

UDC 004.82

DOI: 10.15587/1729-4061.2020.198527

*Удосконалено модель журналу подій інформаційної системи. Модель містить послідовності подій, що відповідають реалізованим послідовностям управляючих дій в рамках як процесного, так і функціонального підходів до управління. Для кожної пари подій, що належать до одного процесу, заданий строгий лінійний порядок в часі. Модель призначена для побудови опису прототипу бізнес-процесу «як є».*

*Запропоновано прецедентну модель бізнес-процесу, що описує особливості його відомих реалізацій, відображених в журналі подій. Модель об'єднує множину реалізованих послідовностей робіт кожного процесу і враховує час виконання цих робіт, а також необхідні для них ресурси. При описі часу виконання робіт процесу враховуються затримки при доступі до спільних ресурсів на підприємстві. Модель дозволяє прогнозувати строки завершення множини конкуруючих за ресурси бізнес-процесів при видаленні або додаванні нових процесів в це множини.*

*Розроблено технологію зміни послідовності доступу до ресурсів для набору конкуруючих за ці ресурси бізнес-процесів в рамках процесного управління. Запропонована технологія використовує прецедентну модель бізнес-процесу для розрахунку порядку доступу до ресурсів. Технологія дає можливість розрахувати сумарне скорочення затримок у часі виконання по відношенню до строків завершення бізнес процесів при конкуренції цих процесів за ресурси. Технологія дозволяє вибрати порядок доступу до ресурсів з найменшим запізненням по відношенню до строків завершення робіт для відомих варіантів виконання бізнес-процесу. Це дає можливість ОПР оцінити можливість запуску нових процесів, що використовують спільні ресурси, на основі скорочення часу очікування при доступі до цих ресурсів*

*Ключові слова: бізнес-процес, процесне управління, ресурс, подія, журнал подій, прецедент, затримка доступу до цих ресурсів*

Received date 24.12.2019

Accepted date 06.03.2020

Published date 30.04.2020

## 1. Introduction

The process approach to management is based on the description of a company as a system of inputs, outputs and business processes that transform input resources into products or services at the output. Each business process contains a sequence of actions that ensures the creation of the products needed by a consumer [1]. The effectiveness of process management is assessed by the degree of customers' satisfaction. The latter depends not only on the quality of products but also on the timeliness of its delivery.

The process management cycle includes the stages of the construction of the models of a business process, business processes management using these models, and adjustment of a model based on the results of analyses of business process implementation [2].

# DEVELOPMENT OF THE TECHNOLOGY FOR CHANGING THE SEQUENCE OF ACCESS TO SHARED RESOURCES OF BUSINESS PROCESSES FOR PROCESS MANAGEMENT SUPPORT

**S. Chalyi**

Doctor of Technical Sciences, Professor\*

E-mail: serhii.chalyi@nure.ua

**I. Levykin**

PhD, Associate Professor\*\*

E-mail: ihor.levykin@nure.ua

**A. Biziuk**

PhD, Associate Professor\*\*

E-mail: andrii.biziuk@nure.ua

**A. Vovk**

PhD, Associate Professor\*\*

E-mail: oleksandr.vovk@nure.ua

**Ie. Bogatov\***

E-mail: ievgen.bogatov@nure.ua

\*Department of Information Control Systems\*\*\*

\*\*Department of Media Systems and

Technologies\*\*\*

\*\*\*Kharkiv National University of Radio Electronics

Nauky ave., 16, Kharkiv, Ukraine, 61166

Copyright © 2020, S. Chalyi, I. Levykin, A. Biziuk, A. Vovk, Ie. Bogatov

This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0>)

The model of a business process includes a description of the sequence of operations taking into consideration the necessary resources [3]. The sequence of operations is assigned by the algorithm of conversion of materials, components, and information obtained at the input into the goods and information at the output. Resources play the role of restrictions. The untimely delivery of resources can affect the sequence of operations of a business process, as well as change its duration. The duration of a business process consists of the duration of separate operations, as well as the intervals of waiting for resources.

In general, the process approach involves the management of a system of interacting, interconnected business processes that use the company's shared resources. Competition of business processes for resources leads to delays in accessing them, untimely completion of a process and customers' dissatisfaction [4].

The problem of competition for resources is particularly relevant for end-to-end business processes [5]. The latter provide products and services to external consumers. The external consumers are those outside a company that implements the business process. In practice, such consumers have a significant impact on the terms of the launching and execution of end-to-end processes [6].

End-to-end business processes cover several subdivisions of an organization. Such processes share resources with other business processes that are implemented in these subdivisions under the supervision of their managers. Therefore, timely adjustment of the models of the end-to-end business process in order to change the sequence of access to resources is a relevant task. The solution of this task creates conditions for the timely implementation of a set of end-to-end business processes within the time limits suitable for a consumer.

---

## 2. Literature review and problem statement

---

The problem of adjustment of a model of business processes is traditionally solved after the completion of the stage of its life cycle analysis [1, 7]. This problem is solved based on the comparison of the models of business processes of two kinds: “as is” and “to be”.

The first model is constructed by experts at the stage of implementation of the process management and contains an “ideal” description of a sequence of operations [2]. When constructing this sequence, the specificity and conditions of processing the data, used by a business process, are taken into consideration [8].

