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A Formalised Approach to Optimal Adoption of a Complex of Technical Means

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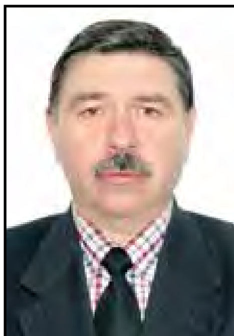

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ABSTRACT

The research relates to the field of automation of technological preparation of production in transport equipment manufacturing sector and proposes the concept of choosing the optimal design model for a complex of technical means within a control system in automated production. The factors characterising the dynamics of the processes have been studied, and the corresponding mathematical models have been drawn up, considering the cost characteristics and the economic feasibility of adopting integrated technical means.

The main objective of this work is to propose consideration of all parameters that have weight, including the dynamics of technical and economic processes. It is shown that cost characteristics are direct indicators of economic efficiency of the implemented complex of technical means.

Methodically, this work was carried out based on economic and mathematical analysis of adoption of a complex of technical means at a transport equipment manufacturing enterprise considering approaches previously suggested by researchers.

Thus, for the most accurate determination of the final cost of a certain product option, it is necessary to consider all factors of design decisions. Based on these data, a model of cost characteristics of products is built, analysing which it is possible to select the optimal product design, optimal assemblies and units with specific components and specific quality indicators. This allows obtaining the optimal technological version of the design solution during manufacturing.

A method of searching for an optimal production cycle when introducing an automated production system is proposed. It is proposed to consider the losses associated with temporary freezing of funds, including the need to perform a convolution of optimisation criteria. To formalise the process of making optimal decisions, it is also proposed to harmonise the products and market needs. Besides, the search methodology should include the search for an optimal group of employees responsible for implementation of specific and narrowly focused tasks, which makes it possible to improve the quality indicators of automated production with an adopted complex of technical means (CTM).

To minimise the time spent on entire commissioning of a product from the development stage to receipt of the finished product, it is required to speed up the development work. This can be done by increasing production capacity, as well as by reducing the time of partial cycles of the structure's existence.

Even though the model is becoming excessively redundant, we suppose that introduction of additional elements is necessary to consider all the nuances that help choosing the best solution regarding optimisation issues, which will allow determining of the full economic efficiency of the complex.

Keywords: *transport equipment manufacturing, complex of technical means (CTM), cost characteristics, optimisation of technological processes.*

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INTRODUCTION

Any transport equipment manufacturing, automotive or aircraft-building enterprise faces an acute problem of reducing the design and technological cycle of production. In the age of information technology, development of production automation is one of the highest priority areas. However, many engineering tasks are still notable for their complexity and it is not possible to quickly automate the entire technological process, therefore, a phased formalisation of the order of production routes is still relevant.

The *objective* of the study is to develop technique to select the optimal technical means to be integrated into the production complex to obtain optimal technical and economic indicators considering variability of technical and economic processes depending on the influencing external and internal production factors.

The increase in the efficiency [1] of production is a criterion of adoption of a new technology or of a scientific and technological solution both from a technical and from an economic point of view.

Numerous studies, including international research, aimed at finding optimal solutions to ensure manufacturability suggest conclusion that adoption of innovations, traditionally considered in the literature, have many subclasses. Careful strategic planning is required [2] to integrate new technological approaches into existing production processes, or to develop new proposals for fundamentally new products. The implementation of the complex of technical means (CTM) allows for systematisation in project management issues, as well as for quality control after adoption of certain innovative proposals.

The *method* used to identify the optimal full production cycle is reduced to the analysis of the dynamics of expenses and income.

Several works, e. g., the project conducted by Hungarian researchers [3], and focused on the study of effective use of information and communication technologies, show that the use of integrated technical solutions based on decision support systems helps enterprises to cope with the problems of uncertainty and complexity, to increase the effectiveness.

The hypothesis that intensification of work can lead to a reduction in the full production cycle of a product was confirmed by the mathematical model presented by the authors in [4]. It was shown that this approach can lead to a decrease in effectiveness of contributions.

RESULTS

General Approaches

The developed method for assessing cost characteristics contains several assumptions, while an important point cannot be ignored: the product quality vector is determined through the multidimensional technical component of the production process. Naturally, adoption of fundamentally new solutions will create an opportunity to expand the ideas on finding the optimal production cycle.

