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Digitalization of the organizational structure of an agro-industrial enterprise based on the GERT-network computational model

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Abstract. The article discusses an approach to digitizing the organizational structure of an agro-industrial enterprise based on the GERT network model. The transformation of the business process of coordinating primary procurement needs into a GERT network is shown. The possibility of transforming the GERT network for performers of functions is identified to further optimize the organizational structure of the business process in agro-industrial enterprises. The results of calculating the obtained GERT network taking into account the features of the business process are presented. The proposed equivalent transformations of the GERT network provide the possibility of fast digital modelling and, therefore, enable efficient reorganization of the enterprise's organizational structure.

1 Introduction

High competition in the market of goods and services is a guarantee for the overall development of all businesses, including modern enterprises in the agro-industrial complex [1-4]. It is evident that effective enterprise management without the use of digital technologies and a process approach is no longer possible today [5-8]. The large scale of agro-industrial enterprises, which often have a distributed cluster structure, necessitates the use of modern digital tools for modeling business processes to avoid inconsistent actions of decision-makers (top management) and disruption of interaction between structural units and subsystems of their information support. Scaling up the business and complicating the organizational structure of enterprises give rise to new challenges in the implementation of digital technologies and automation in agriculture. These challenges are often related to forecasting the company's activity [9-11].

Specifically, in the procurement departments of a company, a specialist can provide a forecast of the time required to purchase a product or service based on their experience. However, with multiple factors influencing this forecast, this task becomes increasingly

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challenging each day, which can ultimately lead to erroneous results or excessive time and human resource costs.

Moreover, in procurement activities, there are numerous criteria and data that decision-makers must consider, which a specialist cannot quickly analyze in real-time. Formalizing the organizational structure of the enterprise based on the GERT network model [9-11] will enable top management to plan their time based on given criteria and data arrays necessary for decision-making. The proposed approach of GERT network modeling will enable the determination of the probability of achieving the decision-making criteria by top management and the time required for it.

2 Materials and methods

In this article, we will consider the decision-making process for approving the primary procurement need.

2.1 Description of the business process «approve primary procurement need»

The formation of the primary need is the first step in the procurement process [12-14]. Typically, the need is collected not only for a specific item but for the entire class of materials, equipment, and supplies within the surveyed community/department/group. That is, the company has announced the collection of needs from the community for the class of materials, for example, workwear and shoes. The community fills out a template on the need to purchase the material. After collecting the needs, the purchaser forms a general document in the information management system.

First, and most importantly, it is necessary to determine the type of need and the method of financing (from which account it will be paid). This is necessary to determine the future strategy for approving the procurement need, i.e., to select the persons who will make the decision on the purchase.

Next, the following main parameters are filled in: MTR code (previously entered in the reference book for further use), the required quantity for procurement, planned delivery time, time of involvement in production, planned price with an indication of the source of the basic cost of MTR on the date of filling out the need, consignee (warehouse to which MTR will be sent) [15].

After filling out all necessary data, the document is sent for approval.

In our example, there are 3 approvers. Each Approver makes a decision based on their area of responsibility. To decide on approval or rejection, a number of parameters must be evaluated, and if they meet the requirements, the Approver approves the document.

The first Approver checks the correspondence of the MTR description in the system with the description presented in the requirement. Also, the correctness of the specified initial maximum price is verified, whether it corresponds at the moment and will be relevant during the trading period. And the last criterion within the responsibility of the first Approver is to ensure that the conditions for implementation are met (the correct type of shoes is chosen for the mechanizer in which he can work in the future).

The second Approver checks whether the need corresponds to the production requirement. The specified delivery time is checked against the date of involvement in production. The availability of free funds from financing for this need is also checked.

The third Approver checks the possibility of accepting the goods, i.e. the availability of free space to accept the need in the warehouse. Also, a check is carried out for the presence or absence of MTR in their warehouses. If the required MTR is available in the warehouse, it is necessary to clarify whether it is free for operation or reserved for production. If there is a free stock for implementation, the approver transfers the need from procurement to involvement, thus not approving the document. If MTR is not found in the warehouses, the approver approves the need.

If all approvers have made a decision to approve the need, a request for bidding is formed, where potential suppliers offer their prices and delivery conditions for this procurement. However, within the scope of this article, we will focus on the need.

Let us represent the sub-process «approve the need for procurement» in EPC notation in Figure 1.

