v_1(t), v_2(t), \dots, v_v(t))$. If the changes in $x_i(t)$ are related to at least one $y_j(t)$ output, then the PS is spoofed.

The total PS stability means that the response of the $y(t)$ outputs during a given time interval, $0 \leq t \leq T$, can determine the initial state of the system's $x(0)$ given the effect of $v(t)$.

4. Results. The adequacy of the management system model for the development of manufacturing enterprises under decentralization was tested on the application of the stevedore virtual enterprise located within the territory of UTC in the same customs area as the port. The components of vector $X(x_1, x_2)$ - the state of the enterprise:

$$X = \begin{pmatrix} x_1(t) \\ x_2(t) \end{pmatrix}, \tag{25}$$

where x_1 is the return on assets and x_2 is the profitability of assets. The components of matrix A determine the nature of production:

$$A = \begin{pmatrix} a_{11} a_{12} \\ a_{21} a_{22} \end{pmatrix}, \tag{26}$$

where a_{11} is the coefficient of autonomy; a_{12} is the cost of the production enterprise per 1 UAH in the processing of vantage; a_{21} is the coefficient of wear and tear of the main assets (cargo-driven, reloading, and transporting mechanisms); and a_{22} is the share of employees with high qualifications who take part in cargo processing. The components of matrix B are the links between the inputs in the PS and various changes in the production system:

$$B = \begin{pmatrix} b_{11} b_{12} \\ b_{21} b_{22} \end{pmatrix}, \tag{27}$$

where b_{11} is the increase in capital investments; b_{12} is the renewal of fixed assets; b_{21} is the part of the cost of research and development work; and b_{22} is the part of the advanced technologies used in processing goods.

The components of matrix C are the links between the variable PSs and the output variable vector functions $Y(t) = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}$. The structure of this matrix allows influencing different outputs of $Y(t)$:

$$C = \begin{pmatrix} c_{11} c_{12} \\ c_{21} c_{22} \end{pmatrix}, \tag{28}$$

where c_{11} is the increase in production volume; c_{12} is the increase in tax revenues to the UTC budget; c_{21} is the employment rate is the number of employees of the company who are in UTC; and c_{22} is the increase in own revenues per 1 employee in cash units. The components of matrix D are the links between the vector of PS input $V(t) = \begin{pmatrix} v_1 \\ v_2 \end{pmatrix}$ and the vector of output $Y(t)$; budgetary efficiency:

$$D = \begin{pmatrix} d_{11} d_{12} \\ d_{21} d_{22} \end{pmatrix}, \tag{29}$$

$$Y(t) = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = C\varphi(t)x^0 + \int_0^t C\varphi(t-\tau)BV(\tau)d\tau + DV(t) =$$

$$= \begin{pmatrix} 0.09 & 0.42 \\ 0.68 & 0.34 \end{pmatrix} e^{\begin{pmatrix} 0.63 & 0.71 \\ 0.15 & 0.57 \end{pmatrix}} \times \begin{pmatrix} 1.33 \\ 0.035 \end{pmatrix} + \tag{30}$$

$$+ \int_0^t \begin{pmatrix} 0.09 & 0.42 \\ 0.68 & 0.34 \end{pmatrix} e^{\begin{pmatrix} 0.63 & 0.71 \\ 0.15 & 0.57 \end{pmatrix}(t-\tau)} \times \begin{pmatrix} -0.18 & 0.38 \\ 0.0006 & 0.29 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} d\tau + \begin{pmatrix} 0.22 & 0.3 \\ 0.5 & 0.08 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix}$$

Let us look at the reaction of the output variable - y_2 - budget efficiency (the part of the company's taxes in the UTC budget) vector of output indicators of the operating company $Y(t)$ when changing the input characteristic b_{22} - the part of advanced technologies, which are used in the processing of vantages by 0.05. Due to the change in the input characteristic $b_{22}^* = b_{22} + 0.05$, the output component $y_2^*(t)$ will take the following values for the period $t = 1$:

$$y_2^*(t) = \int_0^t [0{,}278 + 0{,}163(t - \tau)]0{,}193 + [0{,}313 + 0{,}056(t - \tau)]0{,}23 d\tau = y_2^*(t) \times 1{,}1 \tag{31}$$

5. Discussion. Thus, a 17% increase in the input characteristic b_{22} of advanced technologies in cargo processing leads to an increase in budgetary efficiency, i.e., a 10% increase in taxes for the manufacturing company in the UTC budget. An efficient solution with an increased share of advanced technologies is left in the PS composition for development. The UTC can use the model effectively to manage the sustainability of a company's development and optimize its performance indicators. However, the completeness of sustainability management depends significantly on the information that characterizes the financial, economic, production, and technical and innovation parameters of both enterprises and on UTC activity.