Based on the proposed method, it is required to determine those assemblies or groups of parts that are advisable to be replaced, or, on the contrary, to allow the continuity of existing technical solutions. To accurately determine the cost characteristics, it is necessary to consider, in addition to the above, dynamic parameters.

The factors of design solutions do not have a clearly dependent relationship, while considering the interaction of the elements of functions at each production level, those factors will make it possible to develop an optimal system.

When developing fundamentally new CTM, it is necessary to start from the basic version, by introducing innovations into weak links and not affecting the existing and well-functioning production facilities. The issue of unification in this matter is quite relevant. Modelling has shown that introduction of fundamentally new and original design solutions leads to impossibility of standardising either the technological process or CTMs themselves. Renouncing proven solutions often leads to economic loss due to the cost of producing new units and system elements, to loss of time and unjustified cost overruns, which, in turn, can lead to a delay in production and organisational difficulties caused by a new approach to production cycle.

Information technology in world practices is an integral step to improve quality of production of parts while reducing the cost and terms of adoption of technology [5].

When implementing promising technological processes at an enterprise, the economic effect is achieved primarily by saving production resources and, by increasing sales, thus reducing the cost of the product.

Costs have always been the main criterion that determines economic feasibility of introducing a CTM. Analysis of the price characteristics of products and their units includes design, production and operating costs applied to a specific maintenance unit. Meanwhile, the work [4] shows that it is impossible to reliably estimate the quality indicators of CTM based on data on the cost of a single unit.

The dynamics of production processes is determined by such factors as obsolescence of any product and control systems; speed of production and commissioning of new CTM. These factors determine the effectiveness of the developed products, while decisions ignoring those factors might turn to be far from rational ones.

To consider the positive technological progress in implementation of CTM, multiple criteria should be introduced that are responsible for economic indicators, while the proposed cost properties can be used as a synonym for economic efficiency.

The Suggested Techniques and Solutions

The desire to shorten the full cycle of a product as much as possible is logical and is a natural consequence of emergence of innovations in design and technological solutions. As a result, when starting to develop a new version of CTM, it is necessary to determine duration of the common cycle of the innovation system's existence. This parameter can be determined only based on the output technical features of the finished product.

At the initial design stage, the experience gained should be limited to indicative estimates based on statistical data.

There is a one-size-fits-all proposal that could be the key to solving many problems referring to design obsolescence issues. To minimise the time from development to series production start, it is necessary to reduce lead times and to focus on capacity growth.

The work [4] showed that «acceleration of initial stages of the cycle can be achieved mainly by forcing contributions by moving funds and increasing their amount, as well as through a more rational labour management».

The expansion of production capacity leads to a reduction in the product life cycle, due to shortening of the production stage, although in some cases this may lead to a violation of the optimal supply/demand ratio. Thus, it becomes possible to introduce various series of CTM into production, considering assessment of the economic effect from adoption of such innovative approaches and the optimal time for development and implementation of production.

Analysing some graphs of income and expenses (Pic. 1 [4]), we can mention the economic feasibility of making decisions on implementation of CTM.

Curve $R(\tau)$ is a graph of total expenses for all costs associated with operation of both the already used CTMs and those being adopted [6; 7]. The generalised fund $Fd(\tau)$ is determined through the integral of the economic effect from beginning of the full cycle τ_0 to beginning of the operation τ for the implemented CTM:

$$Fd(\tau)=\int_{\tau_0}^{\tau} R(\tau)\,d\tau.$$

The economic effect (return) $EE(\tau)$ is determined by the income received from operation of a specific series of CTM. Return on assets $\Psi(\tau)$, in turn, is an integral value:

$$\Psi(\tau)=\int_{\tau_0}^{\tau} EE(\tau)\,d\tau.$$

Profit $f(\tau)$ is calculated as the difference between the economic effects before and after introduction of CTM:

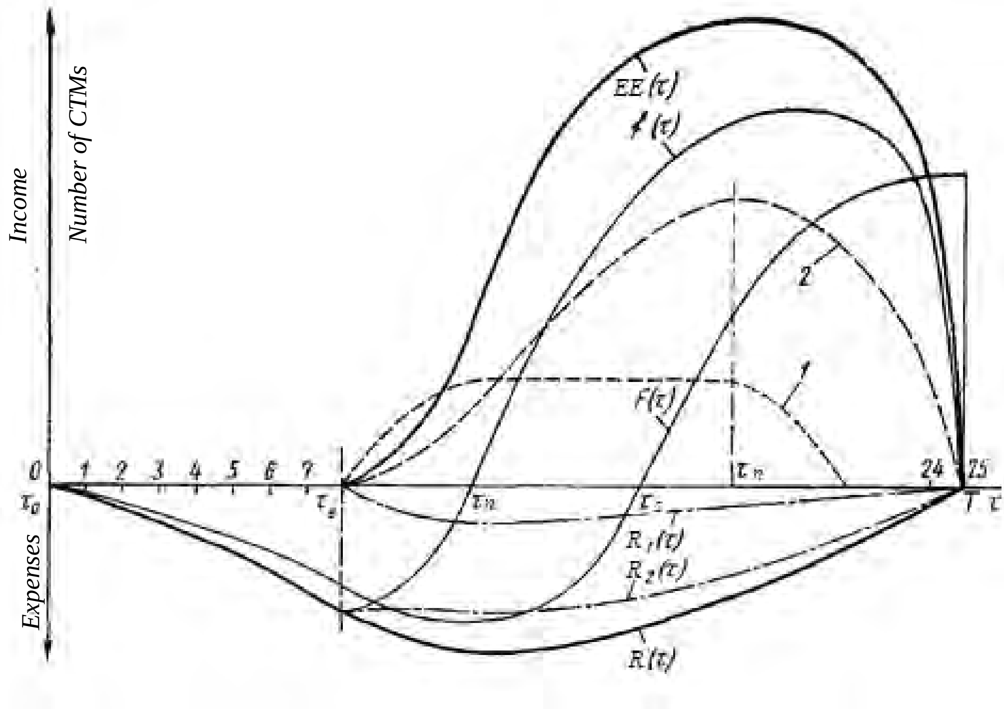
$f(\tau) = EE(\tau) - R(\tau)$.

The economic effect, that is, the excess of income over expenses, appears only after a certain moment of time τ, when the equality $EE(\tau) = R(\tau)$ is reached, which is clearly shown in the graph (Pic. 1). Until this moment, despite availability of economic resources, there are frozen funds. The moment of time τ_n is the starting point for the growth of self-sufficiency, when a part of frozen funds overlaps, exceeding the utility function in terms of the cost function.

At some time τ_s, the integral $F(\tau) = \int f(\tau)d(\tau)$, passing through the zero mark, takes a positive value. The time τ_s is called the «self-sufficiency time». After that, the period begins when the «net» profit from implementation of CTM increases. The profit margin is defined as:

$$\tilde{F}(\tau)=\int_{\tau_s}^{T}\left[EE(\tau)-R(\tau)\right]d\tau.$$

However, such a definition of economic efficiency of deposits does not correctly indicate the full volume of economic processes, since it does not consider the significant losses associated with temporary freezing of funds. Next, the criteria are rolled up and multicriteria optimisation is performed. This approach is described in more detail in [8].



Pic. 1. Dynamics of income and expenses. R(τ) – total expenses, including for operation – $R_1(\tau)$; for production – $R_2(\tau)$; 1 – release of CTMs;2 – number of operated CTMs [4].

Considering time delays due to movement of funds, funds are created that allow getting profit, expressed in *K* percent. If the costs incurred at the initial stage (as a rule, during the first year) were frozen for the entire period of the use of CTM series, then the calculation is carried out for *n* years since the retention does not bring economic profit:

$$\Delta Fd = (1+K)^n \int_0^1 R(\tau)d\tau - \int_0^1 R(\tau)d\tau =$$

$$= \left[(1+K)^n - 1\right]\int_0^1 R(\tau)d\tau = \left[(1+K)^n - 1\right] Fd_1,$$

where $Fd_1 = \int_0^1 R(\tau)d\tau$ represents the frozen contribution during the first year.

As well as for the case when freezing or a significant reduction in funds occurs during the *i*-th year, the money fund changes downward by an amount defined as:

$\Delta Fd_i = [(1 + K)^{n-i} - 1]\, Fd_i$.

