UDC 007.5
DOI: 10.15587/1729-4061.2021.240163

# DEVELOPING INTERACTIVE INTERACTION OF DUAL BUFFERING SYSTEMS AND CONVERSION CLASS SYSTEMS WITH CONTINUOUS SUPPLY OF TECHNOLOGICAL PRODUCTS

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***Many modern industrial production facilities consist of sequentially operating systems with a continuous supply of technological product. The task of stabilizing the qualitative and quantitative parameters of output products at all stages of such production is a very difficult task and often leads to additional time and money costs. Therefore, improving the efficiency of these processes is a relevant issue.***

***A review of analogous solutions to this type of problem revealed the variability of their authors' approaches. However, all of them are aimed at optimizing existing control trajectories, rather than creating a new, more accurate trajectory.***

***Earlier, as part of the description of the basic principles of structural and parametric optimization of the management of production processes of this type, only the improved work of technological subsystems was reported.***

***This paper describes the principles of control over the proposed dual buffering system and its interactive interaction with other technological subsystems.***

***The introduction of buffering systems makes sequential technological subsystems more independent of each other. That makes it possible to increase the degree of freedom for each control subsystem and thereby improve the efficiency of finding the optimal mode of operation of the entire cybernetic system.***

***A conceptual model of the dual buffering system was built, the stabilization of the quantitative parameter at the output of the buffering system was substantiated through the development of an adaptation mechanism, and simulation modeling of the synthesized system was carried out.***

***The study shows that the use of buffering systems could improve the quality of energy utilization and reduce the wear of technological mechanisms by 14 % in general***

***Keywords: dual buffering system, interactive interaction, adaptive control system, reserve levels***

*Received date 13.08.2021*
*Accepted date 14.09.2021*
*Published date 29.10.2021*

***How to Cite:*** *Lutsenko, I., Koval, S., Tytyuk, V. (2021). Developing interactive interaction of dual buffering systems and conversion class systems with continuous supply of technological products. Eastern-European Journal of Enterprise Technologies, 5 (4 (113)), 20–25. doi: https://doi.org/10.15587/1729-4061.2021.240163*

## 1. Introduction

Within the framework of research into the principles of controlling systems with continuous supply of the technological product, there is an issue related to maximizing the quality of resource utilization with the preservation of the qualitative and quantitative parameters of the system at the output [1, 2]. This is due to the limited number of degrees of freedom for the control system and, as a result, the lack of options for control trajectories.

Another reason for the inefficient operation of such systems is the additional losses during the launch of the entire technological process. The frequency of such launches proportionally depends on the discrepancy between the quantitative parameter at the output of the previous system and the input of the subsequent technological system of the transformative type.

These two main issues can be addressed by arranging dual buffering systems between continuous systems. Buffering systems, which are to be placed between each technological subsystem, order and accept products from the previous system of the transformative class and transfer it to the next system after request of the latter. That is, the buffering system controls the replenishment mode and makes the work of neighboring technological subsystems invisible to each other.

The dual buffering system is an object that provides an independent implementation of the replenishment function and the function of issuing stocks, and the information exchange between interacting sub-objects is ensured through independent monitoring by these sub-objects of the level of stocks of the buffering mechanism [3].

Thus, the management of continuous technological processes with the stabilization of qualitative and quantitative parameters of the output product is a very relevant task that must be scientifically solved.

## 2. Literature review and problem statement

Issues related to improving the productivity of systems with continuous supply of technological product through design improvements are described in work [4]. It is shown that by reducing the size of the technological subsystem, an increase in the efficiency of operations was achieved. Thus, the authors only varied the input parameters of the system.

Cost reduction due to adaptive sampling of the search for the optimal control trajectory in production with continuous processes is described in [5]. The advantages of the theory of highways in optimal control and the process of finding the location of control sampling points are shown. However, with a small number of degrees of freedom and, accordingly, options for control trajectories, the search for a particular point of the optimum in them is not expedient.