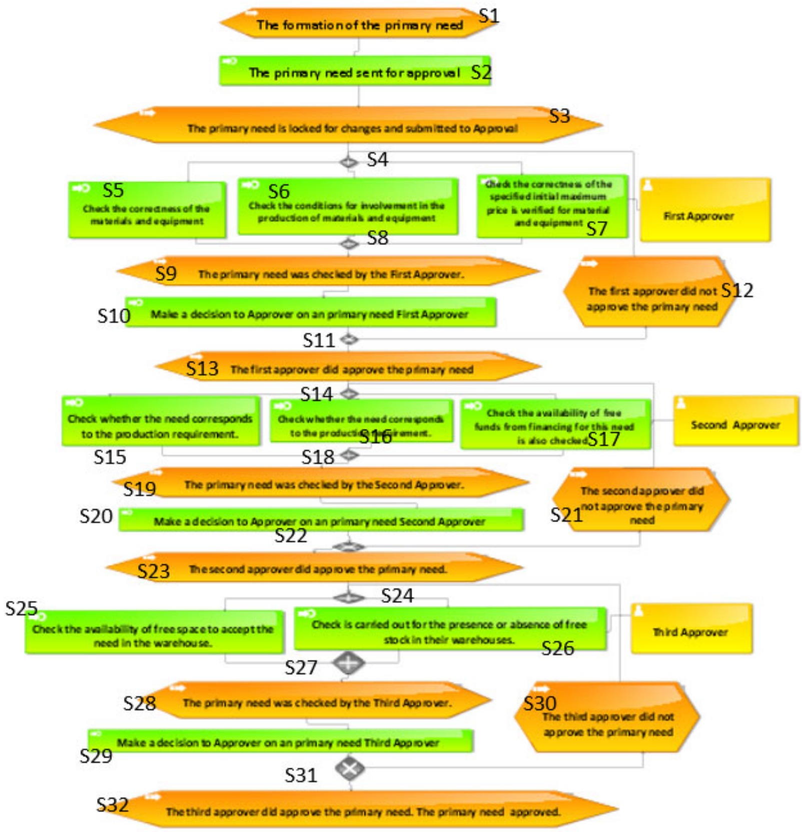

Fig. 1. «Approve the need for procurement» in EPC notation.

3 Results

3.1 EPC to GERT Network Conversion Process

Let us compare the EPC and GERT network of this business process. The question of translating a business process model into a GERT network model was addressed in Zyryanov's work in 2012. Table 1 compares the elements of the EPC with the GERT network, as well as indicating the performers by objects. The first three EPC objects are the starting events, and during the approval of the procurement request, they take 0 hours.

Table 1. Comparison of Model Objects.

EPC model object executor	EPC model object	Object types of the EPC model	GERT network node	GERT network node type
-	S1	Event	V1	STEOR
-	S2	Process	V2	STEOR
-	S3	Event	V3	STEOR
First Approver	S4	Connectors	V4	[EOR, DT]
First Approver	S5	Process	V5	STEOR
First Approver	S6	Process	V6	STEOR
First Approver	S7	Process	V7	STEOR
First Approver	S8	Connectors	V8	[AND, ST]
First Approver	S9	Event	V9	STEOR
First Approver	S10	Process	V10	STEOR
First Approver	S11	Connectors	V11	STEOR
First Approver	S12	Event	V12	STEOR
First Approver	S13	Event	V13	STEOR
Second Approver	S14	Connectors	V14	[EOR, DT]
Second Approver	S15	Process	V15	STEOR
Second Approver	S16	Process	V16	STEOR
Second Approver	S17	Process	V17	STEOR
Second Approver	S18	Connectors	V18	[AND, ST]
Second Approver	S19	Event	V18	STEOR
Second Approver	S20	Process	V20	STEOR
Second Approver	S21	Event	V21	STEOR
Second Approver	S22	Connectors	V22	STEOR
Second Approver	S23	Event	V23	STEOR
Third Approver	S24	Connectors	V24	[EOR, DT]
Third Approver	S25	Process	V25	STEOR
Third Approver	S26	Process	V26	STEOR
Third Approver	S27	Connectors	V27	[AND, ST]
Third Approver	S28	Event	V28	STEOR
Third Approver	S29	Process	V29	STEOR
Third Approver	S30	Event	V30	STEOR
Third Approver	S31	Connectors	V31	STEOR
Third Approver	S32	Event	V32	STEOR

Next, we will specify the parameters of the GERT network arcs. The parameter is the time to complete the arc. An arc represents a connection between two nodes in the GERT network [16-18]. To simplify notation, we introduce the index k, which will replace the indices i,j in all characteristics of this work.

The parameter p_{ij} is the conditional probability of executing the arc < i, j > given the activation of node i. The probability has a distribution from 0 to 1.

The moment-generating function $M_k(S)$ for normal distribution is calculated by the formula $e^{sm} + (1/2)S^2\sigma^2$. But if the random variable $Y_{i,j}$ is equal to a constant, then $M_k(S) = E\ [e^{sa}] = e^{sa}$.. The W-function for the transition of node i to j of the GERT network is defined as $W_k(S) = p_k M_k(S)$.