Accordingly, if all the funds spent on development and adoption of a CTM series were frozen for *n* years (the service life of the structure), then the total losses, considering losses incurred due to exclusion of these funds from circulation, can be determined as *Fd*:

$$Fd = \sum_{i=1}^{n}\left[(1+K)^{n-i} - 1\right] Fd_i + Fd_T = \sum_{i=1}^{n} Fd_i (1+K)^{n-i},$$

since $\sum_{i=1}^{n} Fd_{iT} = Fd$ – total amount of cash costs, considering various unaccounted parameters, the final value will be determined as:

$$Fd = \sum_{i=1}^{n}(1+K)^{n-i}\int_{i-1}^{i} R(\tau)d\tau.$$

To determine the overall economic effect, it is appropriate to use a continuous form, and not a separate expression for *Fd*. For this purpose, we divide the calendar period (one year) into small discrete time sections Δτ, satisfying the condition $n_1 \bullet \Delta\tau = T$, and compose the limit:

$$\lim_{n_1\to\infty}\sum_{i=\frac{T}{n_1}}^{n_1\Delta\tau}(1+K)^{\frac{T}{n_1}(n_1-i)} R(\tau)\Delta\tau =$$

$$\lim_{n_1\to\infty}\sum_{i=\frac{T}{n_1}}^{\frac{T}{n_1}(n_1)}(1+K)^{\frac{T}{n_1}(n_1-i)} R(\tau)\Delta\tau = \int_0^T (1+K)^{(T-\tau)} R(\tau)d\tau.$$

Generally, we can write:

$$Fd = \int_0^T (1+K)^{(T-\tau)} R(\tau)d\tau.$$

To solve the optimisation problem of effectively increasing turnover of funds for organising production, let us consider in detail the structure of the function $R(\tau)$.

According to the complete scheme of the production cycle, this function $R(\tau)$ can be represented through a number of components, each of which is also determined by several indicators. For example, cost component of the «preparatory phase of development of a new series» is determined by four cost items (18 components in total).

It should be noted that some indicators partially overlap each other, and the function $R(\tau)$ can be rewritten as:

$$R(\tau)=\sum_{i=1}^{n} r_i(\tau),$$

where $r_i(\tau)$ are current expenses for the i-th specific cycle.

The costs are described by a finite function defined only in a limited region $\tau_i-\tau_j$; $i, j \in \{1, \ldots, n\}$, which takes zero values in other intervals. Thus, the function $R(\tau)$ itself is determined in the 0–T range and tends to zero outside this interval.

It should be noted that integration of electronic computing systems allows opening new horizons in development of any industry.

The performance and manufacture of many modern products (cars, washing machines, robots, or machine tools) and their production depend on the ability of the industry to take advantage of advances in technology and incorporate them during the design phase into both products and manufacturing processes.

Such production systems, in which CTM is already integrated, as well as the systems integrating an interdisciplinary approach to engineering design, from a technical and managerial point of view, become significantly more competitive in relation to their predecessors [9].

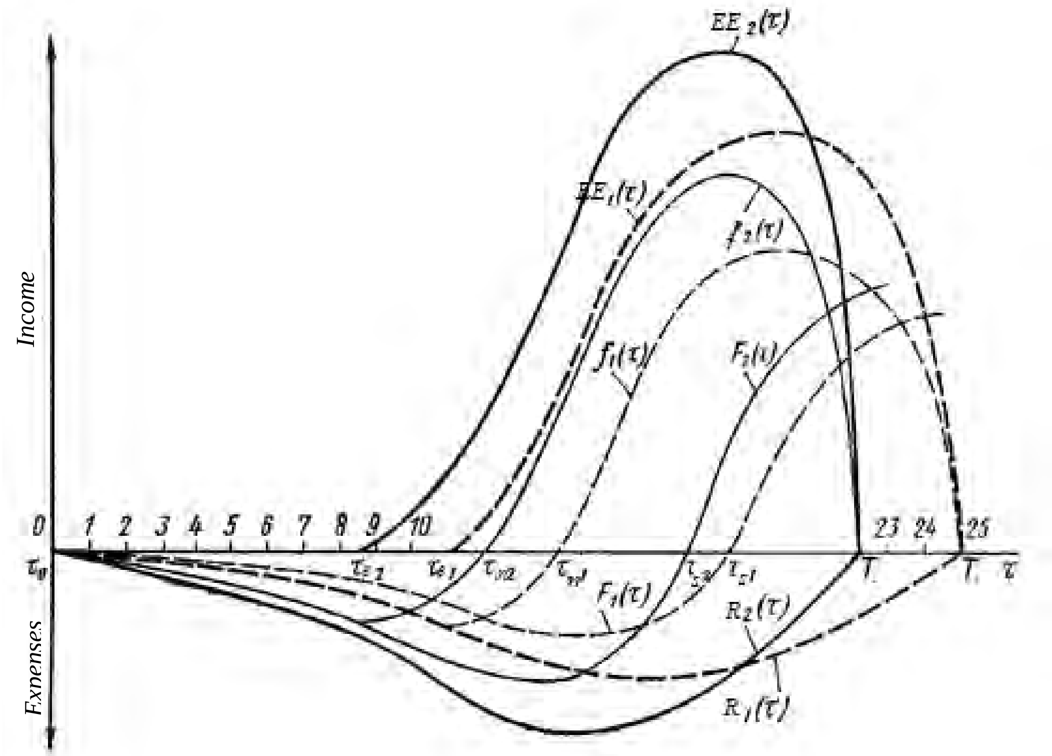
Identification of each component influencing costs can be carried out based on statistical data.

