Efficiency of Controlling the Production System at Airports Using the Single Information Space for Ensuring Technological Processes*

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Abstract. Within the framework of the single information space paradigms for ensuring technological processes at airports, considered are the efficiency criteria currently used in production processes at airports. It is shown that the efficiency criteria, as a rule, include one or a set of indicators for assessing the efficiency of the production system, which allows quantifying the individual properties of such systems or their elements, as well as their interaction. Considered are the integral efficiency criteria giving a generalized specification of the production system. It is shown that the correct definition of the physical essence and mathematical expression of the efficiency criteria and their rational division into main and auxiliary ones makes it possible to evaluate their condition more objectively, compare various options for production systems' implementation and visualize the prospects of their development. As a separate group of efficiency indicators, considered are the indicators for assessing the efficiency of controlling production systems at airports, including the assessment of control quality and such control system properties as readiness, efficiency, sustainability, and continuity. Proposed is the method of designing efficiency criteria that meets the representativeness requirement. For this purpose, the efficiency criterion is presented in the form of a functional, which is defined according to the functions most significantly affecting the quality of production systems and their control processes. Such a view of the efficiency criterion is based on considering the control process to be both information-driven and intellectual by its nature, and associated directly with the creative activity of the person making the decision in a certain production system.

Keywords: airport, production potential, efficiency.

1 Approaches to Assessing the Efficiency of Production Systems at Airports

High-quality implementation of typical tasks at airports requires constant analysis, evaluation, and selection of the most rational options for tackling these tasks. This selection is based on the forecast and comparison of the possible results achieved with the help of the chosen course of action with the goals of an airport or its particular departments and services. The measure used to assess options in terms of achieving a goal or solving a problem is called the "measure of efficiency", or shortly, "efficiency". In general, it can be said that the concept of "efficiency" characterizes the ability of the production system at an airport to achieve its goals or cope with its tasks.

The criterion of efficiency is a numerical measure, quantitatively characterizing the degree of goals' achievement or problems' solution. The criterion of efficiency, as a rule, includes one or a set of indicators for assessing the system's efficiency, allowing quantifying the specific properties of the system or its elements and their relationship. It gives an integral, generalized characteristic of the production system. The correct definition of the physical essence and mathematical expression of the criteria of efficiency as well as their rational division into the main and auxiliary ones make it possible to more objectively evaluate the condition of the production systems at airports, compare their variants and to visualize their development prospects. It is especially true when using a single information space to ensure technological processes at airports [1, 2].

By now, four requirements for efficiency criteria (indicators) have been formulated:

- representativeness (strict compliance with the goal efficiency indicator implemented by the system);
- sensitivity (the ability of the efficiency indicator to change its value when the system parameters change);
- ease of calculation;
- visibility (the clear physical meaning of the efficiency indicator).

At the same time, the task of selecting indicators and efficiency criteria is complex, since there are no formal rules for their selection. The problem is solved informally. Its decision depends on the analyst's level of training, clear understanding of the purpose of the assessment and intuition.

In order to choose the most acceptable course of action from the set of options characterized by the corresponding criterion of efficiency, it is necessary to define the rule of the choice option or the assessment criterion. When considering the quantitative methods to substantiate decisions, the most common assessment criteria are usually used: the principle of maximum gain, the principle of guaranteed results, the principle of domination, etc. Thus, to assess the efficiency of the production system at airports, it is necessary to determine not only the efficiency criterion and indicators but also the assessment criterion.

2 Efficiency Criteria for Production Systems

We shall consider the criteria for production systems' efficiency which are most commonly used in practice.

2.1 Efficiency Criterion for Production Systems Based on the Total Implemented Production Potential

Any production system at a particular airport has certain potential production capabilities. These potential production capabilities are called "production potential".

Depending on the organization, technical condition and resource supply of the airport, the production potential of the system can be fully or partially implemented. Only the part of the production potential that will actually be implemented, that is, skillfully used under the specific conditions of the given airport (current weather conditions, flight schedules, etc.), will have a direct impact on the course and outcome of technological processes at the airport.

As a value containing a generalized assessment of the production system, the production potential complies with the goal of its functioning; it can be measured and serve as an integral characteristic of any production system at an airport.