Paper [6] describes the general concepts of the operation of dynamic systems over continuous time and the possibility of decentralization of settings. However, that does not affect the effectiveness of management and does not solve the paper's goal of structural changes in systems to achieve improved management.

Optimization of the parameters of the reverse oscillation control model was shown in [7]. The cited work reports an approach to the selection of optimal parameters for controlling crystallizer oscillations in the process of continuous casting. However, the optimization was aimed at reducing the depth of the vibration traces and was carried out within the limits imposed by the process parameters affecting the quality and performance of continuous casting.

There are many studies tackling innovations in the field of improving optimization algorithms. Those include an algorithm for optimizing continuous processes based on a natural hydrological cycle, based on the continuous movement of water in nature [8], and a combination of the method of hybrid spectral collocation and the method of homotopy analysis [9] and multimodal optimization, which uses a combined method that includes optimization of a swarm of particles and continuous optimization of an ant colony [10]. However, the authors used a variety of indicators as performance criteria that are not verified as criteria indicating the mode of maximum efficient utilization of the input resources of the system.

It was in work [11] that the method of structural-parametric optimization in systems with a continuous supply of technological products from the technological subsystem was described. The sectional-modular model of the dynamic technological system, which provides independent stabilization of the qualitative parameter of the technological product, was also described in detail. This approach made it possible to increase the possibility of search engine optimization for each management subsystem individually. However, the cited paper does not reveal the issue of synthesis of sequentially connected technological systems and dual buffering systems, which could make it possible to manage the entire chain of the continuous technological process interactively and establish individual control trajectories for each subsystem. That would make it possible to improve the overall quality of the entire production chain by reducing energy costs and reducing the wear of technological mechanisms.

Thus, the options described above for solving the problem of increasing the efficiency of continuous technological processes have demonstrated the variability of their authors' approaches. However, all of them [4–10] are aimed at optimizing existing control trajectories, rather than creating a new, more accurate trajectory. In [11], only the improved operation of technological subsystems was presented, which does not reveal the whole idea of an innovative approach to the optimization of transformative class systems with a continuous supply of a technological product.

## 3. The aim and objectives of the study

The aim of this work is to study the principles of control over a dual buffering system and interactive interaction with other technological subsystems in a single chain of a continuous technological process, which could ensure an increase in the optimization capabilities of control processes.

To achieve the set aim, the following tasks have been solved:

– to build a conceptual model of the dual buffering system for a production line with a continuous supply of a technological product;

– to substantiate the stabilization of the quantitative parameter at the output of the buffering system by controlling the lower and upper level of reserves based on relatively independent operation of the control subsystems of neighboring systems of the transformative type.

## 4. The study materials and methods

In order to achieve an increase in the capabilities of the control processes of the entire production line with a continuous supply of the technological product, it is necessary to include dual buffering systems between each technological subsystem. Such structural changes would allow each control subsystem in each technological unit to work independently and thereby expand the possibilities of searching for the optimum.

The practical implementation of such a principle may be constrained by two factors.

The possibility of intermediate buffering may be excluded for technological reasons.

The second factor has an economic basis. Buffering systems link large volumes of intermediate products. In addition, the performance of converting systems should be the higher, and the size of the buffering mechanisms the greater, the closer they are to the beginning of the technological process. Otherwise, the principle of continuity of the process and the possibility of its optimization at subsequent stages could not be ensured.

However, work of the dual system in interactive interaction with systems of the transformative type makes it possible to solve the following tasks:

– reduction of the cost of manufactured products by reducing the cost of moving systems or a transformative type system;

– reducing the risks of shortage of finished products;

– increasing the number of control trajectories in search of finding the optimum for the previous and subsequent systems;

– the possibility of optimizing production processes, including with a continuous supply of the technological product.

The operation of the dual buffering system is shown below. Checking the operability of the synthesized structure of the source, which generates the product of directed action, is presented in the form of a diagram depicted in Fig. 1. The proposed interface model refers to automatic control systems for technological products.