The second model is actually a case of a business process and is formed after it is completed [9]. Both subjective data from executives and objective description of the sequence of process actions are used as input data during constructing this model. This description is shaped by the management system in the form of an event log. An event log has a different form when using functional and process approaches to management. In the first case, a log includes a set of time-ordered events of some business processes that solve a common problem. In the second case, a log includes a set of event-based tracks, each of which records a single execution of one business process. The event contains a record of the implemented process and the time of its execution [10]. The process mining methods are used to construct a model of a business process “as is” [11]. Using the event logs obtained in the framework of the functional management approach requires a pre-formation of process tracks [12].

Existing methods of process mining make it possible to construct the models of separate business processes taking into consideration the time of operations execution recorded in the log [13]. However, these methods have three significant drawbacks that make it difficult to apply them to support real-time process management. Firstly, the methods of process mining are focused on constructing the “as is” models once a business process is completed. This does not make it possible to dynamically adapt the “to be” model directly during the process implementation. Secondly, the mining technology is focused on constructing and analyzing models of separate processes. At the same time, the process management should take into consideration the interaction and competition for resources of at least a few end-to-end business processes of an enterprise. Thirdly, the existing

methods take into consideration the resources of business processes when constructing their models [2]. However, these methods do not address restrictions at the shared access to resources and the associated delays in the implementation of a business process.

Thus, information from event logs of business process record the actual sequence of execution of operations and that is why it can be used to change dynamically the sequence of the access to resources. It is appropriate to make such adjustments to process models during the implementation of a business process in order to meet the customers’ requirements in terms of operations completion. However, the existing methods for improving the process models based on analysis of event logs can be used only at the stage of analysis of the business process lifecycle. That is why the problem of adjusting the process models by changing the sequence of access to the shared resources of a company during the implementation of business processes requires its solution.

---

## 3. The aim and objectives of the study

---

The aim of this study is to develop the technology of changing the sequence of access to shared resources for a set of business processes while they are completed for the timely completion of their operations according to the requirements of a customer.

To accomplish the aim, the following tasks have been set:

- to update the model of an event log taking into consideration the differences in recording events at the functional and process approaches to management;
- to develop a case-based model of a business process “as is” with the intervals of waiting for resources based on analysis of an event log;
- to develop the technology of changing the sequence of access to shared resources of business processes during their implementation;
- to fulfill the experimental testing of the proposed technology of changing the sequence of access of business processes to shared resources.

---

## 4. Improvement of the model of an event log taking into consideration the records of events in functional and process approaches to management

---

The event log (log)  $Q$  in process management includes a set of tracks  $Q_i$ . Each track is a record of the implementation of one variant of a business process from all the possible options presented in the “to be” model. The track consists of a time-ordered sequence of events  $e_{i,j}$ :

$$Q = \{Q_i\}, Q_i = \langle e_{i,1}, e_{i,2}, \dots, e_{i,j}, \dots, e_{i,J} \rangle. \quad (1)$$

Each event  $e_{i,j}$  is a record of execution of action  $d_{i,j}$  of the process. Track  $L_i$  as a whole is a display of action sequence  $D_i$  of this process.

The actions of a process at each implementation can be performed both sequentially and in parallel. However, these actions are recorded on the log track sequentially as the correspondent operations are completed. That is why the events within one track are related by a strict linear order.

The sequences of events of different tracks reflect different variants of a business process. The course of action for

each of these options may be different. That is why the events for a log are generally related by a partial order.

Log  $F$  in functional management consists of a sequence of events recording the performance of the actions from a variety of business processes, for example,  $P_i, P_n, P_s$ :

$$F = \{F_l\}, F_l = \left\langle \begin{matrix} e_{i,1}, \dots, e_{n,1}, \dots, e_{s,1}, \dots \\ e_{i,2}, \dots, e_{n,2}, \dots, e_{s,2}, \dots \end{matrix} \right\rangle. \quad (2)$$

Event sequence  $F_l$  contains the records of the parallel execution of some processes. That is why the events within  $F_l$  are related by a partial order. Unlike log  $Q$ , this log contains information about the sequence of access to resources of several business processes within one record  $F_l$ .

Then the generalized log model  $L$ , which provides an opportunity to change the sequence of access to the resources of a company for some business processes, is represented as a set of pairs of events  $(e_{i,j}, e_{i,j+1})$ . Each of these pairs refers to the same implementation of a business process. For these pairs, strict linear order  $G$  is assigned:

$$L = \{L_i\}, L_i = \{(e_{i,j}, e_{i,u}) : \forall i \forall j \forall u (e_{i,j} G e_{i,u})\}. \quad (3)$$

Linear order  $G$  assigns a linear sequence of events over time:

$$\forall i \forall j \forall n (e_{i,j} G e_{i,u} \vee e_{i,u} G e_{i,j}), \quad (4)$$

$$e_{i,j} G e_{i,u} \Rightarrow t_{i,j} < t_{i,u}. \quad (5)$$

This order is asymmetrical and, therefore, characterized by anti-reflexivity and transitivity. Anti-reflexivity determines that the order is not assigned for separate events from a log:

$$\forall i \forall j \neg (e_{i,j} G e_{i,j}). \quad (6)$$

The transitivity condition makes it possible to link pairs of events into single track  $Q_i$  both for  $Q$ -type logs and for  $F$ -type logs:

$$\forall i \forall j \forall u \forall s (e_{i,j} G e_{i,u} \wedge e_{i,u} G e_{i,s} \Rightarrow e_{i,j} G e_{i,s}). \quad (7)$$

The generalized log representation (3) in the form of orderly pairs of events shows that event logs both in the process and functional management can be used to construct a case-based model of a business process “as is”. Approaches to constructing process-ordered events from  $F$ -type logs were considered in paper [12].