Suppose that a production system has n elements of the supports of the production potential, each of these having the production potential $P_i(t)$. If "absolutely" perfect organizations and technologies are used in all processes, both material and informational, then the total implemented production potential of the system equals to

$$TP_1(t) = \sum_{i=1}^{m} P_i(t)\,. \qquad (1)$$

If there are deviations from the "ideal" in the processes related to the resource support for the implementation of the production potential and these deviations for the *i-th* technological process are characterized by the coefficient $0 < \alpha_i(t) < 1$, then the total implemented production potential of the system equals to

$$TP_2(t) = \sum_{i=1}^{m} P_i(t)\alpha_i(t)\,,$$

where TP_2 characterizes the degree of production potential's implementation, given the existing technologies of resource provision and the ideal level of controllability and organization of the system.

In practice, the ideal organization and controllability of the production system do not exist. If we introduce a coefficient characterizing the quality of control for the *i-th* technological process $0 < \beta_i(t) < 1$, then the total implemented production potential of the system equals to

$$TP_3(t) = \sum_{i=1}^{m} P_i(t)\alpha_i(t)\beta_i(t) \qquad (2)$$

where TP_3 characterizes the degree of production potential's implementation, given the existing technologies of resource provision and the existing level of controllability and organization of the system.

As the criterion of the production system's efficiency, characterizing the level of equipment and technologies of resource provision, the following indicator may be used:

$$\mathrm{A}(t) = \frac{TP_2(t)}{TP_1(t)}.$$

As the criterion of the production system's efficiency, reflecting int. al. the standard of system control's quality, the following indicator may be used:

$$\mathrm{B}(t) = \frac{TP_3(t)}{TP_2(t)}.$$

A similar approach can be applied with a different composition and interpretation of the coefficients. Basically, it corresponds to the energy approach [3-7].

2.2 Efficiency Criterion for Production Systems Based on the Relative Speed of Technological Processes' Resource Allocation at Airports

The alternative for the total implemented production potential TP_1 defined according to formula (1) is the relative speed of movement of the unit of technological processes' resource allocation at an airport $V_1(t)$.

$$V_1(t) = \frac{\sum_{i=1}^{n} v_i(t) p_i(t)}{\sum_{i=1}^{n} p_i(t)},$$

where $v_i(t)$ is the maximum speed of movement of the unit of technological processes' resource allocation at an airport performed by the *i-th* object - support of the production potential; $p_i(t)$ is the production potential of the *i-th* support of the production potential.

The alternative for the total implemented production potential TP_2 is the variable $V_2(t)$,

$$V_2(t) = \frac{\sum_{i=1}^{n} v_i(t) p_i(t) \alpha_i(t)}{\sum_{i=1}^{n} p_i(t)},$$

where $\alpha_i(t)$ is the coefficient characterizing the technology of transportation of technological processes' resource allocation at an airport.

The actual relative speed of movement of technological processes' resource allocation at an airport, taking into account the quality of control, equals to

$$V_2(t) = \frac{\sum_{i=1}^{n} v_i(t) p_i(t) \alpha_i(t) \beta_i(t)}{\sum_{i=1}^{n} p_i(t)},$$

where $\beta_i(t)$ is the fraction of decrease in the relative speed of movement of technological processes' resource allocation at an airport, depending on the quality of control.

As the criterion of the production system's efficiency, at least two indicators can be used:

$$\mathrm{A}(t) = \frac{V_2(t)}{V_1(t)},\ \mathrm{B}(t) = \frac{V_3(t)}{V_2(t)}.$$

The analysis of these variables allows making conclusions about the quality of transportation and control technologies and, in general, about the mobility of the production system at airports.

2.3 Efficiency Criterion for Production Systems Based on "the Cost of Losses Averted"

When making decisions regarding the development of a specific production system at an airport, it is necessary to be able to assess the feasibility of such measures.

Suppose an airport has a certain absolute income per year, equal to $D(t)$, and does not comprise a production system with the potential $p(t)$. Suppose the airport may suffer from damages amounting to $Y(t)$ on average per year as the result of possible external influences. Then the airport's real annual income will be determined by the variable $D_p(t) = D(t) - Y(t)$. Suppose a new production system with the potential $p(t)$ can be installed at the airport, its cost being equal to $C(t_0)$. It is assumed that the new production system is able to reduce (prevent) possible annual damage by $\Delta y(t)$, whereby $\Delta y(t)$ is the function of the production potential. Then it can be argued that the real income of the airport will increase and equal to $D_{pl}(t) = D_p + \Delta y(t)$. Considering the above-mentioned, in T years the new production system will be able to generate income calculated according to the formula:

$$\Delta y(T) = C(t_0) \prod_{i=1}^{T} (1 + s(i)),$$

where $s(i)$ is the annual share of the initial investment in the production system $C(t_0)$; $C(t)$ is the cost of installing the production system.