The priorities of sustainable development of the enterprise form a set of primary goals of defined activity, taking into account the specifics of the sector and the peculiarities of the UTC development. Thus, the management of stable development of a company based on priorities leads to an analysis of sector-specific features of the company, the identification of areas of stable development (parametric components), the formation of specific, measurable indicators of the functional state of the company, and UTC.

The state of PSs located in the UTC territory at any time can be described by their capital resources and productive capacity, which are regulated by the investment and innovation activities that ensure their stable development. The problem of optimal management can be represented in the form of discrete matrix objects, the dynamics of which are described by a linear matrix equation (Kallrath, 2012):

$$X_{t+1} = A(t)X_t + B(t)U_t + F(t), \tag{32}$$

where N is the given time interval; X_t is the matrix of the PS state at time t, whose changes reflect the indicators; U_t is the matrix of PS control; and $A(t)$, $B(t)$, and $F(t)$ are the matrices of the PS parameters, which characterize its function. Therefore, $A(t)$ is the PS matrix, which determines the nature of production at a given interval of time; $B(t)$ is the PS link matrix with external factors, which influences the efficiency of PS work; and $F(t)$ is the PS output indicator link matrix.

The elements of the matrices are in the form of functions of the scalar argument t, which are defined for each interval of time $t = 0-1, 1-2, \ldots, N-2-N-1$.

The initial position of the state vector X_0, PS, is known. Control constraints are not imposed. The determination of the state X_{t+1} PS is carried out via dynamical programming. The results of investigations of the state of the PS in the composition of the UTS in a more general case can be viewed using the matrix equation in the form of:

$$X_{t+1} = A_1(t)X_t + X_t A_2(t) + B_1(t)U_1(t) + U_2(t)B_2(t), \tag{33}$$

where N is the given interval of time; X_t is the matrix of the PS state, for which the parameters are defined in the form of phase coordinates of size $(n \times R)$; $U_1(t)$ and $U_2(t)$ are matrices of PS control in the form of investments, dimensions $(m \times k)$ and $(n \times r)$, respectively; and $A_1(t)$, $A_2(t)$, $B_1(t)$, and $B_2(t)$ are matrices PC^1, PC^2, whose elements are in the form of scalar arguments t, statuses PC^1, and PC^2, respectively, specified for each interval of time $t = 0, 1, \ldots, N$.

The advantage of these systems of type (24) is that they describe the simultaneous state of many PSs and their one-to-one effect.

The problem of controlling PS $X_{t+1} = f(X_t, t, U_t)$ is that for the interval of time $[0, N]$ for any state matrix PS X_0 and X_N, there will always be a control U_t, for example, for the cost of investments, at which there is a connection Z_t of the system (24), which satisfies the conditions:

$$Z_0 = X_0, \ Z_N = X_N \tag{34}$$

The criterion for PS leadership, whose state is described by the linear stationary control system $X_{t+1} = A(t)X_t + B(t)U_t$ on the interval $[0, N]$, is the condition that $rang(B, AB, A^2B, \ldots, A^{n-1}B) = n$.

The control U_t^{opt} will be optimal by minimizing the function $Y(U_t)$ if:

$$Y(U_t^{opt}) = \min_{U_t \in U} Y(U_t) \tag{35}$$

Therefore, for example, among the investments, there are those PSs that achieve maximum productivity with their minimum size. Among permissible controls, there are optimal controls $U_1(t)$ and $U_2(t)$ PS, the state of which is determined by the system of equations (24). In this case, the PS control is achieved by the

solution of the recurrent matrix equation (24), and the formula defines the minimum value of the function (25):

$$Y_{\min} = Y\big(U_t^{opt}\big) = S_p(X_0^* \theta_0 X_0 + X_0^* \Phi_0 + \Phi_0^* X_0 + \gamma_0), \tag{36}$$

where $S_p(\ldots)$ is the matrix sequence; X_0^* is the transposition matrix of the initial state of the PS; θ_0 is the matrix of parameters of changes in the state of the PS due to short-term inputs to its inputs of the resource for the management of the company's development; Φ_0^* is the transposed matrix, which is determined by recurrent equations in wrapped time; and γ_0 is the number of initial investments.

