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Software Package for Visualization and Modeling Based on BPMN Notation

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Abstract

The article is devoted to the creation of software for visualization of complex processes. Since scientific organizations and business structures have demand for analysis and optimization of ongoing processes, the task of its effective modeling and visualization with the possibility of interaction is relevant. The software solutions available on the market are focused either on a static representation of the subject area, without the possibility of conducting computational experiments and optimizing solutions based on them, or on the use of non-standardized representations. A program has been developed that has the ability to animate the visualization of a loaded BPMN scheme, and also contains functionality for modeling the process described by the scheme, with the possibility of flexible parameter adjustment. The developed visualization program displays the result in the browser and a layer with animation of the passage of the involved resources according to the scheme is superimposed on top of the BPMN model. Visualization allows to reduce the probability of errors when modeling complex systems. The work also focuses on aspects of optimization, collecting statistics for subsequent analysis, modeling the process for a given number of time units. This functionality is included in the developed program and can be used both in console mode and in a web browser.

Keywords: visualization of algorithms, data visualization, BPMN notation, BPMN model, BPMN, applied program, process modeling, business processes.

1. Introduction

BPMN notation has become a universal standard for graphical representation of multidirectional processes occurring in commercial and scientific organizations of various sectors. For example, using this approach, it is possible to describe both the air ticket booking system and the process of obtaining a degree. However, BPMN provides a static representation of the process, which may impair the understanding of the scheme by the user, does not give an idea of time and resource costs. This paper discusses an original approach for visualizing business processes using BPMN notation. A program was developed which allows to build a simulation model based on a BPMN scheme. The metrics for evaluating the results of modeling have been developed, which include calculating the average time spent by applications in the system; the average time of resource's occupation.

2. Overview of existing notations

Let's consider examples of existing notations used to describe business processes. IDEF0 is a modeling methodology used for plotting diagrams, maintaining documentation [1]. The result of using IDEF0 is a model consisting of a hierarchical series of diagrams with accompanying explanatory text, illustrating graphic images. The two main components of diagram modeling are functions (represented by named blocks) and data objects that interconnect these functions.

As a function modeling language, IDEF0 has the following advantages:

- consistent and simple language that allows you to briefly describe the business process;
- used by the U.S. Air Force and other government agencies, as well as private industry.

Disadvantages of IDEF0:

- it is impossible to see the algorithm for executing business processes;
- requires some training to develop and read notation;
- the absence of a formal theoretical model, as well as the lack of tools to describe artifacts and information flows;
- does not reflect the reaction of the participants in the process to the events of the external environment. In most cases, due to changes in processes from the outside, either a delay or cancellation of the process at some stage follows, but not a rollback, as it happens in the IDEF0 notation. That is why the IDEF0 notation seems more acceptable for describing technological processes, rather than business processes;
- when adding parallelism in execution to IDEF0, all parallel functions will be executed simultaneously.

IDEF0 is used for top-level modeling of business processes.

Another alternative notation is EPC [2]. Notation is used at the lower levels of the business model description when the task is to describe the detailed progress of the business process.

Advantages – it has the ability to describe the execution of a business process in great detail and accurately, to graphically show all the performers, all the objects used. The advantage of EPC diagrams is the fact that, as in the IDEF0 diagrams, they can specify the input and output data of each function, trace the logic of the movement of input and output data from block to block. In addition, unlike IDEF0, it is possible to parallelize the process by directing it only along one of the alternative branches.

Disadvantages – it has a very wide set of graphic elements, which can be difficult to understand, compared to other notations. In order to develop processes in this notation and read them, preliminary training of employees is required. EPC diagrams do not describe the execution schedule, they omit the issues of synchronizing branches of one process with each other and with other, external processes.

Various models can be used to describe business processes. One of them is UML diagrams [3]. This tool can be used to describe a business process, but it is of little use for further work, since there are a huge number of different UML formats, and there is no single specification. Thus, when creating an application based on UML, it will be necessary to take into account the possibility of obtaining different UML formats, which can be avoided by working with other business process description formats.

Data Flow diagrams (DFDS)[4] were developed back in the seventies, and their purpose is to represent data flows, not actions. Although business process analysts approve of data flow diagrams, they generally agree that this method is outdated and has one big limitation: it focuses on information rather than actions. Data flow diagrams are by definition data-centric and do not provide a clear way to include all stakeholders in the process.

Functional Flowcharts (FBD) [5] may have existed for several decades, but they are still used in mapping business processes. Their attention is focused on the order of tasks or functions in a sequence of ordered blocks. Each functional block can be divided into a separate diagram showing the subtasks in each functional block. Of course, this leads to a large number of diagrams representing a single process, but they are easy to match with a first-level diagram. Some businesses prefer FFD because, despite the need for multiple diagrams, they are relatively easy to follow, even if the process is quite complex.

BPMN (Business Process Modeling Notation) models are a tool for understanding complex multi-level business processes. With the complication of a certain process, there is a need to expand the documentation, knowledge base, instructions that describe the relationship of this process with other existing components. The solution to the problem of increasing complexity for the decision-maker (LPR) to understand can be the construction of a BPMN model describing current processes. The study of graphical visualization of processes allows the LPR to detect inaccuracies, process cycling, potentially problematic areas, and also collect data on the resources involved for subsequent analysis and optimization.

The first version of the BPMN model specification was introduced in 2006, then a number of updates were released, the last of which was published in January 2011. [6] BPEL (Business Process Execution Language) is a standard for the design and execution of business processes, similar in structure to BPMN models. The BPMN specification was introduced in order to bridge the gap between business analysis and technical analysis by providing a standardized graphical notation for the processes described in BPEL [7]. The BPMN and BPEL paradigms use different elements to describe similar business processes, which leads to further inconsistencies. BPMN and BPEL are used at various stages of the BPM lifecycle. In [7], the authors draw attention to the differences between these two approaches and present a number of arguments that show the advantage of BPMN notation in business process modeling. Difficulties in transferring models from BPMN to BPEL and in reverse order were discovered and overcome in the article [8] by creating a BPMN2BPEL system for automatic conversion. Thus, if necessary, schemes in more advanced BPMN specification can be simplified to other BPM formats.