### 5. Development of a case-based model of a business process “as is” with intervals of waiting for resources based on analysis of its event log

The model of a business process “as is” includes a subset of the sequence of actions of a business process implemented in practice. This sequence is formed based on the orderly events of a log. Each event contains timestamp  $t_{i,j}$ , as well as the attributes of the corresponding action, including the name of the operation and necessary resources.

Each action  $d_{i,j}$  includes operation  $o_{i,j}$ , subset  $r_{i,j}$  of the total set of resources  $R$ , used by this action, as well as the duration of its implementation  $\Delta t_{i,j}$ :

$$d_{i,j} = \{o_{i,j}, r_{i,j}, \Delta t_{i,j}\}. \quad (9)$$

It should be noted that the concept of resources  $r_{i,j} \subseteq R$  in a broad sense is used in expression (9). Resources imply all the elements that characterize the action that has been performed. For example, the executor of action is also considered as a resource.

The duration of performing the action  $\Delta t_{i,j}$  according to the log model (3) is the difference between the timestamps of a pair of successive events  $e_{i,j}$  and  $e_{i,j-1}$ , provided that these events relate to different actions:

$$\Delta t_{i,j} = t_{i,j} - t_{i,j-1} | o_{i,j} \neq o_{i,j-1}. \quad (10)$$

Consecutive events will relate to different actions if no waiting for resources was recorded in the log. If resources are waited for, the duration of each action  $d_{i,j}$  consists of two components: interval of waiting  $\Delta t_{i,j}^w$  and interval of performance of operation  $\Delta t_{i,j}^o$ :

$$\Delta t_{i,j} = \Delta t_{i,j}^w + \Delta t_{i,j}^o. \quad (11)$$

Three events  $e_{i,j}, e_{i,j-1}$  and  $e_{i,j-2}$  are used during the calculation of action duration with the interval of waiting. Intermediate event  $e_{i,j-1}$  contains the same name of the operation as event  $e_{i,j}$ , however, the state of the operation (is performed, waiting) will be different.

Time  $T_i$  of performing one variant of business process  $D_i$  consists of the total time of queuing  $T_i^w$  and time of execution of actions  $T_i^o$ :

$$T_i = \sum_{j=1}^J \Delta t_{i,j} = \sum_{j=1}^J \Delta t_{i,j}^w + \sum_{j=1}^J \Delta t_{i,j}^o = T_i^w + T_i^o. \quad (12)$$

The second component in expression (12) is determined by the subject area (production technology, properties of treated objects, etc.).

The first component depends on the sequence of access to shared resources for several business processes  $P = \{P_k\}$ . Then to designate the total time for process implementation, delay and time for action execution, we will use the double index:  $T_{k,i}, T_{k,i}^w$  and  $T_{k,i}^o$ , accordingly.

The model of business process  $P_k$ , which takes into consideration the records in its event log and their timestamps, has the form of a set of action sequences:

$$P_k = \{D_{k,i}\}, D_{k,i} = \langle d_{i,1}, d_{i,2}, \dots, d_{i,j}, \dots, d_{i,J} \rangle. \quad (13)$$

This model describes the execution of the business process “as is”, taking into consideration the characteristics of the company’s activities. That is why the presented model describes a generalized case of the process solution of the relevant problem. For each of the alternative sequences  $D_{k,i}$ , delay time  $T_{k,i}^w$  may differ. Then the statement of the problem of process management support for the set of business processes  $P = \{P_k\}$  based on a change of the sequence of access to shared resources during their implementation takes the form of:

$$\sum_{k=1}^K \max_i (T_{k,i}^w) \rightarrow \min, \quad (14)$$

at assigned terms of implementation  $t_k^c$  of process  $P_k$ :

$$\forall k \forall i \max_i (T_{k,i}) \leq t_k^c - t_{0,k}, \quad (15)$$

and availability of common resources for some business processes:

$$\exists P_m \in P, P_m \neq P_k : R_k \cap R_m \neq \emptyset, \quad (16)$$

where  $R_k, R_m \subseteq R$  are the subsets of resources for processes  $P_k$  and  $P_m$ ;  $t_{0,k}$  is the moment of the beginning of process implementation  $P_k$ .

The example of competition for resources for three business processes within the proposed process model is shown in Fig. 1. This example is based on the fragment of the data from the logs of business processes.

In this example, business processes  $P_1, P_2$  and  $P_3$  compete for resources. Each process is represented by one track. These processes are assigned by the following sequences of actions:

$$\begin{aligned} P_1 &= \left\langle \{o_{1,1}, r_1, \Delta t_{1,1}\}, \{o_{1,2}, r_2, \Delta t_{1,2}\}, \{o_{1,3}, r_3, \Delta t_{1,3}\} \right\rangle, \\ P_2 &= \left\langle \{o_{2,1}, r_1, \Delta t_{2,1}\}, \{o_{2,2}, r_2, \Delta t_{2,2}\} \right\rangle, \\ P_3 &= \left\langle \{o_{3,1}, r_2, \Delta t_{3,1}\}, \{o_{3,2}, r_1, \Delta t_{3,2}\}, \{o_{3,3}, r_3, \Delta t_{3,3}\} \right\rangle. \end{aligned} \quad (17)$$