The function $\Delta y(T)$ is a poor efficiency criterion since it does not reflect the rate of return on investments. Choosing the period during which the initial investment will increase (pay off) by m times is, therefore, advisable; i.e. when

$$m = \frac{\Delta y(T)}{C(t_0)}.$$

Provided that *s(i)* is const, the criterion of m-fold payback will be as follows:

$$T_m = \frac{\log(m)}{\log(1+s)}.$$

Generally speaking, the value of *s(i)* is not constant and decreases with time due to wear (system's aging). The variable *Y(t)* can be obtained on the basis of a retrospective statistical analysis of the damage.

2.4 Efficiency Criterion Based on the Convolution of Particular Efficiency Indicators

Suppose a production system has m properties, each of which, in turn, is characterized by the corresponding fi efficiency indicator. Suppose the contribution of each property to the implementation of the system's production potential is known and estimated by the coefficients λ_i so that

$$0 < \lambda_i < 1 \text{ and } \sum_{i=1}^{m} \lambda_i = 1.$$

And suppose none of the efficiency criteria we have considered so far are suitable for analysis. Then, a new integral efficiency criterion of particular efficiency indicators can be constructed on the basis of convolution, in which the set of efficiency indicators $f_1, f_2, ..., f_n$ is replaced with one function $F(f_1, f_2, ..., f_m)$, namely:

$$F(f_1, f_2, \ldots, f_n) = \sum_{i=1}^{m} \lambda_i f_i.$$

Table 1 shows an example of setting the efficiency indicators of the production system's particular properties and the corresponding coefficients of the indicators' contribution to the integral efficiency criterion *F(f1, f2, ..., fm).*

Table 1. Production system's efficiency indicators and coefficients of the indicators' contribution

Properties	Efficiency indicator	Coefficient
Production readiness	f_1	λ_1
Production capacity	f_2	λ_2
Technological stability	f_3	λ_3
Controllability	f_4	λ_4
Organization	f_5	λ_5

Properties	Efficiency indicator	Coefficient
Observability	f_6	λ_6
Mental capacity	f_7	λ_7
Self-management	f_8	λ_8
Self-sufficiency	f_9	λ_9
Dynamism	f_{10}	λ_{10}

This approach seems quite practical and technology-savvy. It allows using the convolution of both the more complex hierarchy of properties and the relevant indicators. Its main disadvantages are hard-going conditions: conceptual comparability of the variables of individual efficiency indicators, absence of conceptual meaning for the F function and uncertainty in the choice of λi weights. To assess them, it is often necessary to resort to expert assessments.

3 Production System Control's Efficiency Assessment

Control efficiency is an important indicator of any production system's capabilities. Intuitively, efficient control is understood as such a control process, in which, first, the timely development of solutions and plans which are optimal and most appropriate for the specific situation is ensured, secondly, the successful rigorous implementation of these decisions and plans in a timely manner and, thirdly, achieving a high degree of readiness for the implementation of the airport's production capabilities.

However, the intuitive understanding of the "control efficiency" concept does not allow for an objective comprehensive analysis of the subsystem of controlling production systems at airports to develop scientifically based proposals on how to sustain and develop them. The quantitative methods of system analysis are required.[8, 10]

The following main goals for assessing control efficiency in production systems can be considered:

- determine the extent to which the current control system contributes to (or hinders) the implementation of the system's production potential;
- assess the current condition of the control system in order to take measures to maintain it at the required level;
- determine the most promising ways of the control system's development;
- identify the most appropriate ways to improve the forms and methods of control;
- identify to what extent the qualifications of the airport's engineering and technical staff influence the efficiency of solving production problems.

The basic principle of assessing the efficiency of production systems' control at airports is the system approach principle. According to the principle, the control system is considered as not only a set of information-related departments and services at airports, communication systems, automated and special systems, but also as a part of the applied information technologies (IT), decision-making methods and information resources (IR) - a single information space of technological processes' maintenance

[1].

An important feature of airport control processes is their implementation in a separate part of the production system - the control subsystem. In relation to this subsystem, the production system is comprehensive. Therefore, the criteria for assessing the production system and the requirements imposed by the production system are decisive for constructing a system of indicators and criteria for evaluating the effectiveness of airport control processes.