The BPMN specification can be implemented at enterprises of various industries, scale, solving problems in different fields from each other. Thus, in the work [9], the structure of a situation center was created to manage emergency situations in the oil industry. The paper [10] describes the development of an end-to-end process for the implementation of state/municipal services in electronic form using BPMN notation. Schemes for the implementation of the traditional business model of a loan on a crowdinvesting platform, purchase and sale of securities, tokenization of rights and their modification have also been published. [11] Thus, it is concluded that the design method using BPMN is universal and widespread, and the approach can be applied both to the description of business processes and as a basis for software designed for modeling.

Based on the results of the comparative analysis, a table was compiled in which the presence of the property was marked with a "+" sign. Based on the results of the comparison, BPMN notation was chosen as the most universal and widespread.

Table 1. Comparative analysis of notations.

	BPMN	EPC	IDEF0	UML	DFD	FBD
Convenience of understanding the compiled scheme	+	+	-	+	+	+
Quick learning of notation elements	-	-	-	-	+	+
Versatility	+	+	-	+	-	+
The ability to describe complex processes	+	-	+	+	-	-
Support of other software	+	-	-	+	-	-

3. Overview of existing developments

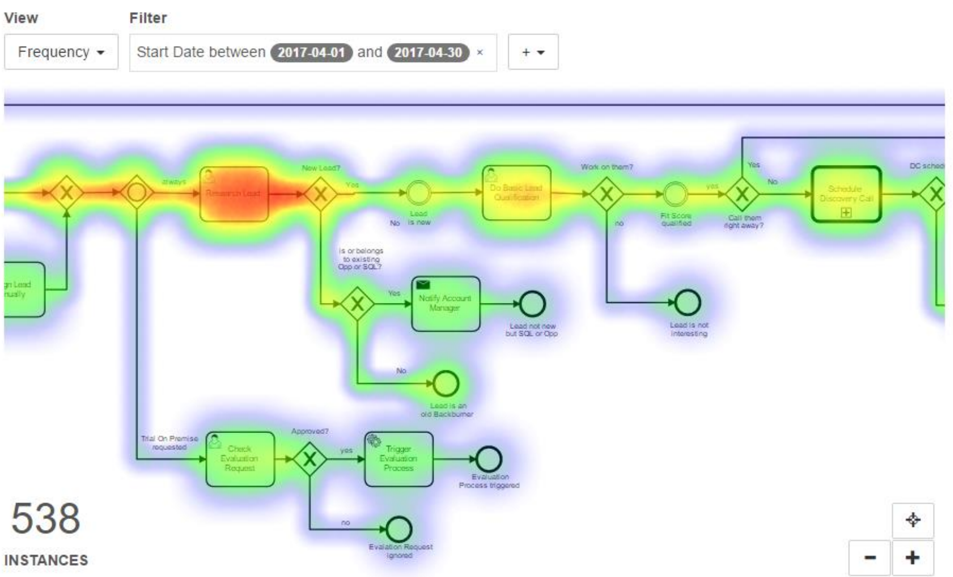
Existing software solutions are focused either on a static representation of the subject area, without the possibility of conducting computational experiments and optimizing solutions based on them, or on the use of non-standardized representations, which, despite their effectiveness, are not always understandable to users far from programming and mathematics [12].

At the moment, there are already platforms for analyzing business processes based on BPMN models. Each of the sites can offer different functionality for users.

Camunda is an open source workflow automation and decision–making platform [13]. The Camunda platform comes with tools for creating workflow models and solutions, operating deployed models in production, and enabling users to perform workflow tasks assigned to them. It is developed in Java and released as open source software under the terms of the Apache license [14].

This platform provides services for the implementation of this platform to the enterprise and further support. It is also possible to implement it for free using open source code, but in this case Camunda does not provide any assistance for the implementation and maintenance of the product.

Also on this platform there are tools for analyzing the effectiveness of the business process, such as, for example, a heat map showing the workload of certain nodes (Figure 1), but this platform does not provide any visualization capabilities.



View: Frequency

Filter: Start Date between 2017-04-01 and 2017-04-30

538 INSTANCES

Figure 1. Heat map of node utilization in the Camunda product

Advantages:

- A wide variety of tools offered
- Availability of open source code
- Product implementation assistance

Disadvantages:

- Does not allow optimization
- A very voluminous product that requires a lot of resources for implementation
- Is not a domestic software.
- There is no possibility to animate the BPMN scheme

ELMA365 is a Low–code BPM system that builds the interaction of employees from different departments into a network of interconnected business processes [15]. So, the platform allows you to get high-quality and easy quick results without unnecessary bureaucracy. The company's strategic goals are achieved through modeling, execution, control and continuous improvement of business processes.

This platform provides services for the implementation of this platform to the enterprise and further support. The platform can also provide a free trial period, however, unlike the previous service, it does not provide free open source code for self-implementation of the product.

This platform has various tools for controlling the business process, but there are no automatic optimization tools as such. The proposed process improvement is built manually, based on a specific business, which is an advantage in terms of the accuracy of possible improvements, but a disadvantage in terms of the speed of supply and the required resources for optimization calculations.

The product also offers ready-made connectors for integration with various services, such as 1C, MS SQL databases, Oracle, PgSQL. Convenient modules for integration with REST and SOAP web services. ELMA loads data from external systems, performs operations with internal systems automatically.

Advantages:

- A wide variety of tools offered
- User-friendly interface
- Using a Low-code approach
- The product is included in the register of Russian software
- Product implementation assistance

Disadvantages:

- Does not allow optimization
- A very voluminous product that requires a lot of resources for implementation
- There is no possibility to animate the BPMN scheme

BPMN.Studio is a free online service for modeling business processes [16]. In the online business process designer, you can quickly simulate a process or a group of processes using the popular business process modeling notation - BPMN 2.0.

This product allows you to create diagrams of BPMN models. In addition, it allows you to import them in various formats, for MS Office or PDF documents, as well as for printing. Also, this web service does not provide any features.

So, there is no animated visualization in this service, and there are also no opportunities to expand this product in the form of adding new functionality by third-party users.