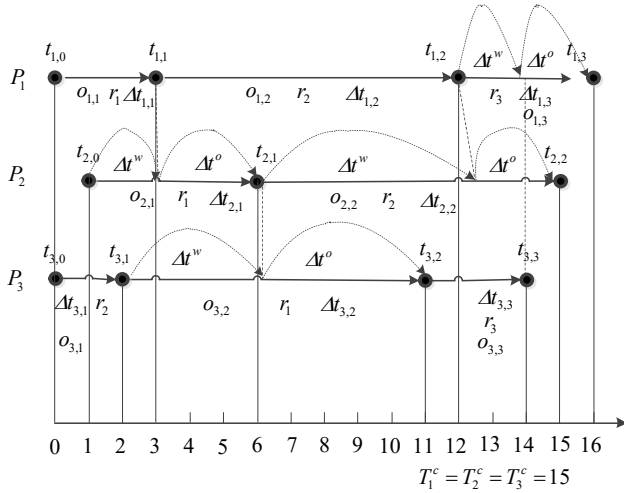


Fig. 1. Example of competition for resources between three business processes

Processes  $P_1$  and  $P_2$  compete for resource  $r_1$ . This resource at moment  $t_{1,0}$  is first taken by process  $P_1$ . That is why process  $P_2$  waits until the resource is free till moment  $t_{1,1}$ . At this moment operation  $o_{1,1}$  finishes. The interval of waiting for process  $P_2$  is designated as  $\Delta t^w$ . The indices of the process and action in Fig. 1 are not shown for simplification. At moment  $t_{1,1}$ , operation  $o_{2,1}$  of the second process is launched. The interval of its performance is designated as  $\Delta t^o$ .

Operation is completed at moment  $t_{2,1}$ , after which the access to this resource is obtained by the third process, waiting since moment  $t_{3,1}$ . These processes compete for resources  $r_2$  and  $r_3$  similarly. In the example shown in Fig. 1, the same moment for completion of all three processes:  $t_1^c = t_2^c = t_3^c$ . The second and the third processes were completed on time or ahead of time, and the first process did not satisfy restriction (15). However, if resource  $r_3$  had been first received by the third process, then by the first process, all the three processes would have been performed on time.

## 6. Development of the technology of changing the sequence of access to shared resources of business processes during their implementation

The developed technology implements the case-based approach to management based on the analysis of the logs of business processes. The case-based approach is aimed at the construction of cases for solving complex knowledge-intensive problems and subsequent using these cases to construct the algorithms for solving new but similar problems. The previously presented case-based model of a business process contains the known sequences of actions to implement it. The use of this model is based on the idea that the orderliness of actions in time is described by a set of temporal rules [14] that reflect the hidden causal relationships between the actions of a business process [15].

The technology realizes refinement of case-based models of a subset of business processes and then uses these models to calculate the duration of performance of processes, taking into consideration delays in the access to resources. Because the duration of the operation of a process is fixed, in order to change its duration, it is necessary to control the total duration of delays when accessing resources according to (12). These delays depend on the order of access to resources, as shown in Fig. 1. The order of access to resources is changed to satisfy the user's restrictions (15) and then to minimize total delays in access to resources according to (14).

The technology uses case-based models (13) of the subset of business processes  $P$  competing for shared resources. The intervals of waiting and of operations execution are assigned in this model for each action (11).

When solving problem (14), this technology is used iteratively and is therefore implemented before the beginning of each action  $d_{i,j}$  for each of the business processes  $P_k \subseteq P$ .

The technology of the change of the sequence of access to shared resources of business processes includes the following stages.

*Stage 1.* Clarification of the case-based model of business processes competing for resources.

The purpose of this stage is to reduce the number of alternative implementations in a case-based model (13) as the business process progresses. This makes it possible to enhance the accuracy of calculation of the time of completion of a business process.

*Step 1.1.* At this step, such sequences  $D_{k,m}$ , which at moment  $t_{i,j}$  of the completion of the previous action  $d_{i,j-1}$  from current sequence  $D_{k,i}$  do not contain any coinciding initial sequence of actions  $\langle d_{m,1}, d_{m,2}, \dots, d_{m,j-1} \rangle$ , are removed from model  $P_k$ . The resulting set  $P_k^1$  takes the form:

$$P_k^1 = P_k \setminus \left\{ D_{k,m} : \forall m \langle d_{m,1}, \dots, d_{m,j-1} \rangle \neq \langle d_{i,1}, \dots, d_{i,j-1} \rangle \right\}. \quad (18)$$

*Step 1.2.* The choice of the sequence of operations  $D_{k,i}$  of the maximum duration. The choice is based on the summation of the duration of actions  $\Delta t_{i,j}$  or the difference between the timestamps of the first and the last events in the corresponding log track.

As a result of this step, a possible sequence of actions of maximum duration will be used to calculate the time it takes to complete a business process. This makes it possible to meet restriction (15).

*Stage 2.* Selection of subsets of processes  $P_k^2$ , each of which uses shared resources for the following actions beginning from moment  $t_{i,j-1}$ . The example of such actions in Fig. 1



at initial moment  $t_{1,0}$  is pair  $\{d_{1,1}, d_{2,1}\}$  using shared resource  $r_1$ . The example at moment  $t_{2,1}$  is pair  $\{d_{2,2}, d_{3,2}\}$ , etc.

**Stage 3.** Calculation of delays  $\Delta t_{i,j}^w$  for all possible sequences of access to resources from  $P_k^j$ .