The following designations are accepted in Fig. 1: sSrcA1$_{PD}$ – cold liquid supply source outlet; sSrcA1$_{ZD}$ – supply source inlet; sSrcP1$_{PP}$ – energy product supply source outlet; sSrcP1$_{ZPS}$ – energy product supply source inlet; sConvA1$_{RD}$ – inlet; sConvA1$_{UD}$ – outlet; sConvA1$_{RP}$ – inlet; sConvA1$_{UPS}$ – outlet; sConvA1$_{ZP}$ – energy product supply intensity setting; sConvA1$_{Z}$ – quality product production setting signal; sConvA1$_{PD}$ –output product; sConvA1$_{ZD}$ – setting the volume of cold liquid supply; sConvA1$_{CL}$ – current loading level of the heating mechanism buffer; sConvA1$_{TE}$ – ambient temperature; sConvA1$_{ET}$ – outlet temperature setpoint; sConvA1$_{INT}$ – intensity of the delivery of a quality product; mBufA1$_{RD}$ – buffering input; mBufA1$_{UCL}$ – current level; mBufA1$_{PD}$ – buffering output; mBufA1$_{SL}$ – initial level; mBufA1$_{RPS}$ – task for the issuance of the target product; mCmpA1$_{T}$ – controlled parameter; mCmpA1$_{S}$ – reference; mCmpA1$_{OUT}$ – output signal; mCmpA2$_{T}$ – reference; mCmpA2$_{S}$ – controlled parameter; mCmpA2$_{OUT}$ – output signal; mFinA1$_{IN}$ – input signal; mFinA1$_{OUT}$ – output signal; mCrdB1$_{IN}$ – input pulse signal; mCrdB1$_{CRD}$ – input transferred signal; mCrdB1$_{OUT}$ – output signal; mCrdB2$_{IN}$ – input pulse signal; mCrdB2$_{CRD}$ – input transferred signal; mCrdB2$_{OUT}$ – output signal; mNoA1$_{IN}$ – input; mNoA1$_{OUT}$ – output; mOr2A1$_{IN1}$ – first input signal; mOr2A1$_{IN2}$ – second input signal; mOr2A1$_{OUT}$ – output signal; mMemA1$_{IN}$ – input signal; mMemA1$_{OUT}$ – output signal; mMemA1$_{RES}$ – input reset signal; mSelA1$_{IN}$ – input pulse signal of current amplitude; mSelA1$_{ET}$ – reference amplitude pulse input; mSelA1$_{OUT}$ – output pulse signal with reference amplitude; mRecA1$_{U}$ – replenishment request; mRecA1$_{RD}$ – obtaining a special product; UP – section for receiving a task signal for the value of the intensity of the energy product supply; UHL – upper level of stocks; ULL – lower stock level; ZCL – current stock level.

By developing an interface model, one can determine which element of the buffering system interacts with another system, where the technology product is transferred, where data are entered to transfer control and receive the task, and where control parameters are set.

Interactive interaction of parallel connected systems of transformative type and dual buffering systems proceeds as follows.

The mCmpA1 and mCmpA2 comparison mechanisms consistently compare the current lower and upper inventory levels, respectively, in the buffering mechanism with the established upper (UHL) and lower (ULL) inventory levels.

If the reserves reach the lower level (information from the UCL section of the mBufA1 – mBufA1$_{UCL}$ mechanism), the mCmpA1 comparison mechanism generates a single pulse signal (mCmpA1$_{OUT}$), which ensures the beginning of the replenishment process. Through the output (mCrdB1$_{OUT}$) of the coordination mechanism and the output (mOr2A1$_{OUT}$) of the two-way mechanism «OR», the signal with the task of producing a quality product enters sConvA1$_{Z}$.

