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MODELING OF INDUSTRIAL SYSTEM DYNAMICS

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Abstract: The existing approaches to the development of automatic control systems focus on design of corporate information systems which do not take into consideration the impact of dynamics. The authors examined the dynamic mathematical models of the production system based on the representation of the object modeling system in the form of elementary units, which allow studying the transient processes. These models permit the analysis of the enterprise functioning through time, taking into account control object features, links and possible combinations of input data, and also run situational simulation by changing input data flows.

Modern market environment requires the company management team to use new management technologies. Current approaches to the question of development of management information and control systems put an emphasis on creation of corporate information systems, which do not take into account the dynamic impact.

If you run business in conditions of market-oriented economy, you use a wide range of resources, but given the fact that environmental influence is changing quite rapidly, it is essential for the enterprise management to have skills in modeling dynamics of industrial system, because it helps to analyze unsteady processes. The previous studies [1 – 6] related to modeling of dynamics of enterprises do not provide a common approach to the problem of management.

The importance of considering the dynamic properties of an object in the enterprise management is difficult to overestimate. In this connection there is a need to develop a methodology for development of management information and control which take into account dynamic properties of production systems. The lack of turnkey solutions of this problem makes this challenge urgent. We offer to demonstrate industrial system as the connections of elementary units, which reflect its most typical features.

Task 1. The program for finished-product output per definite period of time includes n types of products, each of them should be produced into the amount of a_k ($k = \overline{1,n}$) pieces. We will set a task of production control to maximize profits from sales. We will represent the model of the system from the following units: raw materials M_i, work-in-process H_i, finished products F_i, sales D_i, account P_i, payables K_i (Fig. 1).

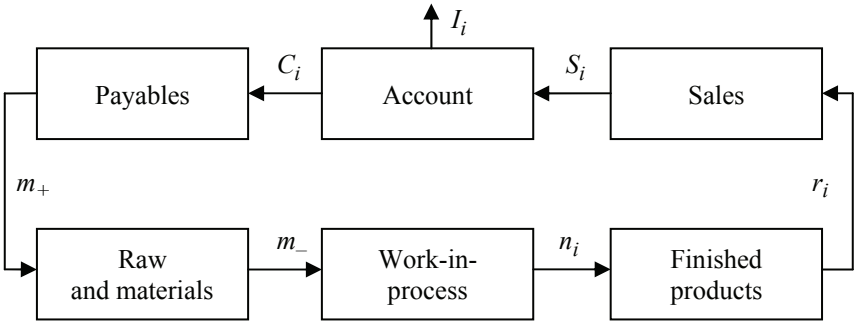

Fig. 1. The model of production control to maximize profits

The formula, which shows the stock presence of materials provided by the suppliers and then put into production:

$$M_{i+1} = M_i + (m_+)_i - (m_-)_i, \tag{1}$$

where $(m_+)_i$ is provision of the materials from the supplier in a day i; $(m_-)_i$ is transferring of the materials from stock into production.

The formula, which shows each of provision and transferring of real assets and withdrawal of certain expenditures related to product costs is as follows:

$$H_{i+1} = H_i + (m_-)_i + A_i^N + (W/B)_i^N + C_i^N - n_i, \tag{2}$$

where A_i^N is accumulated and withdrawal amortization of product costs; $(W/B)_i^N$ is wages (with benefits), referred to the prime cost; C_i^N is all other costs, charge-off; n_i *is* the prime cost of the finished goods, transferred on the day i from production to finished products stock.

The formula which shows input-output of products, accounted in the prime cost is as follows:

$$F_{i+1} = F_i + n_i - r_i, \tag{3}$$

where r_i is products, delivered to customers and accounted in the prime cost.

The formula which shows the sales of products is as follows:

$$D_{i+1} = D_i + (1 + \alpha_i) r_i - S_i, \tag{4}$$

where S_i – payments for products.

The formula which shows availability of monetary assets is as follows:

$$P_{i+1} = P_i + S_i - (W/B)_i^R - E_i^R - tQ_1 - C_i - I_i, \tag{5}$$

where $(W/B)_i^R$ is explicit wages; E_i^R is other explicit requirements of the company; Q_1 is quarterly evaluated profit (1 quarter = 90 days) and tax on profits tQ_1 paid at the rate of t; C_i is resources, transferred to the supplier materials; I_i is working capital.

The formula which shows bills payable is as follows:

$$K_{i+1} = K_i + C_i - (m_+)_i. \tag{6}$$

The task is to construct a simulation of transient processes for different initial conditions q (the number of units of raw materials) and p (cost units of resources) and the definition of the output on a stationary mode or pause.