Advantages:

- Convenient tool for creating BPMN schemes
- Web application

Disadvantages:

- Does not allow optimization
- Lack of opportunities to expand the functionality
- There is no possibility to animate the BPMN scheme

PETERSOFT: BPM is a complete set of tools for automating enterprise management on the 1C: Enterprise 8 platform [17]. Depending on the tasks set, process management technologies, adaptive case management or project management can be used.

This platform allows you to create business process models - a fixed chain of tasks, the sequential execution of which leads to the achievement of the desired result. Models are configured in the visual editor using the business process configuration mechanism. For any point in the process, you can specify the performer and the time for which he must complete this task. Once configured, the business process model can be run unlimited number of times.

This platform has various tools for monitoring business processes and their implementation, but there are no optimization tools. There are only analysis tools, but improvements are not offered either in manual or automatic versions.

Advantages:

- A wide variety of tools offered

- User-friendly interface
- The product is included in the register of Russian software
- Product implementation assistance

Disadvantages:

- There are no tools to optimize processes
- A voluminous product that requires a lot of resources for implementation
- There is no possibility to animate the BPMN scheme

Optimization of business processes requires either the creation of your own proprietary solution, or the introduction of a complex system that requires a large amount of resources.

The Bizagi platform is similar in functionality to the development being created, but cannot be studied in detail, since it is not available in Russia. Judging by the description, this system is focused on the automation of current business processes, and not on the analysis of criteria for evaluating the results of computational experiments, in order to further optimize.

The general model of these products is similar to each other, but each has its advantages and disadvantages. Each of the platforms allows you to work with business processes, but these platforms provide comprehensive solutions for deep manual analysis of business processes in the company. This implies a long and extensive work on auditing and providing possible solutions, which requires a lot of resources.

A large number of software uses color as a way to improve the quality of visualization. Indeed, color accents can simplify the understanding of some types of visualization, such as graphs. However, there is no color specification in BPMN notation, the blocks have black borders, white background. The difference in colors can distract users when modeling a highly composite process, as it happens in EPC notation. However, for customization purposes, the developed software has the ability to customize the image for animation. For example, an image of a part can be used to model a plant, and an image of a document can be used to simulate the processing of an application in a call center. Thus, the LPR is easier to navigate in the scheme, the resource involved is clear, the visualization becomes more visual than when using classical notation elements.

4. Solution method

When solving the problem of optimizing a business process, it is not enough to rely only on the BPMN model, testing hypotheses in practice is necessary. Such a test in a real business environment can be time-consuming, moreover, during testing, the possibility of experimenting with various settings in the BPMN nodes of the model is limited. In this case, it is necessary to apply modeling – to build a virtual model and conduct research on it.

The advantages of modeling are the speed of process simulation; the ability to change parameters in such a way that allows you to test and investigate various hypotheses, and these changes will not affect the real process. Based on a variety of computational experiments, it is necessary to choose the best combination of parameter values based on the criteria for evaluating the simulation results, after which the model can be applied to modify business processes.

To solve the described problem, software was developed that allows implementing a simulation model based on the BPMN model, visualizing the flow of elements in this model with the ability to change the parameters of the model for its optimization.

When analyzing a specific business process, it is necessary to initially make a description of it using BPMN notation. For correct modeling by the developed program, the compiled model must meet certain rules that are not included in the notation. So, some blocks must have a description of certain parameters, for example, the name of the function and its parameters for implementing the input stream generator.

The compiled model is transferred to the developed program, in which its further configuration can be implemented. It is indicated in what form the simulation should take place – using the web interface or in console mode. The web interface is clear, easy to understand, it has the ability to configure simulation parameters. Console mode is necessary to speed up the simulation, which reduces the operating time for multiple launches of the model in case of selecting its optimal parameters in any way.

After the end of simulation process, the resulting parameters can be obtained from the model. Statistics are uploaded on the occupancy of specific nodes, as well as on the number of generated and released entities in each individual block.

For the entity generator node, statistics on the total number of generated entities are displayed. For the final node releasing entities from the model, the number of released entities, the total time spent by all entities inside and the average time of one entity are output. Such statistics are displayed separately for each such block, which allows you to compare different "paths" of entities. For example, when modeling the application acceptance process in some department, the application may be rejected at the very beginning, or it may be accepted and processed. Similar values for the number of rejected and processed applications may indicate imperfection of the selection process, problems in the system or in the business process as a whole.

The algorithm described in the previous paragraph is implemented in a software package designed to visualize business processes based on the BPMN model. The program was executed in the Python3 and JavaScript programming languages using HTML in the PyCharm development environment. The PixiJS library (a package for visualizing dynamic interfaces in web pages) was used as auxiliary libraries. The choice of the Python3 programming language is due to its flexibility when working with both the mathematical apparatus and the web interface. JavaScript and HTML markup language were used to animate the processes described in the BPMN scheme.

Functionally, the complex is divided into four parts (Fig. 2):

1. Blocks responsible for the functionality of a particular node of the business model. For example, a block generator or a block responsible for emulating "work". Such blocks have a common interface and the program can be easily supplemented with new blocks with other functionality.

2. The kernel module, which is responsible for creating a specific model from blocks, implementing the collaboration of these blocks, as well as for the type of visualization of the model.

3. An XML file parsing module that receives data from a model description file and translates it into a format convenient for the kernel.

4. A web application module that is used when visualizing a business process using a web page, and not using a console.

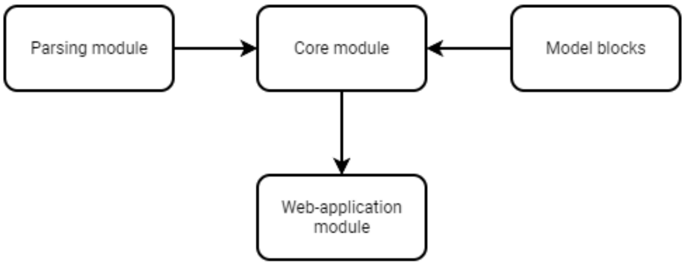


Figure 2. Block diagram of the software package

Figure 3 shows the scheme of operation of the software package. The first step is to send the file to the parsers, which filter out the redundant information contained in the BPMN notation, convert the components into specific blocks. After conversion, these blocks fall into two separate independent cores – logical and visual.