Output (sConvA1$_{UD}$) and input (sSrcA1$_{ZD}$) provide a single replenishment request signal. Based on this information, from the output (sSrcA1$_{PD}$) of the cold liquid supply source, a directed product is transferred to the input (sConvA1$_{RD}$) of the quality product production system.

At the end of the product transfer to the system, a single output signal is generated from the sConvA1$_{UPF}$ section, which enters the input (sSrcP1$_{ZPF}$) of the energy product supply system. This system transmits the energy product to the sConvA1$_{RP}$ input from the output of the sSrcP1$_{PP}$ section. Based on this, the sConvA1$_{ZP}$ section, which received the signal from the ZP section, sets the value of the intensity of the energy product supply. After the completion of the technological operation in the sConvA1 system, the target product from the *sConvA1$_{PD}$* section enters the mBufA1$_{RD}$ section of the buffering mechanism. The next replenishment operation is provided by the mFinA1 mechanism, which generates a single pulse signal (mFinA1$_{OUT}$) after the completion of the reception of the batch of products.

A distinctive feature of the dual buffering system is its relative independence of functioning on the control subsystems of the transformative class system.

It was proposed to use a mechanism that adaptively selects the lower and upper level of stocks based on the intensity of the supply of the target product from the previous technological system and the intensity of consumption by the subsequent one. This approach allows independent operation of control systems and uninterrupted operation of the previous and subsequent systems of the transformative type.

The implementation of the function of forming the trajectory of quasi-optimal control is provided by the mAdpA1 mechanism (Fig. 2).

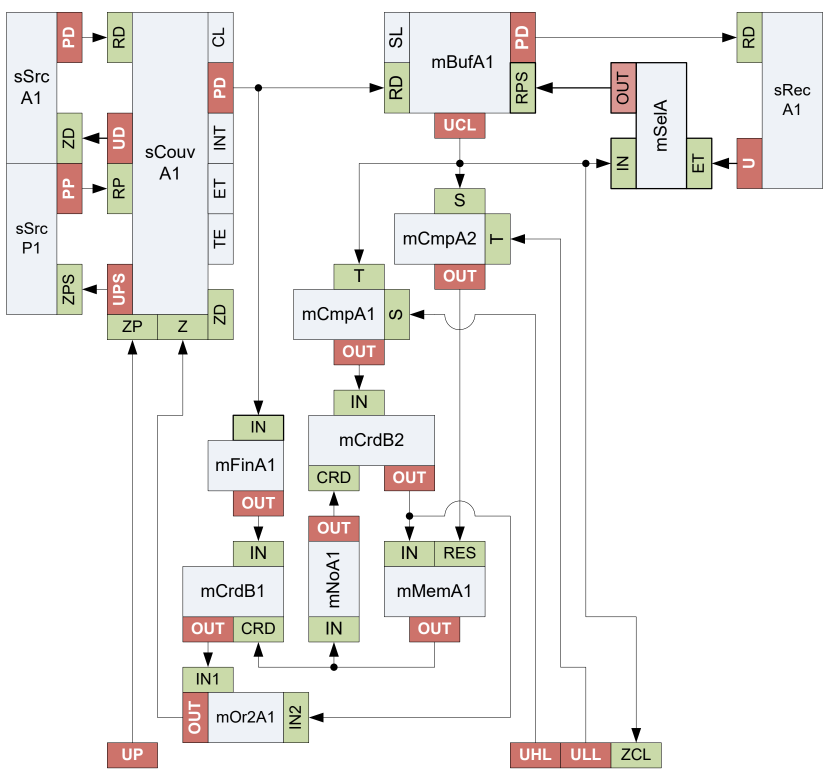


Fig. 1. Interface model of dual buffering system for production systems of transformative class with continuous supply of technological products