Problems of optimal control can be put as follows: determine such values of q and p, which satisfy the conditions $(1)-(6)$ and provide maximum criteria of working capital

$$I_1 = l(A+\alpha r) - tQ_1 = lA + (1-t)Q_1 . \quad (7)$$

Task 2. The added value, money flow for accounts and payments of company $y_{a.p}$ are continuous, integral company characteristics are known: monthly revenue E_m, expenses E_{exp}, the average of owner's long term and working assets $K(t)$, external funds $E_{e.f}$ are enough stable aggregate economic indicators of their business activities.

We will set a task of production system control to maximize the effectiveness of the reproduction of capital.

We will represent the model of the system from the elementary units (Fig. 2).

The formula which shows capital growth in the economic systems of reproduction with continuous flows proceeds and payments is as follows:

$$K(t) = K_0 e^{\beta\rho/\tau}, \quad (8)$$

where K_0 is the initial amount of capital at the time moment $t = 0$; ρ is margin, that is, the ratio of profit to cost; β is capitalization rate of profit, which shows the proportion of profit in capital increase.

The formula which effectiveness of the reproduction of capital is as follows:

$$E = \rho/\tau; \quad (9)$$

$$E_m = y_a/K_p; \quad (10)$$

$$E_{exp} = y_{b.e}/K_a; \quad (11)$$

$$E_{e.f} = y_{a.p}/K_p; \quad (12)$$

$$K_p(t) = K_0 + \beta; \quad (13)$$

$$y_{n.o} = y_a - y_{b.e}; \quad (14)$$

$$y_{p.v} = y_{p.c} + y_a , \quad (15)$$

where E is effectiveness of the reproduction of capital; y_a is the value of added cost; K_p is production assets; K_a is total assets; $y_{n.o}$ is net output; $y_{b.e}$ is business expenses, admitted in added cost; $y_{p.v}$ is product value of company; $y_{p.c}$ is primary cost.

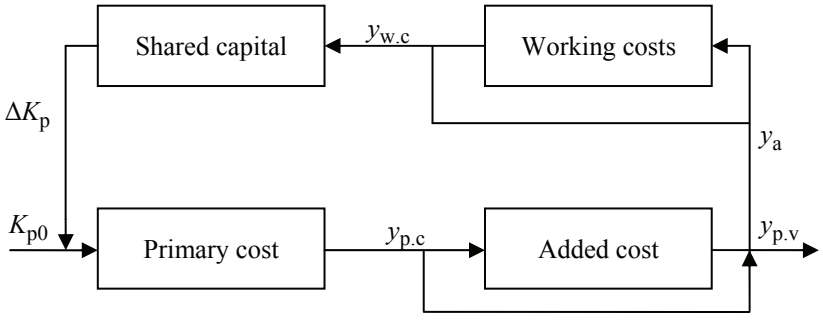

Fig. 2. The model of the production system control to maximize the effectiveness of the reproduction of capital:
K_{p0} is the initial production assets; $y_{w.c}$ is working costs

Optimal control problem can be put as follows: it is needed to find the variables value added y_a, which satisfy the conditions (8) – (15) and provide maximum efficiency criterion of reproduction of capital

$$E_m = y_a / K_p . \quad (16)$$

Task 3. May the quantities of material and financial flows (assets and sources of funds) are known: trade stock with original cost $Z(t)$, monetary assets $D(t)$, trade creditors $K(t)$, internal funds $U(t)$, deliverables $f_1(t)$. We will set a task of production system to maximize the sales.

We will represent the model of the system from the elementary units (Fig. 3).

The formula which shows that revenue stream is synchronous with the outflow of goods from the stock market and sales restrictions are absent is as follows:

$$f_2(t) = T_Z Z(t), \quad (17)$$

where $f_2(t)$ is sales with initial cost of products; T_Z is stock turnover period; $Z(t)$ is product stock with initial cost of products.

The formula which shows the goods delivery on a credit basis form trade payables, while the inflow of goods supplied leave behind the time of payment is as follows:

$$f_3(t) = f_1(t - T_k), \quad (18)$$

where $f_3(t)$ is payment for shipments; T_k is period of deferment of payment of deliveries.

The formula shows that revenue exceeds the cost of sold goods, which means the formation of a flow of revenue stream merger of costs and profits. Profit flows come from a block of internal funds $U(t)$, increasing the total withdrawal from it and thus fixing the connection of profit to equity.

$$f_4(t) = f_5(t) - f_2(t), \quad (19)$$

where $f_4(t)$ is profit; $f_5(t)$ is revenue.