The return of funds, which is possible after adoption of a new CTM system, starts from the moment of time τ_e. Obviously, returnable money cannot immediately get into circulation and can only be considered as a possible additional profit. Income is determined for the function $f(\tau)$ during the time interval τ_e in percentage K until a certain moment T.

Profit can be determined through the integration of each component:

$$\phi(\tau)=\int_{\tau_e}^{T}(1+K)^{(T-\tau)} f(\tau)\,d\tau.$$

The dependences $\Phi(\tau)$, as well as $\varphi(\tau)$, are not new in the description of costs and relate to the traditional formulas of enterprise economics.



Pic. 2. Influence of intensity of financing on efficiency of CTM; indices «1» correspond to the initial variant, indices «2» correspond to the competing one [4].

Generalised functions $f(\tau)$, like the function $R(\tau)$, consist of a number of components, which are the most important, however, the most difficult to be formalised. The true profit is determined by the function $f(\tau)$ on the interval τ_e – T and, like the function $R(\tau)$, in this area can be represented as:

$$F(\tau)=\phi-Fd=\int_{\tau_e}^{T}(1+K)^{(T-\tau)}f(\tau)-\int_{\tau_0=0}^{T}(1+K)^{(T-\tau)}R(\tau)d\tau.$$

In relation to expenses, we get:

$$g=\frac{\phi-Fd}{Fd}=\frac{\int_{\tau_e}^{T}(1+K)^{(T-\tau)}f(\tau)-\int_{0}^{T}(1+K)^{(T-\tau)}R(\tau)d\tau}{\int_{0}^{T}(1+K)^{(T-\tau)}R(\tau)d\tau}.$$

Getting an opportunity to calculate the absolute value and the relative value of «net profit», one can proceed to determining the optimal system for intensifying deposits when organising production using the new CTM series. «The decision on effectiveness of an innovative project is made considering the values of all constituent applications» [10].

For convenience of considering several options for adoption of CTM (Pic. 2), we will present the lifetime of the structure under the initial financing option as T_1 and the total funding of the base option as Fd_1. Then, using the integral approach, you can write:

$$Fd_1=\int_{\tau_0}^{T_1}(1+K)^{(T_1-\tau)}R_1(\tau)d\tau,$$

where $P_1(\tau)$ – costs in the original version;

φ_1 – total costs.

$$\phi_1=\int_{\tau_0}^{T_1}(1+K)^{(T_1-\tau)}f_1(\tau)d\tau\ .$$

For the updated version, we rewrite the expressions as:

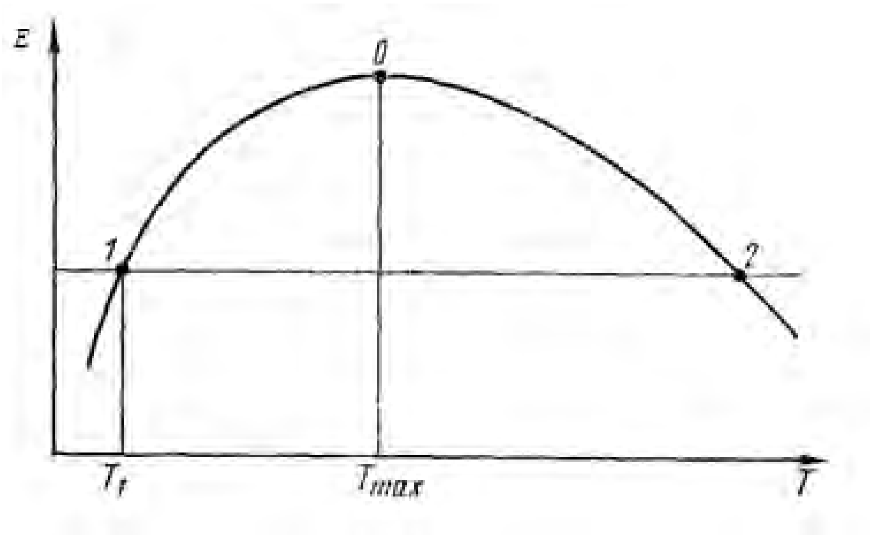
$$Fd_2=\int_{\tau_0}^{T_2}(1+K)^{(T_2-\tau)}R_2(\tau)d\tau$$