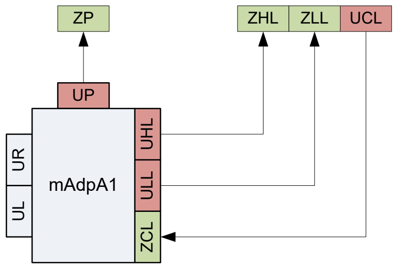


Fig. 2. Mechanism of adaptation of the upper and lower levels of the buffering system: $mAdpA1_{ZCL}$ – section for issuing the current value of the stock level; $mAdpA1_{ULL}$ – lower level of reserves; $mAdpA1_{UHL}$ – upper level of reserves; $mAdpA1_{UP}$ – energy product supply control; $mAdpA1_{UL}$ – left control boundary; $mAdpA1_{UR}$ – right control boundary; ZP – energy product supply control; ZHL – setting the upper level of stocks; ZLL – setting the lower level of stocks; UCL – current inventory level

At the first stage of the study, UL management was determined, at which the maximum of added value was achieved, and UR management, at which the maximum efficiency of the transformative class system was reached. In the process of operation of the entire chain of subsystems, the mAdpA1 mechanism, while estimating the volume of receipt and consumption of stocks, selected the optimal values for the upper and lower levels and thereby stabilized the quantitative parameter of the dual buffering system.

## 5. The results of studying a dual buffering system

**5. 1. Construction of time diagrams of the conceptual model of the dual buffering system for a production line with a continuous supply of a technological product**

Based on the buffering described above, a simulation of its process was carried out, taking into consideration the relative independence of the previous and subsequent control subsystems of the transformative type systems. In order to make sure that the problem of synthesis of the controlled system was solved correctly, an automatic functioning model of all complete mechanisms that perform the necessary functions within the synthesized structure in a specially created modeling environment for controlled systems EFFLI was built [12].

Using the developed mechanisms [13], optimal systems of two classes were created: physical product conversion systems (CS) and physical product buffering systems (BS). Thus, access to the study of the internal structure of the transformation system and the possibility of isolating its subsystems was obtained.

The results of the system operation in the EFFLI software designer, namely the streams of transmitted information between sections of objects, are represented on time diagrams. Fig. 3 shows the signals for recording the movement of internal products of the previous one from the buffering system of the transformative class, which involves the sSrcA1 cold liquid source system, the sSrcP1 energy product source system, and the sConvA quality product production system.

Fig. 4 shows time diagrams demonstrating the signals of recording the interaction of the transformation type system and the buffering system, namely the process of heating the cold liquid in the technological subsystem and its further movement into the buffering mechanism.

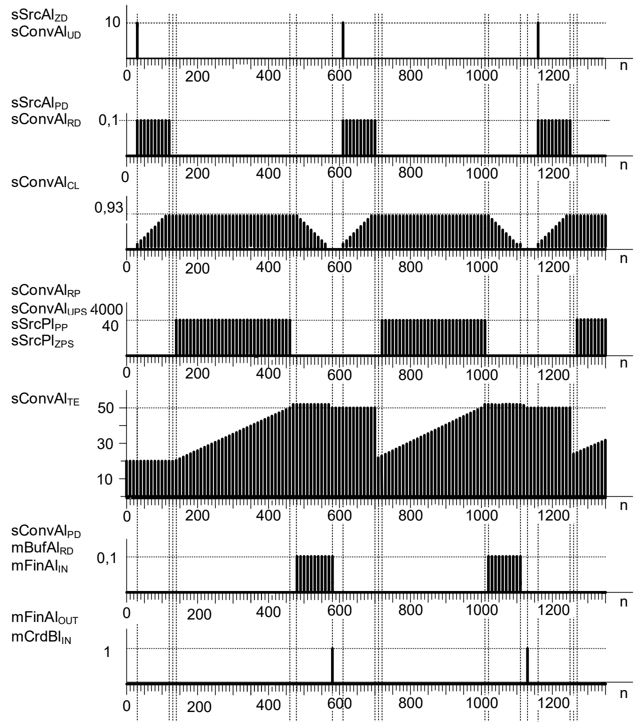


Fig. 3. Time diagrams explaining the principles of functioning of the conversion class system