The logical core is responsible for modeling all processes occurring in the simulation. The following logical core blocks are implemented:

- Start – the block responsible for generating entities. The start_functions module is connected to it, which contains various functions of ways to generate entities. For example, constant is the generation of a constant number of entities every unit of time, or random is the generation of a random number of entities in a given interval every unit of time.
- Delay – the block responsible for simulating the operation of entities within the block. It stops the progress of a specific entity for a certain time in order to simulate any action performed on the entity at a specific point in the process. It also has a separate module of delay_functions functions, which prescribes various ways to set the working time in the block. To add a new function in this or the previous block, it is enough to add the function itself to the corresponding module and adjust the BPMN file.
- End – the block responsible for releasing entities that have reached the end point in this process. Collects various statistics on the average time of entities inside.
- Selection – the block responsible for the logical fork in the path of the entity.
- Parallel_open and parallel_close are blocks responsible for dividing one entity into several parts and then combining these entities into one.

The visual core is responsible for outputting information to the user. It can be a console or web application. It has separate visual blocks, each of which is attached to the corresponding logical block. All visual blocks have a common interface, so the logical block does not change its behavior when changing the type of visual core.

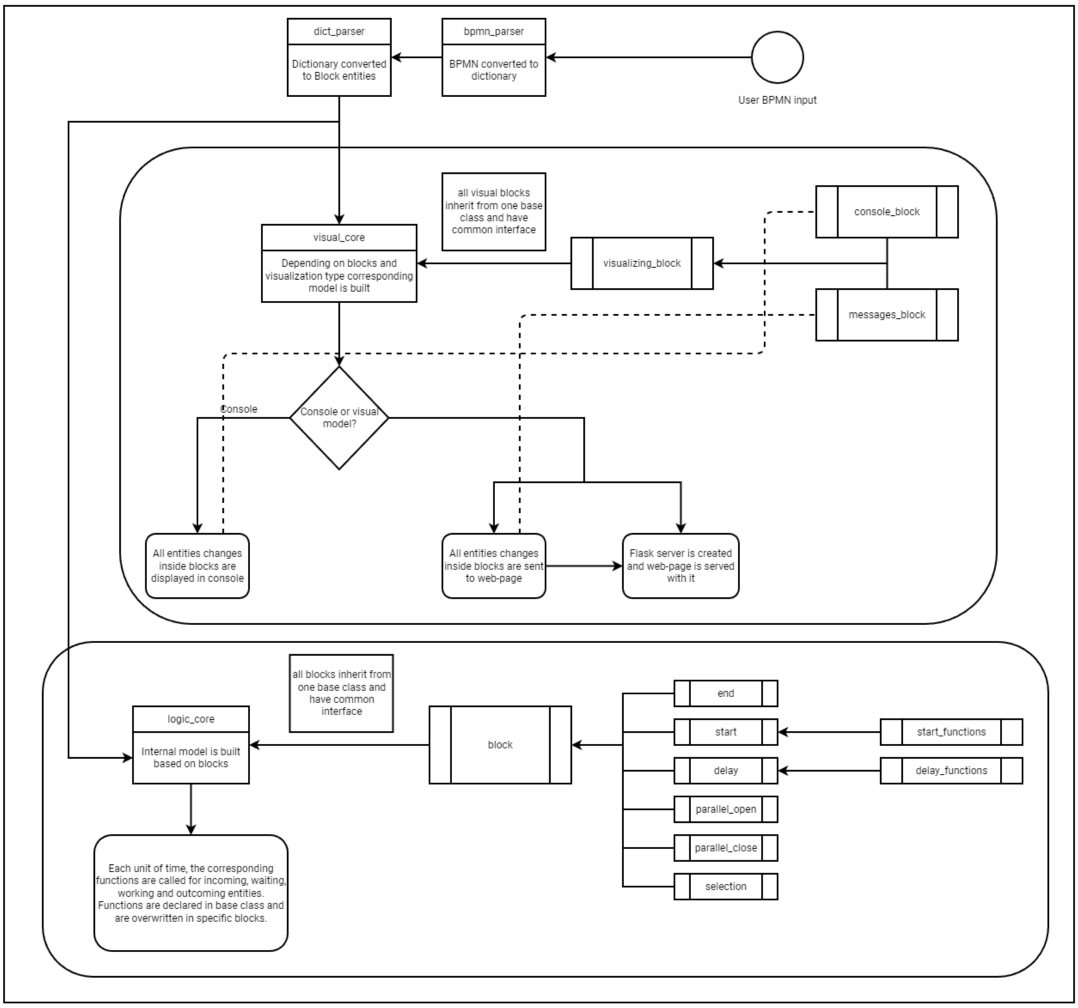

dict_parser
Dictionary converted to Block entities
bpmn_parser
BPMN converted to dictionary
User BPMN input
all visual blocks inherit from one base class and have common interface
console_block
visual_core
Depending on blocks and visualization type corresponding model is built
visualizing_block
messages_block
Console
Console or visual model?
All entities changes inside blocks are displayed in console
All entities changes inside blocks are sent to web-page
Flask server is created and web-page is served with it
all blocks inherit from one base class and have common interface
logic_core
Internal model is built based on blocks
block
end
start
start_functions
delay
delay_functions
parallel_open
parallel_close
selection
Each unit of time, the corresponding functions are called for incoming, waiting, working and outcoming entities. Functions are declared in base class and are overwritten in specific blocks.

Figure 3. Scheme of operation of the software package

The provided software package has already implemented some functions for modeling pseudo-random delays and input flows in the delay and start blocks, respectively.

Both blocks have a random function, which, when created, takes two values - minimum and maximum, and returns a random number in the specified interval each time it is called. For a delay block, this number means how long a particular entity, whose actions led to the function call, will be delayed in a particular block. In the start block, this function is called every unit of time, and the resulting value indicates how many entities will be generated in the block at a particular point in time.

Also, for the Delay block, a function was written that allows you to introduce the concept of "performance" and allocated resources into the model - a linear function of the dependence of time on resources. This function is defined by five values - the minimum and maximum values of resources that can be in the block (*Rlow* and *Rhigh*), the values of time that the entity will spend inside the block with the minimum and maximum resource values (*Tlow* and *Thigh*) and the amount of *Rcurr* resources that are allocated in the current block in the current model.