**Step 3. 1.** Formation of all possible sequences of access to  $P^* = \langle d_{i,j}, d_{m,1}, \dots \rangle$  shared resources since moment  $t_{i,j}$ .

For example, for set  $\{d_{1,1}, d_{2,1}\}$  in the example shown in Fig. 1, such pairs  $\langle d_{1,1}, d_{2,1} \rangle, \langle d_{2,1}, d_{1,1} \rangle$  are formed at this step.

**Step 3. 2.** Calculation of delays  $\Delta t^w$  for all sequences of actions, competing for resources.

For each pair  $\langle d_{i,j}, d_{m,l} \rangle$ , moment  $t_{i,j}$  of the beginning of the action with high priority  $d_{i,j}$ , operation duration  $\Delta t_{i,j}^o$  within this action, as well as the moment of request for shared resources  $t_{m,1}$  for the action with a lower priority  $d_{m,l}$  are taken into consideration:

$$\Delta t_{m,l}^w = \begin{cases} t_{i,j} + \Delta t_{i,j}^o - t_{m,l}, & \text{if } t_{i,j} + \Delta t_{i,j}^o - t_{m,l} > 0, \\ 0, & \text{otherwise.} \end{cases} \quad (19)$$

**Step 3. 3.** Calculation of time of completion  $t_{m,l+1}$  of current action  $d_{m,l}$  with delay  $\Delta t_{m,l}^w$ :

$$t_{m,l+1} = t_{m,l} + \Delta t_{m,l}^w + \Delta t_{m,l}^o. \quad (20)$$

Steps 3. 1–3 are repeated cyclically for all the subsequent actions before completion of all business processes from initial set  $P$ .

The result of this step is forecasted time  $T_{k,i}$  of completion of each process  $P_k$  for each sequence of access to resources at moment  $t_{i,j}$ .

**Stage 4.** Calculation of delays  $\Delta t_k^c$  of performance for each process  $P_k \subseteq P$ .

The calculation is performed by comparing  $T_{k,i}$  and restriction  $t_k^c$ :

$$\Delta t_k^c = \begin{cases} T_{k,i} - (t_k^c - t_{0,k}), & \text{if } t_k^c - t_{0,k} < T_{k,i}, \\ 0, & \text{otherwise.} \end{cases} \quad (21)$$

The calculation is performed for each sequence  $P^*$  of access to resources.

**Stage 5.** Calculation of total delay  $\Delta T^c$  for all processes for each sequence  $P^*$ .

**Stage 6.** Calculation of time  $\delta T^c$ , released due to a decrease in delays:

$$\delta t_k^c = \begin{cases} t_k^c - t_{0,k} - T_{k,i}, & \text{if } t_k^c - t_{0,k} > T_{k,i}, \\ 0, & \text{otherwise.} \end{cases} \quad (22)$$

The calculation is performed for each sequence  $P^*$  of access to resources.

**Stage 7.** Calculation of total time saving  $\delta T^c$  for all processes for each sequence  $P^*$ .

**Stage 8.** Ordering sequences  $P^*$  by the value of total time of delay  $\Delta T^c$ , and then by the value of released time  $\delta T^c$ .

## 7. Experimental testing of the technology of a change in the sequence of access of business processes to shared resources

We consider the simplified model of interaction of three business processes competing for three shared resources, shown in Fig. 1. Simplification involves, firstly, the limitation of the number of actions of the process, as well as the

number of shared resources. As the number of processes and resources increases, only computational costs will be increased. The second simplification implies that each process is represented by only one track. However, this simplification also does not have a significant impact on the experimental testing of the technology, as according to problem statement (14), it is necessary to select only one track for each business process.

The original information about the sequence of actions was obtained from the analysis of the logs. The fragments of descriptions of a pair of successive events on the example of the logs of the Volvo IT company are shown in Fig. 2.

This example provides two consecutive events from the same implementation of a business process, in this case, the first event contains the record about waiting for the resource allocation. The event description also includes timestamps and resources. The log contains information about the operation, the time it is completed and resources, which makes it possible to represent each action of the process in form (9) and calculate its duration.

Event1		
org:resource	value="Carolyn"	← Resource
concept:name	value="Queued"	← Operation
lifecycle:transition	value="Awaiting Assignment"	
time:timestamp	value="2010-08-11T14:49:10+02:00"	← Time
Event2		
org:resource	value="Kannan"	
concept:name	value="Accepted"	
lifecycle:transition	value="In Progress"	
time:timestamp	value="2010-08-11T15:08:47+02:00"	

Fig. 2. Fragments of event descriptions in the initial log

Thus, the logs of actual processes can be represented in the form of orderly pairs of events (3) and make it possible to get the considered model of a business process “as is” (13).

The purpose of experimental testing is to determine whether it is possible to support decision-making by a DM to prioritize competing business processes. In order to prove the sequence of access to resources, a DM must have information on forecasted untimely completion of processes, as well as on possible time-saving. In the first case, it is necessary to coordinate the terms postponement with consumers of the products of these business processes. In the second case, it is possible to fulfill additional orders in parallel with the existing business processes and, thus, to improve the efficiency of an enterprise in general.

The results of the experiment are given in Table 1.

The order of access to resources for processes corresponds to the order of the lines for each variant, for example,  $P_1, P_2$ , and  $P_3$  for variant 1.