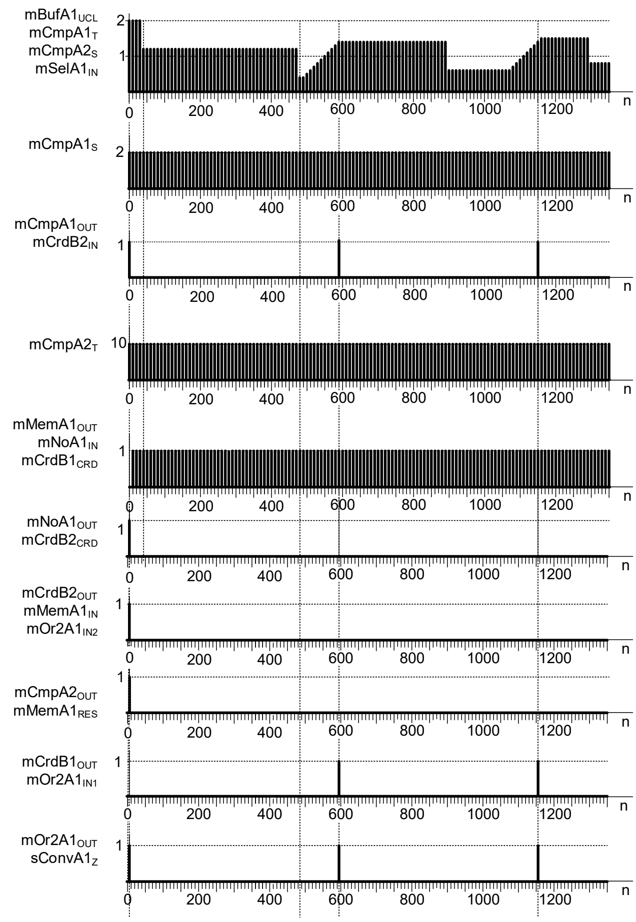


Fig. 4. Time diagrams explaining the principles of functioning of the dual buffering system

The time diagrams showing the signals of work registration following the buffering system of the transformative classroom system are shown in Fig. 5. After transferring the hot liquid to the sRecA1 system for further processing, a single pulse signal is formed from the $sRecA1_U$ section to request the transfer of an additional portion of a quality product.

Thus, our work on the construction of time diagrams makes it possible to explain in detail the principles of functioning of the entire chain of interrelated systems and their integrated interaction.

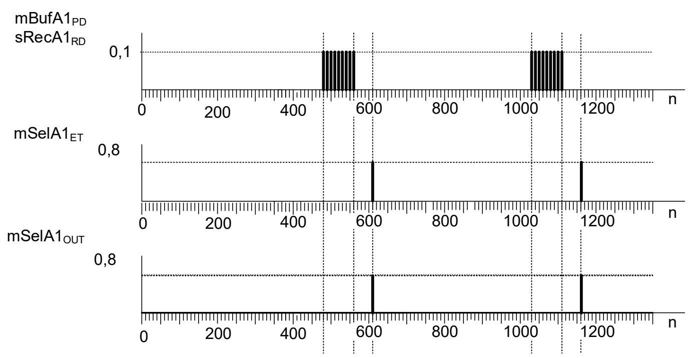


Fig. 5. Time diagrams showing the signals of interaction between the buffering system and the subsequent transformative class system

**5. 2. The results of controlling the lower and upper level of stocks in the dual buffering system to stabilize the quantitative parameter at the output of the system**

As discussed above, the chain of interconnected converter and buffering systems was tested in a specially created EFFLI controlled systems simulation environment. The report of the results of the dual buffering system's operation with the specified parameters is shown in Fig. 6, built in Microsoft Excel.