The current number of resources is a value that can be changed, thus changing the "performance" of the block and affecting the "performance" of the model as a whole, which is necessary when conducting research and optimization. To calculate the delay time in such a function, first, the coefficient k of the straight line that passes through the points of minimum and maximum performance (formula 1) is calculated, and then, based on this coefficient and the straight-line formula for two points, the time is calculated (formula 2)

$$k = \frac{Tlow - Thigh}{Rlow - Rhigh} \quad (1)$$

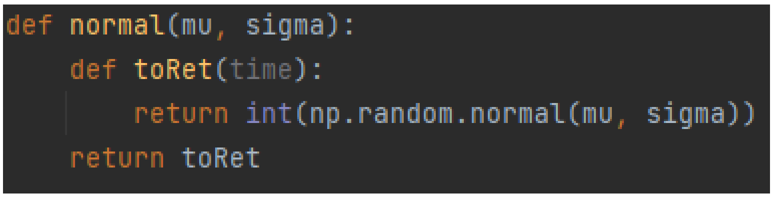
$$Tcurr = k * Rcurr + \ Thigh - k * Rhigh;\ k = \frac{Tlow - Thigh}{Rlow - Rhigh} \quad (2)$$

There is also a separate function for the Start block, which returns the number of entities that need to be generated in the block at a particular point in time based on the initially given *Seq* sequence, which has length *L*. To determine the number of generated entities *N* at time t, the formula 3 is used

$$N = Seq_j; j = \begin{cases} t; t < \ L \\ t\ mod\ L; t \geq L \end{cases} \quad (3)$$

Using this function, you can simulate the uneven flow of entities at different times. For example, to denote a different number of requests on different days of the week, you can take one unit of model time per day and provide the value Seq = [10,12,13,11,12,40,35]. Thus, a higher load on the system during the weekend will be shown. Also, using Seq = [1,0,0] you can show that entities are generated in the model only once every three units of time.

However, the functions provided may not be sufficient and the user may need to use their own function. For example, add a function that uses the normal distribution. This is easy to implement - all you need to do is add your own function to the start_functions.py or delay_functions.py file for the Start and Delay blocks, respectively. For example, to add a normal distribution function to the Delay block, you need to write the code in Figure 4 in the corresponding file.



```
def normal(mu, sigma):
    def toRet(time):
        return int(np.random.normal(mu, sigma))
    return toRet
```

Figure 4. Function generator code for the Delay block

This function generates a new function based on the passed distribution parameters. This function must accept the value of the current time of the model, even if it does not use it. The example uses a normal distribution generator from the third-party numpy library. Also, the generated function must return integer values.

After adding this function, to apply it, you only need to update any block in the model by changing the name of the function it uses to normal and changing the parameters to the appropriate ones.

Figure 5 shows the user interface of the developed software package.

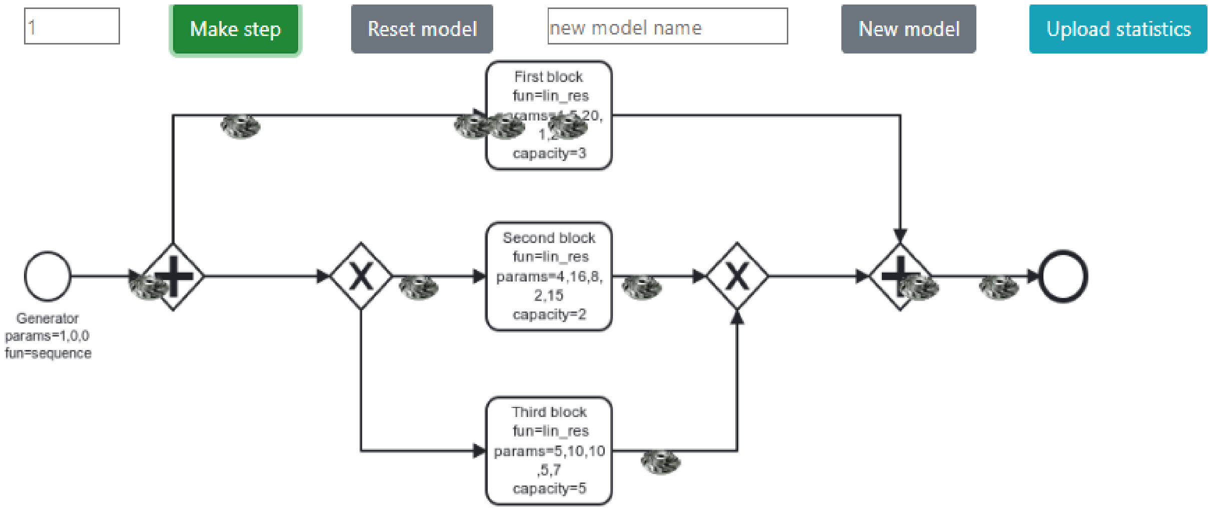


Figure 5. User interface of the software package

The application window consists of two parts - the model setting part and the model itself. The model is presented as a .png image, on top of which the parts moving around the model are displayed. At the top part of user interface are buttons used to configure, optimize, and get statistics.

- The "Make step" button allows you to run the model for one unit of time. Also, this button is connected to the input field before it - you can enter a non-negative integer into it to run the model immediately for the entered number of steps.
- The "Reset model" button allows you to completely clear the model of all entities inside and reset the internal time of the model to the initial value. Thus, the model and all statistics collected on it will be reset to the original value.
- The "New model" button allows you to replace the model with a new one, if it exists in the path specified in the program. The path to the folder with BPMN format models must be specified when launching the model inside the code.
- The "Upload statistics" button allows you to download a file with statistics for blocks in json format. This file can be used to analyze the performance of the model.

As an example of visualization, a simplified scheme of a parts painting plant is used (Fig. 6).