The resources for which business processes competed are represented in columns with titles  $r$ . The duration of performing operations – in the columns with titles  $\Delta t_j^o$ , time is rounded up to hours. The length of delays at the access to resources is presented in columns  $\Delta t_j^w$ . The time of delay for business processes relative to the deadlines set by a customer is shown in column  $\Delta t_k^c$ , and the time released when a process is completed early is shown in the column with the title  $\delta t_k^c$ . Resulting time of delay/early execution is shown in columns  $\Delta T^c$  and  $\delta T^c$  respectively.

Table 1

Calculation of time to implement business processes at a change of the sequence of access to resources

No.	$P_k$	$t_0$	$r$	$\Delta t_1^o$	$\Delta t_1^w$	$t_1$	$r$	$\Delta t_2^o$	$\Delta t_2^w$	$t_2$	$r$	$\Delta t_3^o$	$\Delta t_3^w$	$t_3$	$t^c$	$\Delta t_k^c$	$\delta t_k^c$	$\Delta T^c$	$d$
1	1	0	1	3	0	3	2	9	0	12	3	2	2	16	15	1	0		
	2	1	1	3	2	6	2	3	6	15		0	0	15	15	0	0		
	3	0	2	2	0	2	1	5	4	11	3	3	0	14	15	0	1	1	1
2	2	1	1	3	0	4	2	3	0	7		0	0	7	15	0	8		
	3	0	2	2	0	2	1	5		7	3	3	0	10	15	0	5		
	1	0	1	3	4	7	2	9	0	16	3	2	0	18	15	3	0	3	13
3	3	0	2	2	0	2	1	5		7	3	3	0	10	15	0	5		
	1	0	1	3	0	3	2	9	0	12	3	2	0	14	15	0	1		
	2	1	1	3	2	6	2	3	6	15		0	0	15	15	0	0	0	6
4	1	0	1	3	0	3	2	9	0	12	3	2	2	16	15	1	0		
	3	0	2	2	0	2	1	5	4	11	3	3	0	14	15	0	1		
	2	1	1	3	2	6	2	3	6	15		0	0	15	15	0	0	1	1
5	2	1	1	3	0	4	2	3	0	7		0	0	7	15	0	8		
	1	0	1	3	4	7	2	9	0	16	3	2	0	18	15	3	0		
	3	0	2	2	0	2	1	5		7	3	3	0	10	15	0	5	3	13
6	3	0	2	2	0	2	1	5		7	3	3	0	10	15	0	5		
	2	1	1	3	0	4	2	3	0	7		0	0	7	15	0	8		
	1	0	1	3	4	7	2	9	0	16	3	2	0	18	15	3	0	3	13

The results presented in the last two columns provide a DM with support for the choice of the sequence of access to resources. That is why the result is ordered by the values of  $\Delta T^c$  and  $\delta T^c$ .

The resulting orderly set of sequences of access to resources for moment  $t_0$  has the form of  $\{ \langle P_k, P_m, P_s \rangle, \Delta T^c, \delta T^c \}$ :

$$\{ \langle P_3, P_1, P_2 \rangle, 0, 6 \}, \tag{23}$$

$$\{ \langle P_1, P_2, P_3 \rangle, 1, 1 \}, \{ \langle P_1, P_3, P_2 \rangle, 1, 1 \}, \tag{24}$$

$$\{ \langle P_2, P_3, P_1 \rangle, 3, 13 \}, \{ \langle P_2, P_1, P_3 \rangle, 3, 13 \}, \tag{25}$$

$$\{ \langle P_3, P_2, P_1 \rangle, 3, 13 \}.$$

The variant of access to resources  $\langle P_3, P_1, P_2 \rangle$  ensures the completion of all business processes on time. In addition, 6 hours will be saved due to a decrease in delays for processes  $P_3$  and  $P_1$ .

The variants of setting priorities  $\langle P_2, P_3, P_1 \rangle$ ,  $\langle P_2, P_1, P_3 \rangle$ ,  $\langle P_3, P_2, P_1 \rangle$  are characterized by a delay in completing business processes for 3 hours, however, these priorities enable allocating 13 hours for one more process of execution of an additional order.

It is probably inappropriate to use the remaining two sequences  $\langle P_1, P_2, P_3 \rangle$  and  $\langle P_1, P_3, P_2 \rangle$ , since the specified sequences do not enable completing one of the business processes on time and do not give a considerable reduction of delay time.

**8. Discussion of results of the development of the technology of a change in the sequence of access to shared resources of business processes during their implementation**

The result of this research is the technology that makes it possible to dynamically change the sequence of actions of business processes competing for the same resources so that

these processes could be performed before the deadline set by the customer.

The technology uses the case-based approach. This approach involves the construction of a case for a business process that includes all the options of its implementation in practice. To construct a case for a business process, one uses an event log containing the information about the implementation of one or more sequences of actions in that process. Such sequences describe the performance of business processes or functional tasks.

The improved model of an event log (3) is different in the fact that it sets a strict linear order over time (5) only for pairs of events. The original log may contain a "mixed" sequence of events having the form (2), reflecting the parallel execution of some processes within one functional task. That is why assigning the order for separate pairs of events makes it possible to allocate the tracks for the execution of a business process "as is" both at the process and at the functional management approaches. Each of these tracks determines the sequence of actions in a case-based model.

The developed case-based model of a business process "as is" (13) combines a set of possible options for its implementation. The totality of the performed options for a particular business process makes its case. Each variant of implementation of a business process consists of a linear action sequence (9). The interval of waiting for resources is assigned for each action (11). This interval arises as a result of the competition of some processes for the appropriate resource. The duration of the implementation of a business process as a whole consists of the total time of waiting and time of performing actions (12). Using a case-based model makes it possible to calculate the duration of the business process implementation at changing the time of waiting for separate actions (Fig. 1).