and

$$\phi_2=\int_{\tau_0}^{T_2}(1+K)^{(T_2-\tau)}f_2(\tau)d\tau\ ,$$

where $R_2(\tau)$ – production costs for the modernised production process (forced version).

The real profit in the first case is defined as $F_1=\varphi_1-Fd_1$, for the forced option the equality $F_2=\varphi_2-Fd_2$ is true. To analyse the effectiveness of the changes made, let’s analyse the ratio of profit indicators:



Pic. 3. Efficiency as a function of intensity of financing of operations [4].

$$\bar{E}(\tau)=\frac{F_2}{F_1}=\frac{\int_{\tau_{e2}}^{T_2}(1+K)^{(T_2-\tau)}f_2(\tau)d\tau-\int_0^{T_2}(1+K)^{(T_2-\tau)}R_2(\tau)d\tau}{\int_{\tau_{e1}}^{T_1}(1+K)^{(T_1-\tau)}f_1(\tau)d\tau-\int_0^{T_1}(1+K)^{(T_1-\tau)}R_1(\tau)d\tau}.$$

The work [4] has previously offered detailed analysis of statistical data showing that «the function $\bar{E}(T)$ has the form shown in Pic. 3, and can be analytically represented as a ratio of approximating polynomials. The left branch of this curve (section 1–0) means that with excessive intensification of operations, leading to a reduction in the full cycle, the efficiency of contributions decreases. This is explained by the following: for each technological process there are minimum terms of operations, which at a given level of technology development cannot be practically reduced».

The graph (Pic. 3) shows that the more time is spent with less funding, the more orderliness is in the algorithm of the tasks performed. In case of a decrease in deposits, the adoption of CTM significantly slows down and leads to additional costs associated with retention of funds and depreciation of products due to obsolescence of products and technological solutions.

All factors that have a direct or indirect impact on the system are considered in the functions $R_1(\tau)$, $R_2(\tau)$, $f_1(\tau)$, $f_2(\tau)$, for two cases: with the previously used CTM and for the forced version. Functions (Pic. 2) are defined by polynomials with the same degree for each corresponding pair of factors, but with different coefficients for the full-time cycle.

As stated in [4]: «The integrals $Fd_2(T_2)$ and $\varphi_2(T_2)$ have a form similar to the form of the functions $Fd_1(T_1)$ and $\varphi_1(T_1)$».

Many researchers were engaged in optimisation of production processes, e.g., G. K. Goransky, N. M. Kapustin [11; 12]. The stages of adoption of CTM are most fully studied in works by S. P. Mitrofanov. It should be noted that the technological process shown in his work [13] is a model that includes ready-made technological solutions necessary for effective application of modern information technologies to production automation procedures in general and to procedures for preparing technological production. Same problems are also presented in [14].

Similar issues were also escribed in works [2; 15; 16], which noted the theoretical relationship between strategic adaptation, innovation management practices and business results.

Several domestic works also show the economic feasibility of applying innovations and adopting CTM in production [17; 18].

The modelling is based on the need for initial stages of automation and unification of CTM parameters, however, in real conditions, the approach to each specific request should not be formalised, but aimed at achieving the best result, which is also reflected in [19].

BRIEF CONCLUSIONS

The proposed analysis refers to economic efficiency of boosting the full cycle of the technological process of automated production.

The substantiated choice of the optimal set of technical means is shown based on a diagram of the full production cycle and integrated approach considering such components as the costs of the «preparatory stage of development of a new series», the economic usefulness of CTM and the obsolescence rates.

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