The formula which shows the relations between revenue and sales, expressed in primary cost of sold goods is as follows:

$$f_5(t) = \frac{C_{sal}}{C_{rev}} f_2(t), \quad (20)$$

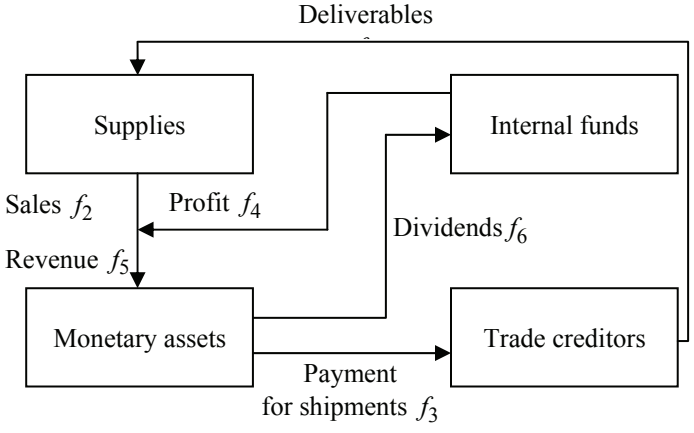

Fig. 3. The model of production system to maximize the sales

The formula which shows fact of payment of profits as dividends is as follows:

$$f_6(t) = C_{\text{div}} f_4(t), \tag{21}$$

where $f_6(t)$ is dividends.

The formulae which show increment of a stock of goods, monetary assets, trade payables, internal funds are as follows:

$$\Delta Z(t) = f_1(t) - f_2(t); \tag{22}$$

$$\Delta D(t) = f_5(t) - f_6(t) - f_3(t); \tag{23}$$

$$\Delta U(t) = f_6(t) - f_4(t); \tag{24}$$

$$\Delta K(t) = f_3(t) - f_1(t). \tag{25}$$

Optimal control problem can be put as follows: it is needed to find values of the stock $Z(t)$ and supply functions $f_1(t)$, which satisfy the constraints (17) – (25) and provide maximum criterion to increase sales

$$f_2(t) = T_Z Z(t). \tag{26}$$

The considered dynamic mathematical model of the production system takes into account peculiarities of the control object, the uncertainty of the input data, their connections and possible combinations. They allow the study of the production system as a whole system, performing a variety of interrelated functions in a specific relationship with the environment, the impact of this environment and undergoing changes under the influence of external and internal factors of production and economic activity.

The models allow situational modeling, changing information elements of input data to make changes in the schedules given the investigated parameters, calculate the resource requirements, evaluate productivity, and increase the efficiency of the production system through timely management decisions.

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Моделирование динамики производственной системы

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Ключевые слова и фразы: динамические свойства; математическая модель; переходный процесс; производственная система; ситуационное моделирование; элементарное звено.

Аннотация: В существующих подходах к проектированию автоматизированных систем управления предприятиями сделан акцент на разработку корпоративных информационных систем, не учитывающих влияние динамики. Рассмотрены динамические математические модели производственной системы, основанные на представлении объекта моделирования в виде системы элементарных звеньев, позволяющие исследовать переходные процессы. Модели позволяют во времени анализировать функционирование предприятия, при этом учитывать особенности объекта управления с взаимосвязью и возможными сочетаниями входных данных, а также производить ситуационное моделирование, изменяя входные потоки информации.

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Modellierung der Dynamik des Produktionssystems

Zusammenfassung: Im existierenden Herangehen an die Projektierung der automatisierten Steuersysteme die Unternehmen akzentuieren auf die Entwicklung der korporativen informativen Systeme, die nicht den Einfluss der Dynamik berücksichtigen. Es sind die dynamischen mathematischen Modelle des Produktionssystems, die auf der Vorstellung des Objektes der Modellierung in Form vom System der elementaren Glieder gegründet sind und erlauben es, die instationären Prozesse zu untersuchen. Die Modelle lassen in der Zeit zu, das Funktionieren des Unternehmens dabei zu analysieren, die Besonderheiten des Objektes der Verwaltung mit der Wechselbeziehung und den möglichen Kombinationen der Eingangsdaten zu berücksichtigen, sowie, die Situationsmodellierung zu erzeugen, die Eingangsströme der Informationen ändernd.

Modélage de la dynamique du système industriel

Résumé: Dans les approches existantes envers la conception des systèmes automatisés de la commande est accentuée l'élaboration des systèmes automatisés corporatifs qui ne prennent pas en compte l'influence de la dynamique. Sont examinés

les modèles mathématiques du système industriel fondés sur la représentation de l'objet du modélage en vue du système des unités élémentaires permettant d'étudier les processus transitoires. Les modèles permettent d'analyser à temps le fonctionnement de l'entreprise en prenant en considération les particularités de l'objet de la commande ainsi qu'effectuer le modelage de situation en mesurant les courants d'information d'entrée.

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