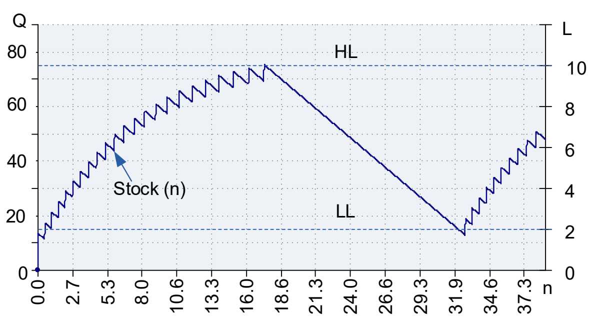


Fig. 6. Plot of changes in the level of stock

Since the continuous technological process is divided into a certain number of sections, the buffering system accumulates the target product in portions – the replenishment curve changes linearly-stepwise. The considered separation system gives the next technological system a product of directed action constantly.

Thus, the buffering system has a quasi-stationary nature of consumption, and the next conversion system – a stationary nature of consumption.

Our study shows that the use of dual buffering systems between the conversion class systems in the general chain of the process with a continuous supply of the technological product excludes the cases of stopping and restarting the entire production line. It is obvious that such a structure of automation of production is preferable and economically more profitable.

## 6. Discussion of research results related to the operation of the dual buffering system

As a result of investigating conversion class systems with a continuous supply of technological products, a conclusion was made about the limited optimization capabilities of their control systems. The solution to this problem was found with the help of structural changes in the production line, namely, by arranging dual buffering systems between continuous technological systems. The interface model of the dual model and its relationship with the previous and subsequent conversion class systems are shown in Fig. 1.

It is obvious that determining the optimal control for each technological system and buffering systems is not a separate task. These systems are connected by a continuous flow of the target product, and, accordingly, optimal control must be sought by determining the optimal trajectory of change in the control over the entire production system.

After conducting a simulation of the production line with a continuous supply of a technological product, one of the options for the operation of such a relationship was obtained (Fig. 3–5). Time diagrams describe in detail all the information flows that explain the principles of functioning of the first conversion class system, the dual buffering system, and the subsequent conversion class system.

With the help of the adaptation mechanism proposed to be used in the control subsystem of the buffering system, it was possible to stabilize the upper and lower level of stocks shown in Fig. 2. That allowed the neighboring control subn systems to work almost independently and thereby expand the optimization capabilities of technological systems.

As a result of the structural and parametric changes of the production line with continuous supply of the technological product, the following advantages and disadvantages were obtained:

– a new approach to improving the efficiency of technological processes with a continuous supply of the target product is proposed, which differs from existing analogs by the presence of buffering systems that gives an increase in the range of search optimization and determining the effective control trajectory for the studied system;

– stabilization of the qualitative and quantitative parameter at the output of the buffering system, which minimizes the risks of restarting the entire production line;

– creation of conditions for interactive and independent operation of control subsystems of each link of the production line;

– the possibility of using intermediate buffering only for processes that can allow for such technological innovations;

– the presence of significant economic costs at the stage of implementation of a given approach.

The practical implementation of the proposed structural and parametric optimization of the management of continuous processes of the conversion class can be constrained by two factors: technological limitations of buffering the product of directed impact, the economic high cost of the improvements being carried out.

Our technological advancements could be used for automatic control systems of production processes of the conversion class with a continuous supply of the technological product.

## 7. Conclusions

1. A conceptual model of the dual buffering system for a production line with continuous supply of a technological product has been proposed. It is proposed to include buffering systems between each technological unit, which makes it possible to divide the chain of interrelated continuous production processes and thereby ensure the independence of their control subsystems. That makes it possible to expand the possibilities of search optimization for each subsystem, and, accordingly, increase the efficiency of resource utilization for technological processes by 14 %.

2. To ensure the stabilization of the quantitative parameter at the output of the buffering system, it is proposed to divide it into two independent modules: buffering subsystems and control subsystems. In the process of operation, the control subsystem sorts out permissible options of the lower and upper level of stocks, which avoids stopping the next continuous technological process by 84 % and set the optimal level of reserves.

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