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MODELING THE IMPACT OF INFORMATION TECHNOLOGY ON THE ADAPTIVE CAPACITY OF INDUSTRIAL SYSTEMS

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The rapid development of digital technologies – particularly manufacturing management information systems, the Internet of Things, artificial intelligence systems, and cloud computing – has opened new opportunities for increasing the flexibility and controllability of industrial enterprises. However, despite numerous examples of digital transformation, the quantitative assessment of the impact of information technology (IT) on the dynamics of production systems, especially under turbulent environmental conditions, remains insufficiently explored. IT can catalyze adaptability, enhancing a system's ability to maintain or restore operability during stressful events. At the same time, IT is a dynamic variable: its level may decline due to wear, insufficient funding, or lack of support. In this context, the issue of modeling the interdependent dynamics between production and IT as components of a single adaptive system becomes especially relevant. This makes it possible to identify typical behavioral scenarios and evaluate the impact of external stressors and the required level of support for digital infrastructure.

This study aims to construct a mathematical model that allows for the investigation of the interaction dynamics between production and IT under changing external conditions and to determine their impact on the adaptability and stability of an industrial system. The objectives of the study are to develop a modified dynamic model that describes the interdependence between production and IT while accounting for the influence of an external stress factor, and to implement numerical modeling of the system's behavior based on given initial conditions and parameters to analyze the adaptability and resilience of the industrial environment.

One of the classical models that can describe the dynamics of interaction between two interconnected systems is the Lotka–Volterra model, also known as the "predator–prey" model. Although initially developed for ecological applications, this model has found broad use in social [1], economic [2], and technical [3] systems where there is interdependence between elements that compete with or mutually reinforce each other. The Lotka–Volterra model interprets production as the resource base in the industrial context. At the same time, IT becomes an element that consumes resources but simultaneously stimulates productivity, efficiency, and adaptability growth.

To describe the interaction between production and IT in an industrial system, a system of first-order differential equations is used:

$$\begin{cases} \dfrac{dx}{dt} = \left(\alpha - \sigma S(t)\right) \cdot x - \beta \cdot x \cdot y + \nu, \\ \dfrac{dy}{dt} = \delta \cdot x \cdot y - \gamma \cdot y + \mu, \end{cases}$$

where **x(t)** – the level of production activity (production), **y(t)** – the level of IT development and efficiency, **α** – the base growth rate of production, **β** – the coefficient representing production costs allocated to IT (competition for resources), **δ** – the coefficient characterizing the feedback effect of output on IT development (contribution of production activity to the advancement of digital technologies), **γ** – the coefficient representing the natural decline of IT level without additional support, **σ** – the coefficient of production sensitivity to external stress, **S(t)** – an external stress factor that varies over time (e.g., economic crisis, logistical disruptions, etc.) and is described by a periodic function that includes oscillatory elements and crisis moments, **ν** – constant external support for production (e.g., government subsidies), **μ** – constant external IT support (e.g., infrastructure investment).

The stress function is defined as a sum of sinusoidal and Gaussian components: $S(t) = 1 + A \cdot \sin(\omega t) + B \cdot \exp\left(-\frac{(t - t_0)^2}{2\tau^2}\right)$, where A is the amplitude of periodic fluctuations (intensity of seasonal influence), ω is the frequency of the sinusoidal component (periodicity of changes); B is the peak magnitude of the impulsive (crisis) impact; t_0 is the time at which the peak of the crisis occurs; and τ is the duration or width of the crisis impulse (describing how long the impact lasts). This form combines periodic influences (seasonal variations or cyclical market downturns) with short-term impulsive events (financial or geopolitical crises). The sinusoidal component accounts for regular, predictable environmental changes, while the Gaussian impulse models a single disruptive event with maximum intensity at time t_0 and a defined duration τ. As a result, the model gains greater flexibility and realism in analyzing the adaptive behavior of industries under changing external conditions.

To investigate the dynamics of an industrial system involving the interaction between production and IT under changing external conditions, numerical modeling of the proposed model was conducted in the GNU Octave environment. The model parameters were selected based on realistic situations that characterize the interaction between production and IT in a variable external environment. Considering internal and external influencing factors, they were chosen to simulate a typical scenario for a medium-sized industrial enterprise operating under periodic fluctuations and potential crises. The parameter values enable the implementation of a dynamic system that reflects the resilience and adaptability of an enterprise capable of maintaining production and IT at a viable level even under stressful conditions (Fig. 1).

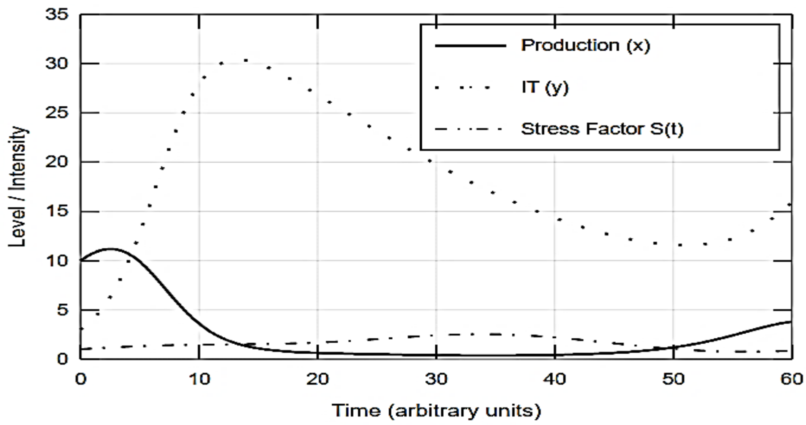

Fig. 1. Dynamics of Production, IT, and External Stress

The numerical modeling results demonstrate the temporal evolution of production levels, IT, and the stress factor. Initially, the system develops steadily: production grows and stimulates IT development due to the positive interaction between the subsystems. Over time, the influence of external stress causes a decline; however, thanks to external support, both subsystems remain viable – production is maintained at a minimal level, and IT stabilizes. The overall dynamics exhibit adaptive behavior, transitioning to a new stable state. In addition to time-based dependencies, a phase portrait of the system was obtained, illustrating a typical cycle: growth, crisis, stabilization. The absence of trajectory convergence to zero confirms the system's capacity for self-sustainability under external pressure.

Thus, the modified Lotka–Volterra model is an effective analytical tool for studying digitally transformed industrial systems dynamics. Incorporating a variable stress factor and external support mechanisms enables a qualitative description and a quantitative prediction of system behavior in unstable environments. This approach provides opportunities for identifying critical resilience thresholds, evaluating the effectiveness of managerial decisions, and developing adaptive digital support strategies that enhance the viability and flexibility of production processes.

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INTERLINEATION METHOD OF 3D FUNCTIONS FOR THE PROBLEM OF DETECTING SOIL POLLUTION WITH HEAVY METALS

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Mathematical modeling of soil contamination by heavy metals is a crucial and timely endeavor, typically conducted by analyzing emission sources, particularly industrial enterprises. The primary factors influencing this process include the volume and composition of pollutants released into the environment, atmospheric transport processes, and chemical and physical interactions with the soil cover [1].

Measuring heavy metal contamination in soil at depth using non-destructive testing is a highly relevant, yet exceptionally complex challenge. Currently, there isn't a single universal device or method that can precisely and directly measure heavy metal