The proposed technology dynamically changes the way resources are accessed for business processes competing for these resources. Depending on the established access sequence, the waiting interval (19) and the completion time (20) of the corresponding actions of these processes

change. As a result, the total time of delay (21) for a business process as a whole changes. The time released by reducing delays (22) can be used to launch new business processes that perform additional orders.

The difference of the proposed technology is that the calculated order of access to resources when the actions of a business process are performed takes into consideration the reduction in the total time of using resources by these processes.

Calculation of the order of access to resources is used before performing each action for a set of business processes that compete for a subset of the company's shared resources. This technology enables a DM to repeatedly redefine the order of execution of business processes from a given set so that all processes should be completed on time, in accordance with the deadlines assigned by customers.

The effectiveness of the developed technology is shown using the example of the competition of three business processes for shared resources (Table 1). In the initial case representation (Fig. 1), one of the business processes is completed with a delay, the second – on time, and the third – ahead of schedule. It was not possible to launch a new business process in parallel to process another order because of the process that is not performed on time.

As a result of using the technology, two groups of sequences of setting priorities that provide additional opportunities for a DM were obtained. The first group (23) is focused on saving time when completing business processes on time and makes it possible to reduce the total duration of their execution by more than 10 %. The second group (25) is focused on allocating time for new order at a small, less than by 10 %, total exceeding the completion time of current business processes.

The advantage of the technology is the possibility to adjust its model before the execution of each business process. The adjustment is based on a change in the order of access to the shared resource for several business processes and leads to a change in the time of waiting for this resource. The choice of a sequence of access to resources is performed to satisfy the set limits for deadlines for completing the business processes competing for these resources.

The drawback of the technology is that the calculated sequence of access to resources depends on a case-based description of a business process. That is why it is possible to calculate the duration of operations only if there is a current sequence in the case-based model.

The selection of cases that contain suitable implemented variants of a business process is a separate task based on the classification of patterns of sequences of actions. The execution of this task involves using fuzzy approaches combined with the architectures of artificial neural network designed to handle large real-time data flows. In particular, this can be done in accordance with the approach proposed in paper [16].

The technology has limitations related to the specificity of the case approach. To operate, the technology requires the existence of event tracks that contain records of the behavior of a business process with timestamps. This set of tracks is formed after repeated implementation of a business process and can be obtained both in the current company and in the organization using similar production technologies.

The technology creates an orderly set of alternative sequences of work execution depending on the order of access to resources for the actions of a business process competing

at a given moment. When ordering these sequences, the restriction (15) is taken into consideration in the first place. Under this restriction, processes are ordered by the magnitude of the total performance delay relative to deadlines set by customers. After this, the minimization of time-frames of operations (14) that makes it possible to launch new processes on the same total set of resources is taken into consideration.

The technology can also be applied in related subject areas, provided that a case process description of the tasks solved is constructed. For example, when solving the problem of accounting for peak traffic in computer systems, represented in paper [17], the tasks of supporting the process of constructing recommendations based on temporal dependencies [18] and temporal limitations [19], detecting user's attacks that distort user's data in information systems [20], supporting the operation of virtual enterprises [21]. These capabilities determine the direction of further improvement of this technology.

---

## 9. Conclusions

---

1. The model of the event log of the information system was improved by introducing orderliness for pairs of events of one process in a single sequence of events that recorded a parallel solution of several problems. The model contains the sequence of events that reflects the implemented sequences of control actions. The model is designed to construct a prototype of a business process “as is” not only for the process approach but also for the functional approach to management.

2. The case-based model for a business process “as is”, based on its event log and including a set of implemented sequences of operations of a process, was developed. Each work of the process is characterized by the executed operation, resources for the operation, as well as the total execution time, which includes the length of delay in access to resources. This model differs from a priori formed model of a business process “to be” by the fact that it takes into consideration the specificity of execution of operations at an enterprise, in particular, changes in the order of operations or their untimely implementation. The specified characteristics of a model make it possible to use it as a case in managing a set of interacting processes to ensure the timely implementation of these business processes. It is also advisable to use this model to predict the deadline for completion operations when additional business processes are launched in order to fulfill new orders from customers.

3. The technology of a change in the sequence of access to resources for a set of business processes competing for these resources was developed. The technology is implemented before starting each activity for business processes from the given set. The technology uses the cases of business processes and calculates the order of access to resources that ensures the lowest total disruption of work deadlines for business processes from a given set. The technology also calculates the reduction of delays in access to resources relative to deadlines of execution of operations. The technology enables a DM to reduce decision-making time when managing a group of interacting business processes based on choosing the order of accessing resources that ensures the least delay in the time of completion of business processes. The technology also makes it possible to estimate the reduc-

tion in waiting time when accessing resources. Based on this assessment, a DM can decide to launch new processes while meeting the deadlines for the completion of operations.

4. The conducted experimental testing showed that the developed technology makes it possible to reduce the number of admissible sequences of access to resources by several times. This enables a DM to make a reasonable

decision about the launch of new processes while limiting the time of their execution. Additionally, there appears the possibility of insignificant, within 10 %, delays in completion of processes to release more than 25 % of the time to implement additional business processes corresponding to new orders. This leads to enhancing the effectiveness of process management.