The stability of PS development during UTC depends on all the parameters that ensure the lifespan of the individual. For example, for the asymptotic stability of PS, the matrices of parameters A_i and of which the elements do not depend on time, it is necessary and sufficient that all roots λ_i of the characteristic equation $\det(A_i - \lambda E) = 0$ have inimitable components, i.e., $Re\ \lambda i < 0$. When controlling PS, as described by equations (10), (11), (23), and (24), the necessary conditions for stable development are the roots of λ_i in the algebraic equation:

$$\det[(A_i + B_i) - \lambda E] = 0 \tag{37}$$

The vector-matrix equations were inherent in the maximum time intervals for which the vector-matrix equations are indicated.

6. Conclusions. Modelling of the management system for the development of manufacturing enterprises under decentralization can help determine the main parameters that impact the UTC. The scientific and methodological approach proposed for its practical implementation can consider the state of the PS as a parameter for its development. The assessment of the PS status and its development dynamics within the UTC framework shows the need to create a system of generalized vector-scalar, situation-oriented indicators. These indicators can help companies identify their state, assess their efficiency, and optimize their target functions to solve their problems. Integrated assessment of the state of an enterprise by vector functional components allows identification of its state based on the management matrix $U(t)$. The financial activity, production, and investment-innovation activity of PS can be taken into account using this approach. Using discrete matrix objects for the optimal management of production systems in the composition of UTSs can aid in ensuring the functioning of each system depending on the state of the others at time t of their production to time $t + 1$. This is associated with their further development under conditions of decentralization. This approach can contribute to economic benefits such as the improvement of economically deprived enterprises and territories, the expansion of new technologies and products, the development of the innovation sector, an increase in employment and demand for the qualified labour force, quality changes in modern life, high economic efficiency and profitability, and the stimulation of new business.

In closing, this research emulates the challenges and opportunities inherent in scientific pursuits amidst a dynamic backdrop. We express our profound gratitude to all who have contributed, either directly or indirectly, to the realization of this study, and we acknowledge the resilience of the scientific community in its pursuit of knowledge and understanding, even in the most challenging circumstances.

Author Contributions: conceptualization: A. U.; software: M. K.; data curation: L. N.; formal analysis: E. Z.; investigation: M. K., and A. U.; methodology: L. N. and E. Z.; project administration: A. U. and L. N.; supervision: E. Z.; validation: A. U. and L. N.; visualization: M. K.; writing – original draft: A. U., E. Z. and L. N.; writing – review & editing: M. K.

Conflicts of interest: The authors declare no conflicts of interest.

Data availability statement: Not applicable.

Informed Consent Statement: Not applicable.

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Управління стійким розвитком виробничих систем в умовах децентралзації

У статті подано огляд аргументів і контраргументів, які використовуються для визначення стану підприємства, оцінки його функціональної ефективності та оптимізації його цільових функцій при реалізації управлінських завдань. Децентралізація підприємств дозволяє їм адаптуватися до конкретних територіальних потреб. Однак це також вносить елемент нестабільності, який може бентежити. Основною метою дослідження є розробка науково-методичного підходу до моделювання системи управління розвитком виробничих підприємств в умовах децентралізації. Систематизація літературних джерел та підходів до проблеми управління розвитком виробничих підприємств показує, що кожному рівню аналізу стану підприємства та оцінки динаміки його розвитку та проблемної ситуації відповідає сукупний набір оцінок, який включає як окремі, індикатори та їх різні групи. В основі лежить важливе визнання стану виробничих систем як основного параметра, що впливає на саму структуру розвитку UTC. Модель використовує потужний векторно-функціональний підхід, що дозволяє багатовимірно оцінювати стан підприємства. Модель перетворюється на відчутну метрику, що сприяє прийняттю обґрунтованих рішень і цілеспрямованим втручанням. Актуальність даної наукової проблеми полягає в тому, що процес управління розвитком підприємства в умовах децентралізації має бути більш структурованим і менш випадковим. Необхідно керувати цим процесом, щоб вижити і розвиватися в умовах агресивного ринкового середовища. Оптимальне керування виробничими системами як дискретними матричними об'єктами дає можливість розглядати функціонування кожної з них залежно від стану інших у момент часу t їх виробництва до часу $t+1$, що пов'язано з їх подальшим розвитком у децентралізованому середовищі. Результати дослідження можуть бути корисними для розробки систем моніторингу та стратегічного управління процесами розвитку виробничих підприємств в умовах децентралізації.

Ключові слова: підприємство, компанія, функціонування, виробнича система, держава, об'єднані територіальні громади.