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GERT method and simulation modeling for probabilistic resource analysis in agricultural processes

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Abstract. The article presents the results of a probabilistic analysis of resources in agricultural processes. The authors performed a comparative analysis of the effectiveness of using the GERT method for assessing the probabilistic-time characteristics of processes with simulation modeling in the Anylogic environment. For the study, the process of "Approval of an application for the purchase of agricultural products" is described. This process is first presented in the ARIS eEPC notation, and then it is translated into the GERT network. Based on the obtained model, the process completion time was predicted. The mathematical expectation and variance of the process execution were calculated. Based on the results obtained, conclusions were drawn regarding labor intensity and accuracy. It is shown that the GERT network and the simulation model are close in accuracy. However, for the given task, the GERT method is a less labor-intensive and more accurate method. This study is important for managing and optimizing processes in agricultural enterprises to improve the efficiency of decision making.

1 Introduction

Currently, the digitalization of agricultural processes is expanding, and the analysis of resources for agrotechnological operations is becoming a challenging task [1-4]. Agribusinesses are scaling and their structures and resource provision are taking on more and more complex forms every day [5-8]. From the point of view of system analysis, new tasks appear that require solutions in various areas and directions of agricultural development.

In this article we will look at how forecasting problems for resource provision are solved during scheduling at agricultural enterprises [9-11]. As an example, the business process "Approval of an application for the purchase of agricultural products" is considered. Analysis

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of this process will allow us to verify the practical applicability of the GERT network apparatus for calculating probabilistic resource characteristics, namely, the time load of performers, that is, decision makers [12]. Taking into account the current level of digitalization of agricultural technological processes, it is important to compare the GERT network apparatus with simulation modeling in terms of accuracy and labor intensity.

2 Materials and methods

To be able to test the practical applicability of the GERT network apparatus for calculating probabilistic resource characteristics, we will consider the model of the process "Approval of an application for the purchase of agricultural products," which was previously presented by the authors in the ARIS eEPC notation in [13].

This process involves two executors, Decision Maker 1 and Decision Maker 2, who are responsible for a number of operations in document approval. According to the goal, it is necessary to convert this process from the ARIS eEPC notation to the GERT network.

The possibility of transferring the discrete event model of the ARIS eEPC process into the GERT network is possible due to the fact that ARIS eEPC is a procedural sequence of functions in the form of a chain of processes, where for each function we have an initial and final event. The event is the result of the function [14].

To describe a process in the ARIS eEPC notation, the following main types of objects are used: function, event, arrow, operator (AND, OR, XOR).

GERT networks have a stochastic structure [15-17]. To describe it, a certain subset of arcs and nodes is necessary. In this case, the node can be executed when all or many arcs are executed.

In a GERT network, nodes describe the state of the system, and arcs describe the transition from one state to another. Each node accepts two functions: input and output.

The input describes the execution condition of the node. The output describes a set of conditions that reflect the result of the node's execution. The first and last nodes are special. In the first node, only the input function is performed, and in the last, only the output function.

Input functions are divided into three types. The first type is AND. A node is executed provided that all arcs included in this node are completed. The second type is OR. Execution of a node provided that any or more of the arcs included in this node are completed. The third type is XOR. This means executing a node provided that only one arc is executed at the specified time.

Output functions are divided into two types. The first type is deterministic output function (DT). Function when all arcs that exit a node are completed. The second type is the probabilistic output function (ST). A function where only one arc leaving a node is executed. Figure 1 provides a visualization of the functions of the GERT network.

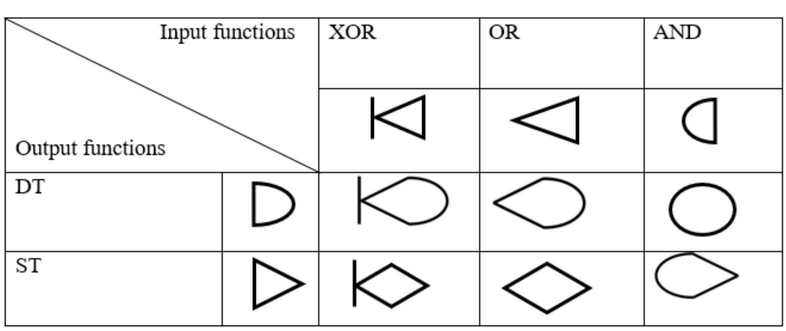

Fig. 1. Functions of the GERT network.

A node can be in one of two states: active or inactive. An active node means that there is some activity happening in the system, and an inactive node means that the system is in a waiting state.

3 Results and discussion

3.1 GERT method results

Figure 2 shows a GERT network model converted from the ARIS eEPC notation for the "Approval of an application for the purchase of agricultural products" process.