To enable the calculation of the mean and variance of the time to approve the need for procurement, we introduce the arc <V32, V1>, which will be the closing arc for the GERT network [19-22].

The characteristics of the GERT network operations are shown in Table 2.

Table 2. Characteristics of GERT network operations.

Arc < i, j >	**Wk**	p_k	**Time parameter in hours**	$M_k(S)$
<V1,V2>	W_1	1	a = 0	1
<V2,V3>	W_2	1	a = 0	1
<V3,V4>	W_3	1	a = 0	1
<V4,V5>	W_4	1	a = 0	1
<V4,V6>	W_5	1	a = 0	1
<V4,V7>	W_6	1	a = 0	1
<V5,V8>	W_7	1	m = 0.5 σ = 0.2	$e[0.5s+\frac{1}{2}(0.04)s^2]$
<V6,V8>	W_8	1	m = 0.6 σ = 0.1	$e[0.6s+\frac{1}{2}(0.01)s^2]$
<V7,V8>	W_9	1	m = 0.5 σ = 0.1	$e[0.5s+\frac{1}{2}(0.01)s^2]$
<V8,V9>	W_{10}	1	a = 0	1
<V9,V10>	W_{11}	1	a = 0	1
<V10,V11>	W_{12}	1	a = 0.1	e(0.1s)
<V11,V12>	W_{13}	0.05	a = 0.1	e(0.1s)
<V12,V4>	W_{14}	1	a = 0	1
<V11,V13>	W_{15}	0.95	a = 0.1	e(0.1s)
<V13,V14>	W_{16}	1	a = 0	1
<V14,V15>	W_{17}	1	a = 0	1
<V14,V16>	W_{18}	1	a = 0	1
<V14,V17>	W_{19}	1	a = 0	1
<V15,V18>	W_{20}	1	m = 0.5 σ = 0.3	$e[0.5s+\frac{1}{2}(0.09)s^2]$
<V16,V18>	W_{21}	1	m = 0.7 σ = 0.2	$e[0.7s+\frac{1}{2}(0.04)s^2]$
<V17,V18>	W_{22}	1	m = 0.8 σ = 0.1	$e[0.8s+\frac{1}{2}(0.01)s^2]$
<V18,V19>	W_{23}	1	a = 0	1
<V19,V20>	W_{24}	1	a = 0	1
<V20,V22>	W_{25}	1	a = 0.1	e(0.1s)
<V22,V21>	W_{26}	0.12	a = 0.1	e(0.1s)
<V21,V14>	W_{27}	1	a = 0	1
<V22,V23>	W_{28}	0.88	a = 0.1	e(0.1s)
<V23,V24>	W_{29}	1	a = 0	1
<V24,V25>	W_{30}	1	a = 0	1
<V24,V26>	W_{31}	1	a = 0	1
<V25,V27>	W_{32}	1	m = 0.9 σ = 0.2	$e[0.9s+\frac{1}{2}(0.04)s^2]$
<V26,V27>	W_{33}	1	m = 1.1 σ = 0.1	$e[1.1s+\frac{1}{2}(0.01)s^2]$
<V27,V28>	W_{34}	1	a = 0	1
<V28,V29>	W_{35}	1	a = 0	1
<V29,V31>	W_{36}	1	a = 0.1	e(0.1s)
<V31,V30>	W_{37}	0.2	a = 0.1	e(0.1s)
<V30,V24>	W_{38}	1	a = 0	1
<V31,V32>	W_{39}	0.8	a = 0.1	e(0.1s)
<V32,V1>	W_A	1	a = 0	1

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3.2 Calculation of time and probability indicators

To calculate the topological equation, it is necessary to determine the coefficients of the first, second, and third-order loop pass.