When assessing efficiency, the following indicators are usually used as efficiency indicators: k - coefficients similar in meaning to efficiency; T - the mathematical expectation of the time of occurrence (completion) of events (processes); $P(t < t_з)$ - the probability of occurrence (completion) of events (processes) within a period shorter than the specified one; W - the mathematical expectation of the fraction of objects with a certain property; M - the mathematical expectation of the fraction of objects (processes) meeting the standard requirements.

The most widely used methods for assessing efficiency indicators are the methods of probability calculus, waiting theory, search theory, network planning, game theory, etc. [3-7].

One of the first integral indicators for assessing control efficiency is the indicator representing a kind of efficiency factor, k_{ef}, reflecting the degree to which potential production capacity is used:

$$k_{\text{ef}} = \frac{\text{P}}{\text{TP}},$$

where P is the implemented production capacity; TP is the potential production capacity.

The internal efficiency indicators allow comparing control systems as tools of control activity. Indicators of external or production efficiency assess the extent to which the control system affects the result of the production system's activity [3, 5, 6].

The internal control efficiency assessment comprises control quality assessment and such properties of the control system as readiness, efficiency, sustainability, and continuity.

1. The assessment of the control system's efficiency and operational readiness was carried out according to the following six indicators:

- the absolute duration of activities needed to set the control system ready;
- time balance;
- the difference between the fixed (scheduled) and actual deadlines;
- the mathematical expectation of the duration of activities to ensure the functioning of the control system;
- the probability of a timely response to destructive factors' influence;
- the probability of meeting the specified (directive, normative) deadlines.

2. The assessment of control quality - according to the degree of optimality of the decisions made (the plans being designed) and the completeness of their implementation.

3. The assessment of control stability – according to the system's reliability, survivability and noise immunity. Notice that the following indicators are used to assess reliability:

- the average uptime of individual elements and the control system as a whole;
- the average time between failures of the control system's elements;
- the probability of reliable functioning of the control system as a whole.

The following factors are used to assess survivability:

- security and vulnerability characteristics of the control system's elements, the probability of their failure, the degree (multiplicity) of their redundancy;
- the level of the control system's functioning after exposure to various types of destructive factors;
- the number of communication channels per control direction;
- impaired control's recovery time.

The main criterion for assessing the sustainability of production processes' control at airports within a certain period is the percentage ratio of the time during which the conditions of control sustainability are fulfilled to the entire period under consideration.

4. The main criterion for assessing the continuity of production control at an airport is the percentage ratio of the time during which the condition of continuity of control is satisfied over the entire period under consideration.

Note that the particular indicators of the internal efficiency of the production system are neither formally nor functionally related to the external efficiency indicator. Within particular efficiency indicators, e.g. sustainability, there are also particular indicators, which are also neither formally nor functionally related to the specific indicator that generalizes them.

Taking into account the initiated proposals and the elimination of uncertainties characteristic of this approach, we can offer two options for constructing a system of criteria and indicators for controlling production systems at airports. The first option is based on the selection of standard stages of activity for the application of a certain production process. Let us call it the functional option. The second option is based on the control system's contribution to the implementation of a certain production system's properties.

We shall consider the first option of assessing the production system's efficiency.

In accordance with the criteria for assessing the production system (1), the control efficiency in the production system was assessed according to the formulas:

$$\mathrm{B}(t) = \frac{TP_3(t)}{TP_2(t)} \text{ or } \mathrm{B}(t) = \frac{V_3(t)}{V_2(t)},$$

where TP_2, $(V_2(t))$ is the total speed of the production potential's movement, characterizing the degree of the production potential's implementation with the existing technologies of resource allocation and the ideal level of controllability and organization of the system; TP_3, $(V_3(t))$ is the speed of the production potential's movement (taking into account the control quality) which characterizes the degree of the production potential's implementation with the existing technologies of resource allocation and the existing level of controllability and organization of the system.

In order to design an efficiency criterion satisfying the representativeness requirement, we shall define it as a function defined on the functions most significantly affecting the quality of the system and control processes. In the production system's activity, we shall single out four stages that, from the point of view of the control process, most significantly influence the solution of the production problem. The coefficient characterizing the control quality can be formulated as follows:

$$\beta = F(f_{\text{o}}, f_{\text{c}}, f_{\text{d}}, f_{\text{p}}) \qquad (3)$$

where f_o is the functional determining the quality of the production system's organization; f_c is the functional determining the controllability of the production system; f_d is the functional determining the quality of decisions in the production system; f_p is the functional determining the quality of planning in the production system.