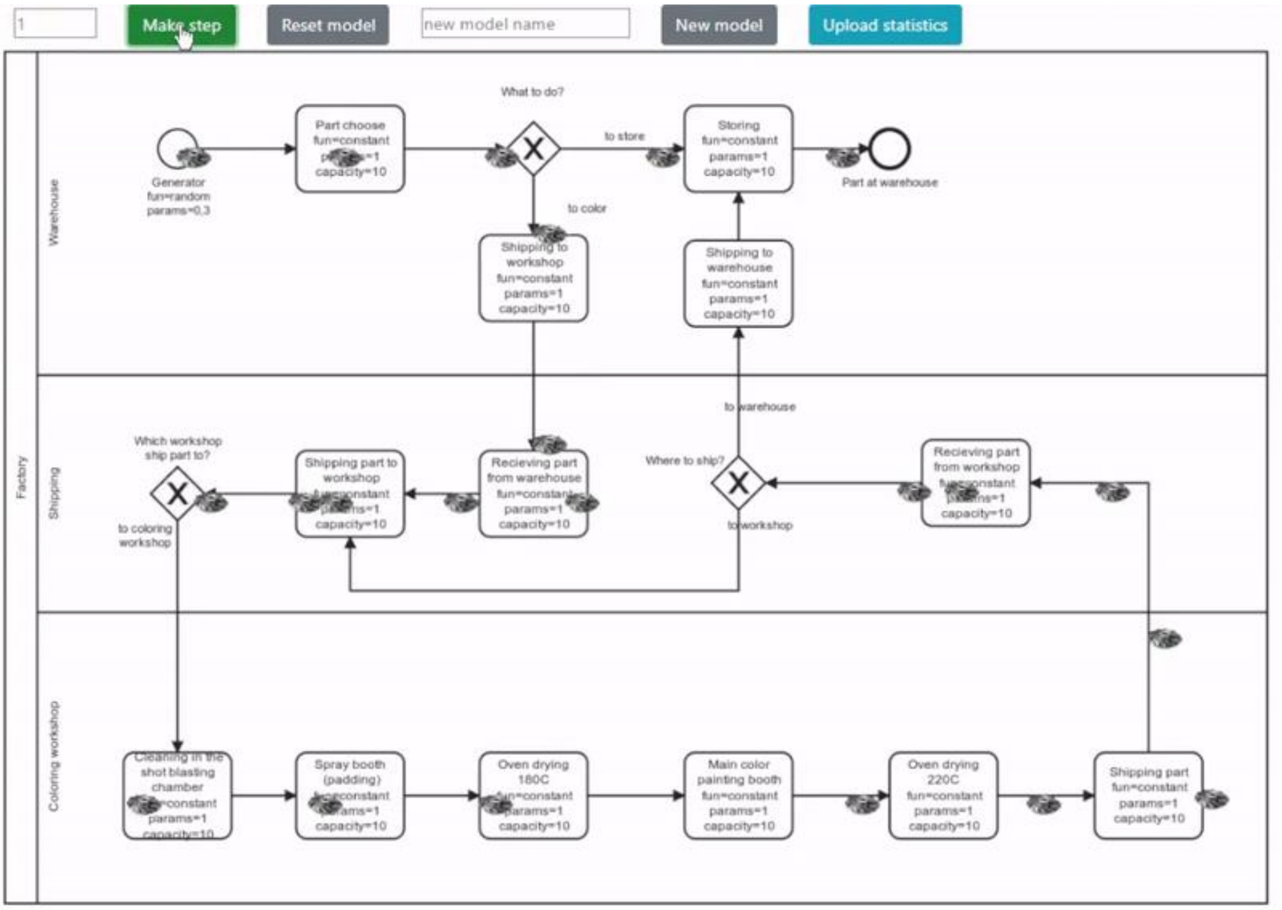
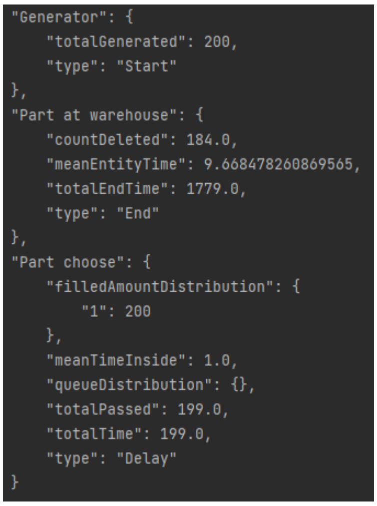


Figure 6. Visualization of the process of painting parts

The animation fragment shown in Figure 6 shows a simulated plant diagram, where the main resource is a part that can be stored or sent for painting. Visualization allows you to reduce the likelihood of errors when modeling complex systems. From the example diagram, the user can conclude that there is no handling of the case where the part was sent to the paint shop by mistake. Thus, to optimize production, you can add an XOR to the block with the question “Which shop is it sent to?” another branch - re-sending to the warehouse.

To study the results of the model for the purpose of subsequent optimization, analysis of processes, the functionality of unloading statistics is implemented. Figure 7 shows the statistics for three different blocks after running the model shown in Figure 5 for 200 time units.



```
"Generator": {
    "totalGenerated": 200,
    "type": "Start"
},
"Part at warehouse": {
    "countDeleted": 184.0,
    "meanEntityTime": 9.668478260869565,
    "totalEndTime": 1779.0,
    "type": "End"
},
"Part choose": {
    "filledAmountDistribution": {
        "1": 200
    },
    "meanTimeInside": 1.0,
    "queueDistribution": {},
    "totalPassed": 199.0,
    "totalTime": 199.0,
    "type": "Delay"
}
```

Figure 7. An example of the resulting model statistics

The statistics show the results of three blocks - Start, Delay and End. The model itself has only one Start and End block each, but the number of created and released entities varies. This suggests that at the time the statistics were taken, 16 entities were inside the model.