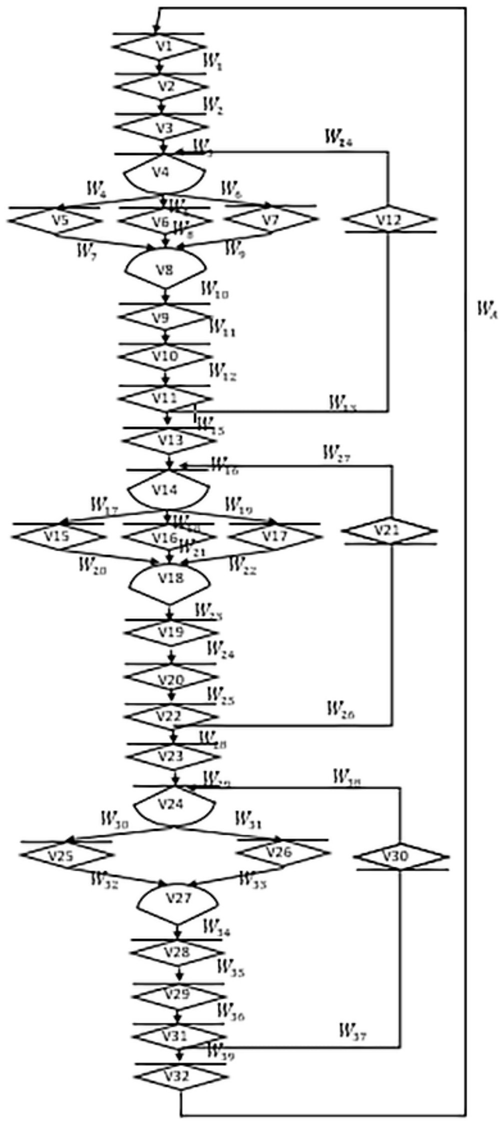

Fig. 2. GERT network of the «coordinate procurement demand» subprocess.

First-order loops:

$$(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14},$$

$$(W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27},$$

$$(W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38},$$

$$W_1W_2W_3(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{15}W_{16}(W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{28}W_{29}(W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{39}(1/W_k)$$

Second-order loops:

$$(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \times (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27},$$

$$(W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38},$$

$$(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38}$$

Third-order loops:

$$(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \times (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38}$$

There are no loops above the third order in this GERT network.

We will write the topological equation according to Mason's rule with the values of the investigated GERT network.

$$\begin{aligned} H = 1 - &(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &- (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &- (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} \\ &- W_1W_2W_3(W_4W_7 + W_5W_8 \\ &+ W_6W_9)W_{10}W_{11}W_{12}W_{15}W_{16}(W_{17}W_{20} + W_{18}W_{21} \\ &+ W_{19}W_{22})W_{23}W_{24}W_{25}W_{28}W_{29}(W_{30}W_{32} \\ &+ W_{31}W_{33})W_{34}W_{35}W_{36}W_{39}\left(\frac{1}{W_k}\right) \\ &+ (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &\times (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &+ (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &\times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} \\ &+ (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &\times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} \\ &- (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &\times (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &\times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} = 0 \end{aligned}$$

Next, we will transform the equation with respect to $W_k(s)$.

$$\begin{aligned} W_k(s) = &W_1W_2W_3(W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{15}W_{16}(W_{17}W_{20} + W_{18}W_{21} \\ &+ W_{19}W_{22})W_{23}W_{24}W_{25}W_{28}W_{29}(W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{39} \\ &/(1 - (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &- (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &- (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} \\ &+ (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &\times (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &+ (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &\times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} \\ &+ (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &\times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38} \\ &- (W_4W_7 + W_5W_8 + W_6W_9)W_{10}W_{11}W_{12}W_{13}W_{14} \\ &\times (W_{17}W_{20} + W_{18}W_{21} + W_{19}W_{22})W_{23}W_{24}W_{25}W_{26}W_{27} \\ &\times (W_{30}W_{32} + W_{31}W_{33})W_{34}W_{35}W_{36}W_{37}W_{38}). \end{aligned}$$

Then, we will substitute the corresponding values of the probability products and $M_k(S)$ from Table 2 to obtain $W_k(s)$. For convenience, we will write the transformed equation immediately.

$$W_k(s) = 0.6688\exp(6.2s + 0.125S^2)/(1 - 0.05\exp(1.8s + 0.03S^2) - 0.12\exp(2.2s + 0.07S^2) - 0.2\exp(2.2s + 0.025S^2) + 0.006\exp(4s + 0.1S^2) + 0.024\exp(4.4s + 0.095S^2) + 0.01\exp(4s + 0.055S^2) - 0.0012\exp(6.2s + 0.125S^2))$$

Next, we will calculate the mean and variance. We will calculate the first and second partial derivatives with respect to the function S=0.

Due to the voluminous calculations, we will present only the results: $\mu_{1k} = 7.414$ $\mu_{2k} = 53.774$ $\sigma^2 = 2.727$.

Thus, the result obtained determines that the coordination of procurement demand will be completed in a time $\mu = 7.144$ with a possible time spread of $\sigma^2 = 2.727$.

4 Conclusion

The peculiarity of this business process lies in the fact that the process was executed by three responsible persons, and the stages of the approval process were very clearly distributed among them. Using the transformation of the GERT network, it is possible to quickly model possible reorganization of the company's organizational structure [23-25]. Or calculate how much faster the approval process will be performed in case of automating the data collection for responsible persons at various stages. This will help to correctly identify vulnerable areas in the business process that need to be optimized in the first place for the overall development of the company.

By transforming the business process into a GERT network, it is possible to calculate the probabilities of completing work within a certain time. This approach is relevant because business processes have a fairly complex structure, and adding or excluding steps in the business process can significantly change the time required for completion. Using the GERT network, it is possible to take into account random deviations and uncertainties that may arise during work. This is important for planning labour costs and identifying vulnerable areas in the system.

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