## References

1. Van der Aalst, W. M. P. (2013). Business Process Management: A Comprehensive Survey. *ISRN Software Engineering*, 2013, 1–37. doi: <https://doi.org/10.1155/2013/507984>
2. Vom Brocke, J., Rosemann, M. (Eds.) (2015). *Handbook on Business Process Management 1. Introduction, Methods, and Information Systems*. Springer. doi: <https://doi.org/10.1007/978-3-642-45100-3>
3. Smirnov, S., Weidlich, M., Mendling, J. (2010). Business Process Model Abstraction Based on Behavioral Profiles. *Lecture Notes in Computer Science*, 1–16. doi: [https://doi.org/10.1007/978-3-642-17358-5\\_1](https://doi.org/10.1007/978-3-642-17358-5_1)
4. Maddern, H., Smart, P. A., Maull, R. S., Childe, S. (2013). End-to-end process management: implications for theory and practice. *Production Planning & Control*, 25 (16), 1303–1321. doi: <https://doi.org/10.1080/09537287.2013.832821>
5. Frye, D. W., Gullidge, T. R. (2007). End-to-end business process scenarios. *Industrial Management & Data Systems*, 107 (6), 749–761. doi: <https://doi.org/10.1108/02635570710758707>
6. Davis, R. (2011). *Processes in Practice: It's the Customer Journey that Counts*. BPTrends.
7. Van der Aalst, W. M. P. (2011). *Mining: Discovery, Conformance and Enhancement of Business Processes*. Springer. doi: <https://doi.org/10.1007/978-3-642-19345-3>
8. Müller, D., Reichert, M., Herbst, J. (2007). Data-Driven Modeling and Coordination of Large Process Structures. *Lecture Notes in Computer Science*, 131–149. doi: [https://doi.org/10.1007/978-3-540-76848-7\\_10](https://doi.org/10.1007/978-3-540-76848-7_10)
9. Van der Aalst, W. M. P. (2019). 20 Years of Process Mining Research – Accomplishments, Challenges, and Open Problems. *1st International Conference on Process Mining*.
10. Van der Aalst, W. M. P. (2014). Process Mining in the Large: A Tutorial. *Lecture Notes in Business Information Processing*, 33–76. doi: [https://doi.org/10.1007/978-3-319-05461-2\\_2](https://doi.org/10.1007/978-3-319-05461-2_2)
11. Gunther, C. W., Ma, S. R., Reichert, M., Aalst, W. M. P. V. D., Recker, J. (2008). Using process mining to learn from process changes in evolutionary systems. *International Journal of Business Process Integration and Management*, 3 (1), 61. doi: <https://doi.org/10.1504/ijbpm.2008.019348>
12. Sergii, C., Ihor, L., Aleksandr, P., Ievgen, B. (2018). Causality-based model checking in business process management tasks. *2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT)*. doi: <https://doi.org/10.1109/dessert.2018.8409176>
13. Kalenkova, A. A., van der Aalst, W. M. P., Lomazova, I. A., Rubin, V. A. (2015). Process mining using BPMN: relating event logs and process models. *Software & Systems Modeling*, 16 (4), 1019–1048. doi: <https://doi.org/10.1007/s10270-015-0502-0>
14. Levykin, V., Chala, O. (2018). Development of a method for the probabilistic inference of sequences of a business process activities to support the business process management. *Eastern-European Journal of Enterprise Technologies*, 5 (3 (95)), 16–24. doi: <https://doi.org/10.15587/1729-4061.2018.142664>
15. Kalynychenko, O., Chalyi, S., Bodyanskiy, Y., Golian, V., Golian, N. (2013). Implementation of search mechanism for implicit dependences in process mining. *2013 IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS)*. doi: <https://doi.org/10.1109/idaacs.2013.6662657>
16. Bodyanskiy, Y., Kulishova, N., Chala, O. (2018). The Extended Multidimensional Neo-Fuzzy System and Its Fast Learning in Pattern Recognition Tasks. *Data*, 3 (4), 63. doi: <https://doi.org/10.3390/data3040063>
17. Kuchuk, N., Mozhaiev, O., Mozhaiev, M., Kuchuk, H. (2017). Method for calculating of R-learning traffic peakedness. *2017 4th International Scientific-Practical Conference Problems of Infocommunications. Science and Technology (PIC S&T)*. doi: <https://doi.org/10.1109/infocommst.2017.8246416>
18. Chalyi, S., Pribylnova, I. (2019). The method of constructing recommendations online on the temporal dynamics of user interests using multilayer graph. *EUREKA: Physics and Engineering*, 3, 13–19. doi: <https://doi.org/10.21303/2461-4262.2019.00894>
19. Chalyi, S., Leshchynskiy, V., Leshchynska, I. (2019). Method of forming recommendations using temporal constraints in a situation of cyclic cold start of the recommender system. *EUREKA: Physics and Engineering*, 4, 34–40. doi: <https://doi.org/10.21303/2461-4262.2019.00952>
20. Chala, O., Novikova, L., Chernyshova, L. (2019). Method for detecting shilling attacks in e-commerce systems using weighted temporal rules. *EUREKA: Physics and Engineering*, 5, 29–36. doi: <https://doi.org/10.21303/2461-4262.2019.00983>
21. Pavlenko, V., Shostak, I., Morozova, O., Danova, M. (2018). Information support for business processes at virtual enterprises with multi-agent technologies. *2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT)*. doi: <https://doi.org/10.1109/dessert.2018.8409189>