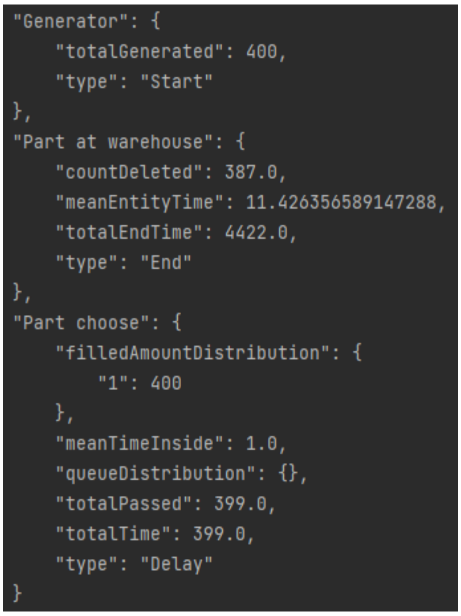
Entities pass through various blocks and stay there for a certain time. However, different entities may pass through different blocks, and as a result, the total time spent by an entity in all the blocks through which it passed may be different for different entities. Therefore, it is necessary to calculate the average time spent inside the Tmean model for all entities. To do this, it is necessary to count the number of all entities that have completely passed through the Ntotal model and the total time that these entities spent inside the model. This time can be calculated by formula 4 based on the time spent by each such entity inside the model $(Tentity_j, j = 1..Ntotal)$

$$Tmean = \left(\sum_{j=1}^{Ntotal} Tentity_j\right)/Ntotal \tag{4}$$

This statistic is calculated for each block separately, and is immediately provided in the meanTimeInside field, but to calculate the global statistics, the totalPassed and totalTime values are also provided separately.

Also, the selected Delay block "Part selection" is the block following the generator, so all entities pass through it. However, only 199 entities came out of it instead of 200 generated, which indicates the presence of one entity inside the block. The empty queueDistribution field indicates that there are no queues in the block, and the filledAmountDistribution field indicates that one part was in operation for 200 units of time in the block.

The model was run for another 200 steps to analyze the changes. The statistics results after an additional 200 steps are shown in Figure 8



```
"Generator": {
    "totalGenerated": 400,
    "type": "Start"
},
"Part at warehouse": {
    "countDeleted": 387.0,
    "meanEntityTime": 11.426356589147288,
    "totalEndTime": 4422.0,
    "type": "End"
},
"Part choose": {
    "filledAmountDistribution": {
        "1": 400
    },
    "meanTimeInside": 1.0,
    "queueDistribution": {},
    "totalPassed": 399.0,
    "totalTime": 399.0,
    "type": "Delay"
}
```

Figure 8. Changes in statistics after an additional simulation run

It can be seen that the generator created another 200 entities. However, according to the number of entities removed by the End block, there are still 13 entities inside the model. The average time of the entity inside the model has increased, which may indicate that there is a certain queue inside the model, which only increases with time, or may be an acceptable error due to the presence of forks with a random choice in the model. For a more accurate study of this phenomenon, the model should be run several more times, resetting it and not resetting it, collecting more extensive statistics for conclusions.

It is worth noting that the time moments of the events that are indicated in the statistics can be considered as continuous random variables due to the fact that as a result of the test (at the start of the program), these variables take one of the random possible values of the interval of the numerical axis. Denote the random variable as *X*. Then *X=f(ω)* is a function defined in the space of elementary events. The most comprehensive way to define a random variable is the distribution law. A continuous random variable is normally distributed if its probability density can be described by formula 5.

$$\varphi_N(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-a)^2}{2\sigma^2}} \tag{5}$$

Where a, σ are the parameters of the normal distribution law. The distribution function of a random variable *X*, distributed according to the normal law, is expressed in terms of the Laplace function according to the formula 6.

$$F_N(x) = \frac{1}{2} + \frac{1}{2}\Phi\left(\frac{x-a}{\sigma}\right) \tag{6}$$

To investigate changes in the model and the impact of these changes on the results, it is necessary to change the model during use. The software package has such functionality. So, you can change the function parameters and the capacity of a particular block, as shown in Figure 9. The delay inside the block is changed from one unit of time to three, and the capacity is reduced from ten to one unit.

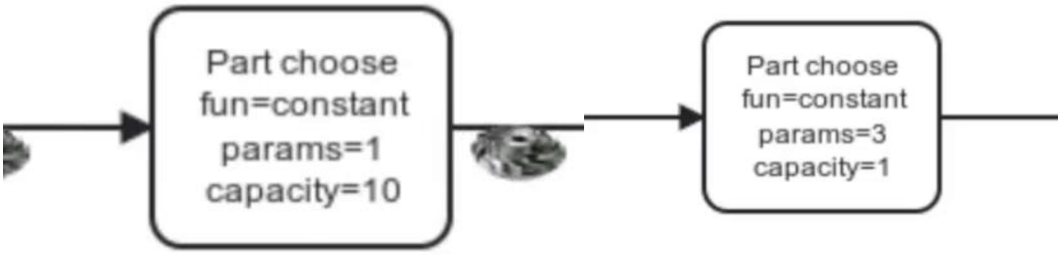
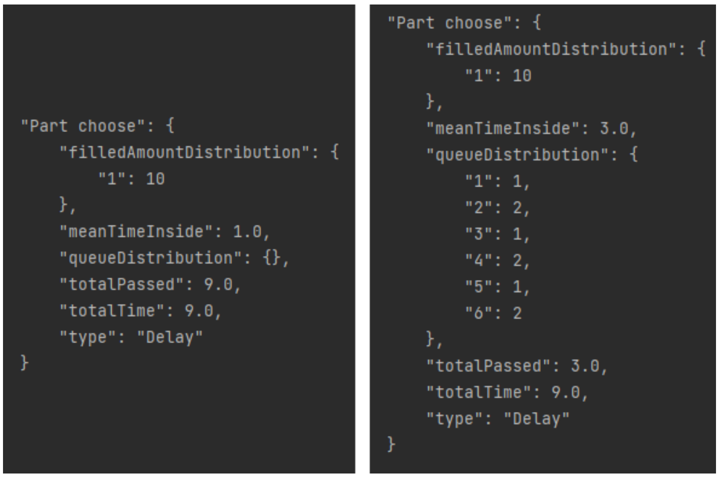


Figure 9. Example of changing simulation parameters

Obviously, such a change will lead to the appearance of a queue at the entrance to this block. This change will be reflected in the statistics. To do this, you can run the model for 10 steps and see the difference in this block (Figure 10).