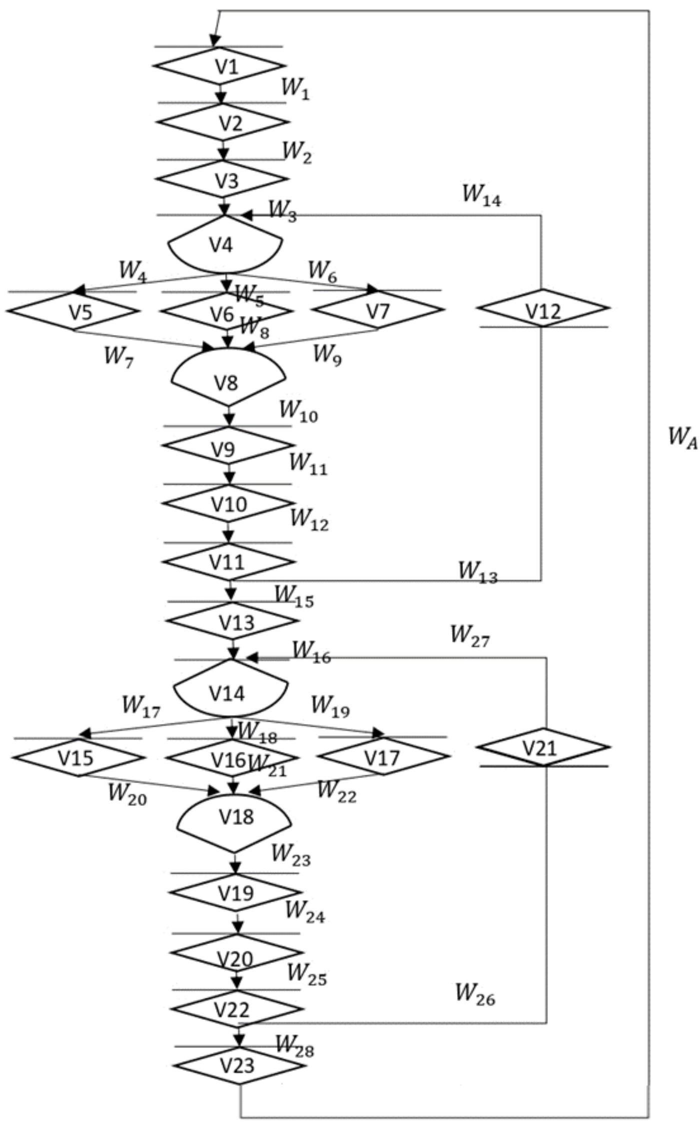

Fig. 2. GERT network of the process "Approval of an application for the purchase of agricultural products".

The parameters of the GERT network arcs are presented in [13]. They describe the time spent on completing each arc presented in Figure 2. Next, the index k is introduced, which corresponds to the notation <*i, j*> and defines the W-function for writing the Mason equation and determining the transmittance of the first (FOL) and second order loops (SOL) [18-20].

FOL:

$$(w_4w_7 + w_5w_8 + w_6w_9)w_{10}w_{11}w_{12}w_{13}w_{14},$$
$$(w_{17}w_{20} + w_{18}w_{21} + w_{19}w_{22})w_{23}w_{24}w_{25}w_{26}w_{27},$$
$$w_1w_2w_3(w_4w_7 + w_5w_8 + w_6w_9)w_{10}w_{11}w_{12}w_{15}w_{16}(w_{17}w_{20} + w_{18}w_{21} + w_{19}w_{22})w_{23}w_{24}w_{25}w_{28}(1/w_A).$$

SOL:

$$(w_4w_7 + w_5w_8 + w_6w_9)w_{10}w_{11}w_{12}w_{13}w_{14}(w_{17}w_{20} + w_{18}w_{21} + w_{19}w_{22})w_{23}w_{24}w_{25}w_{26}w_{27},$$

The Mason equation, transformed with respect to $w_k(s)$ taking into account FOL and SOL for the GERT network under study, will take the following form:

$$w_k(s) = w_1w_2w_3(w_4w_7 + w_5w_8 + w_6w_9)w_{10}w_{11}w_{12}w_{15}w_{16}(w_{17}w_{20} + w_{18}w_{21} + w_{19}w_{22})w_{23}w_{24}w_{25}w_{28}/(1 - (w_4w_7 + w_5w_8 + w_6w_9)w_{10}w_{11}w_{12}w_{13}w_{14} - (w_{17}w_{20} + w_{18}w_{21} + w_{19}w_{22})w_{23}w_{24}w_{25}w_{26}w_{27} + (w_4w_7 + w_5w_8 + w_6w_9)w_{10}w_{11}w_{12}w_{13}w_{14}(w_{17}w_{20} + w_{18}w_{21} + w_{19}w_{22})w_{23}w_{24}w_{25}w_{26}w_{27}$$

Let's substitute the corresponding values of the product of probabilities and $M_k(s)$ from [13] to obtain $w_k(s)$. Let's calculate the mathematical expectation and variance: $\mu =$3.898; $\sigma^2 = 0.994$.