The functional for determining the quality of the production system's organization will be formulated as follows:

$$f_{\text{o}} = F_1(\varphi_{\text{os}}, \varphi_{\text{SIS}}(\theta_{\text{II}}, \theta_{\text{IR}})),$$

where φ_{os} is the functional determining the organizational structure's quality; φ_{sis} is the functional determining the quality of the single information space of technological processes' support at airports; θ_{II} is the functional determining the information infrastructure's quality; θ_{IR} is functional determining the information resources' quality.

In their turn, θ_{II} and θ_{IR} are formulated as:

$$\theta_{\text{I}} = F_2(\xi_{\text{IT}}, \xi_{\text{LLS}}, \xi_{\text{ACS}}, \xi_{\text{CS}}, \xi_{\text{CP}}),$$

where ξ_{IT} is the function determining the quality of information technologies; ξ_{LLS} is the function determining the quality of the location's lighting system; ξ_{ACS} is the function determining the quality of automated control systems; ξ_{CS} is the function determining the quality of the communication system; ξ_{CP} is the function determining the quality of control points.

$$\theta_{\text{IR}} = F_3(\xi_{\text{D}}, \xi_{\text{DB}}, \xi_{\text{FP}}),$$

where ξ_{D} is the function determining the quality of documentary information resources; ξ_{DB} is the function determining the quality of factual information resources; ξ_{FP} is the function determining the quality of the functional part of information resources.

The functional f_c defining the production system's controllability will be formulated as follows:

$$f_{\text{c}} = F_4(\phi_{\text{E}}, \phi_{\text{C}}, \phi_{\text{S}}),$$

where ϕ_E is the function determining the control efficiency; ϕ_C is the function determining the control continuity; ϕ_S is the function determining the control security.

The functional characterizing the quality of the decisions made is defined as follows:

$$f_{\mathrm{d}} = F_5(\psi_{\mathrm{T}}, \psi_{\mathrm{V}}),$$

where ψ_T is the function determining the timeliness of decisions made; ψ_V is the function determining the validity of decisions made.

The functional characterizing the quality of planning is defined as follows:

$$f_{\mathrm{p}} = F_6(\varepsilon_{\mathrm{V}}, \varepsilon_A),$$

where ε_V is the function determining the validity of planning; ε_A is the function determining the accuracy of planning.

Thus, formula (3) can be rewritten as follows:

$$\beta = F(F_1, F_4, F_5, F_6). \qquad (4)$$

The values of the functions the functional is based on (4) can be used as particular indicators of efficiency assessment in order to compare the juxtaposed production systems. The coefficient itself acts as an integral indicator that allows assessing the influence of the control system on the degree of implementation of the production potential or the speed of its delivery.

We shall consider the second option based on the contribution of the control system to the implementation of the properties of a certain production system.

Suppose *TP* is the indicator determining the current value of the possible implementation of the production potential. Suppose this value is determined on the basis of convolution reflecting the integral contribution of all system properties to the implementation of the production potential $TP = F(f_1, f_2, \ldots, f_{10})$. Suppose fi is the contribution indicator of each property of the system to the implementation of the production potential defined as the function $f_i = \varphi_i(f_O, f_C)$ from the properties of organization and controllability, whereby $f_O = f_5$, $f_C = f_4$. Then the current value of the production potential's possible implementation can be formulated as $TP = F(\varphi_1(f_O, f_C), \ldots, \varphi_{10}(f_O, f_C))$. Suppose certain changes have occurred in the control system of the production system, thus leading to a change in the properties of organization and control expressed by the new values f'_O, f'_C. Then the new value of the possible implementation of the system's production potential can be formulated as $TP' = F(\varphi_1(f'_O, f'_C), \ldots, \varphi_{10}(f'_O, f'_C))$. The assessment of the changes in the production system can be made according to the degree of possibility incrementation of the production potential's implementation, formulated as follows:

$$\Delta TP = 1 - \frac{TP'}{TP}.$$

4 Conclusion

Not claiming to make an exhaustive presentation of approaches to assessing the efficiency of controlling production systems at airports, we have examined theoretically only several approaches that most adequately correspond to situations when a single information space of technological process control is used at airports. The proposed method of assessing the criteria for the efficiency of controlling production systems at airports involves not only the qualimetry of operators (decision-makers) according to the existing methods of implementing control functions but also the modeling of their processes according to advanced information technologies.

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