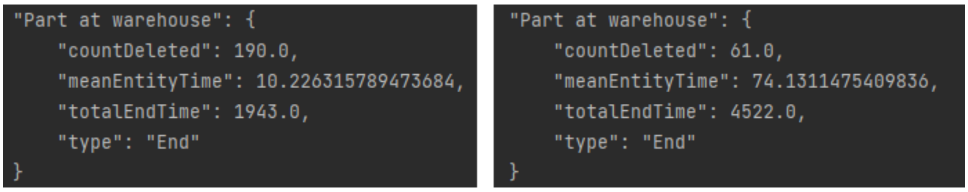


```
"Part choose": {
    "filledAmountDistribution": {
        "1": 10
    },
    "meanTimeInside": 1.0,
    "queueDistribution": {},
    "totalPassed": 9.0,
    "totalTime": 9.0,
    "type": "Delay"
}
```

```
"Part choose": {
    "filledAmountDistribution": {
        "1": 10
    },
    "meanTimeInside": 3.0,
    "queueDistribution": {
        "1": 1,
        "2": 2,
        "3": 1,
        "4": 2,
        "5": 1,
        "6": 2
    },
    "totalPassed": 3.0,
    "totalTime": 9.0,
    "type": "Delay"
}
```

Figure 10. Statistic for a model with a modified parameter.

It can be seen that a queue has appeared in this block, which will probably grow, since the throughput of this block after the change is less than the output stream of the generator. Also, with the help of statistics, you can see how the average time of a part inside the model changes when running by 200 units of time (Figure 11).



```
"Part at warehouse": {
    "countDeleted": 190.0,
    "meanEntityTime": 10.226315789473684,
    "totalEndTime": 1943.0,
    "type": "End"
}
```

```
"Part at warehouse": {
    "countDeleted": 61.0,
    "meanEntityTime": 74.1311475409836,
    "totalEndTime": 4522.0,
    "type": "End"
}
```

Figure 11. Statistic for a model with a modified parameter.

You can notice that the average time has increased significantly, and the number of entities that have completely passed through the entire model has also significantly decreased.

5. Conclusion

This article describes the principle of operation of the developed software package for visualizing business processes based on the BPMN model. The program was developed to improve the existing way of analyzing visual representations of business processes.

The functionality of this program allows you to load various models into it, described in BPMN format, run a simulation model in web format with animation or in console format, stop and resume the simulation, and reset the simulation results or use another loaded model for a new simulation.

Based on the conclusions of the program, the decision maker can make decisions on optimizing the modeled organizational, technical and socio-economic systems. The examples showed the possibilities of visualization, as well as the possibility of changing the model for analyzing processes. A technique for modeling a certain amount of the model's operation time is described, a method for loading statistics obtained after simulation is developed.

The novelty of the research lies in the creation of a unique software package ready for use in the commercial sector. The development is aimed at decision makers who are interested in optimizing business processes, collecting statistics and making decisions based on the information received. Visualization functionality based on familiar BPMN notation facilitates rapid integration of the program into an existing business diagramming system, and additional animation provides improved understanding of processes.

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References

1. Wikipedia: [web-resource]. URL: https://ru.wikipedia.org/wiki/IDEF0 (date of application: 26.06.2022)
2. Wikipedia: [web-resource]. URL: https://en.wikipedia.org/wiki/Event-driven_process_chain (date of application: 26.06.2022)
3. Makarov N. S., Uml: podderzhka proektirovania i instrumentalnie sredi [Uml: design support and tooling] // Journal of Applied Informatics. 2007. №2 [in Russian].
4. Tasvaeva A. N., Diagrammi potokov dannih i variantov ispolzovania kak instrumenti proektirovania informazionnih sistem [Data flow and use case diagrams as information system design tools] // Models, systems, networks in economics, technology, nature and society. 2012. №2 (3) [in Russian].
5. Functional block diagrams [web-resource] / URL: https://rus-visio-blog-archive.github.io/2016/04/06/4605.htm (date of application: 26.06.2022).
6. Chinosi, M., Trombetta, A. BPMN: An introduction to the standard. Computer Standards & Interfaces, 2012. 34(1), pp. 124–134. doi:10.1016/j.csi.2011.06.002.
7. Recker J., Mendling J. On the translation between BPMN and BPEL: conceptual mismatch between process modeling Languages, in: Thibaud Latour, Michael Petit (Eds.), Proceedings 18th International Conference on Advanced Information Systems Engineering, Proceedings of Workshops and Doctoral Consortiums, 2006, pp. 521–532.

8. Ouyang C., Aalst W.M., M. Dumas, Hofstede A.H. From business process models to process-oriented software systems: the BPMN to BPEL way // Technical Report BPM-06-27, BPM Center, 2006.

9. Kulikov G. G., Shamsutdinov R. R., Alimbekova S. R., Gabbasov, R. K. Application of Business Processes Models Generating Methodics Using BPM Notation while Regular, Project and Situation Management in Oil Sector // Bulletin of USATU, 2010. № 14 1(36), c. 136-147 [in Russian].

10. Kulikov G. G., Gabbasov, R. K., Navalihina N. D., Timchenko A. A. he adaptation of the priciples of system engineering and BPMN to the process of transferring the governmental and municipal services into electronic form along with foundation the interdepartmental electronic relations // Bulletin of USATU, 2013. 17 (5 (58)), c. 12-19 [in Russian].

11. Popov E. V., Veretennikova A. YU., Fedoreev S. A. Modelirovanie biznes-processov kraudinvestingovyh platform na osnove tokenizacii aktivov [Modeling of business processes of crowdinvesting platforms based on asset tokenization] // The world of new economy, 2022 [in Russian].

12. Chetverushkin B.N., Sudakov V.A. Factor Model for the Study of Complex Processes // Dokl. Math. 2019. V. 100. – pp. 514–518.

13. The Universal Process Orchestrator [web-resource] / URL: https://camunda.com/ (date of application: 26.06.2022).

14. APACHE LICENSE, VERSION 2.0 [web-resource] / URL: https://www.apache.org/licenses/LICENSE-2.0 (date of application: 26.06.2022).

15. Low-code platform for automation and robotization of business processes and CRM [web-resource] / URL: https://elma365.com/ru/ (date of application: 26.06.2022).

16. Free online service for business process modeling [web-resource] / URL: https://bpmn.studio/ (date of application: 26.06.2022).

17. Software product "PiterSoft: BPM" [web-resource] / URL: https://piter-soft.ru/bpm/ (date of application: 26.06.2022).