Thus, based on the formalization of the decision-making process on the approval of the primary requirement for procurement based on GERT, a result was obtained that determines the time characteristics of the process: process duration $\mu =$3.898 hours and time spread $\sigma^2 = 0.994$ hours.

3.2 Simulation results

Next, we will calculate the probabilistic indicators using a simulation experiment in the AnyLogic software product. For this purpose, a simulation model for the process under study has been developed. The model is presented in Fig. 3. It includes the main components for generating transactions and running the modeling process. Designed as a stochastic network, where each node has certain random variables and probabilities specified for the simulation.

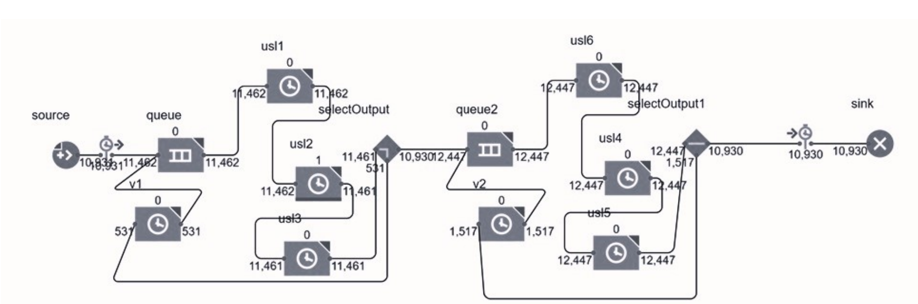

Fig. 3. Process simulation model in Anylogic.

The transition parameters of the simulation model corresponding to the operations of the business process are specified by values taken from Table 1.

For the node of the process under study, the variable usl5 is set at the input of the element: "usl5 + = normal (0.5, 0.2);". Thus, when entering the "usl5" node, a random variable will be generated according to the normal distribution law and added to the usl5 variable. The parameters for the remaining nodes of the model are set similarly. After the model transaction is completed, the values of all variables are summed and the resulting value is added to the sample.

A numerical experiment was carried out using the simulation model. To achieve high accuracy of results, due to the complexity of the model (the presence of feedbacks), the model was run 10 thousand times. This number of model runs is sufficient, because the error does not exceed 1.8%. Model time units are minutes. Figure 4 shows a histogram with the results of the simulation experiment.

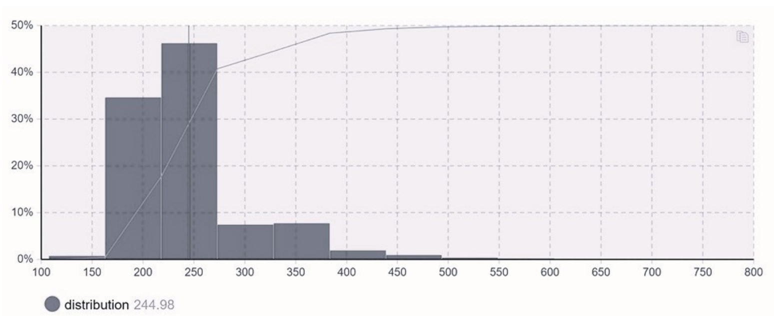

Fig. 4. Calculation of the process simulation model.

On the histogram, the X axis shows the time in minutes, and the Y axis shows the percentile. The probability density function is displayed as a set of vertical bars, each of which corresponds to a specific interval. The height of the column is proportional to the density (or number) of values falling within this interval. The cumulative distribution function is displayed as a broken line over the probability density.

4 Conclusion

Analyzing the calculated numerical characteristics for the process "Approval of an application for the purchase of agricultural products", the following conclusions can be drawn. Calculations were carried out in two ways. In the first case, the calculation was performed through the Mason equation using the GERT network model. The second method is implemented using a simulation experiment in AnyLogic. The calculation results are shown in Table 1.

Table 1. Comparison of calculation results.

Method	Expectation		Variance	
	hours	minutes	hours	minutes
GERT	3.898	233.88	0.994	59.62
Anylogic	4.066	244.98	1.001	60.07

The error of the mathematical expectation and dispersion was calculated in comparison with the results obtained based on the Mason equation and is equal to 4.531% for the mathematical expectation and 0.699% for the dispersion. At the same time, a simulation experiment is more labor-intensive to solve this problem. Analyzing the values obtained by two different methods - based on the calculation of GERT networks and on the basis of a simulation model, we can conclude that the methods are close in accuracy, however, the results of the simulation experiment are random and may differ the next time the experiment is run. Thus, calculations based on GERT networks provide more accurate results that are less susceptible to deviations and do not change when re-calculating using this method. At the same time, it should be noted that the simulation experiment for this process model is more labor-intensive compared to calculating the GERT network, since the simulation model was run 10 thousand times to obtain the specified accuracy of the results.

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