Mechanism for the transition to digitalization of forestry enterprises using correlation analysis

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Abstract. This paper presents the results of a scientific study based on the conducted economic and mathematical modelling. The author's model of key conditions for the use of information and communication technologies (ICT) in the structure of innovative digital optimization of business processes is proposed. Based on the presented model, an integral indicator for assessing the level of provision of innovative development in the context of the transition to import-substituting products, taking into account the crisis and sanctions, is formed. Taking into account the developed integral indicator, the optimality coefficients of the indicators of the group of forestry enterprises were developed, determining the degree of use of digital resources (Kdr_{fc}) and the optimality of the indicators of financing the digitalization of forestry enterprises (Kfd_{fc}). A correlation analysis of the digitalization data of forestry enterprises was carried out. According to the calculation results, it was revealed that the highest level of correlation is noted for variables (y2i) and (y2.3i), caused by the introduction of the latest production equipment based on the use of modern digital technologies. The largest increase is observed in the pulp and paper industry, with a level of 219112.18, according to the results of 2023, but in comparison with the same base period (2020), a significant increase is observed, where the value of the variable (y2.3i) was 148286.57. The most successful, according to the coefficient of optimality of indicators of the use of digital resources of the group of forestry enterprises in digitalization (Kdr_{fc}), are enterprises engaged in furniture production with a variable (x1.4ij) with an index of 0.235, with (I_{ael}) = 7.412.

1 Introduction

Forest industry production is classified as a complex and labour-intensive industry that requires the use of more technologically advanced equipment. Today, the production of innovative products requires the use of equipment based on digital technologies and big data arrays.

The use of breakthrough production technologies is based on various architectural solutions. For example, we can note the widespread hybrid NBIC technologies, the use of which is carried out in the context of innovative development using high-tech breakthrough technologies in the information and communication, cognitive, nano and biotechnological

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areas [1,5,8]. These progressive technologies are used in the form of applied software products and technological solutions.

Considering the forest industry production, it can be noted that all enterprises experience the need to use the latest innovative technologies, primarily based on information and communication technologies using big data, the Internet of Things and cloud services.

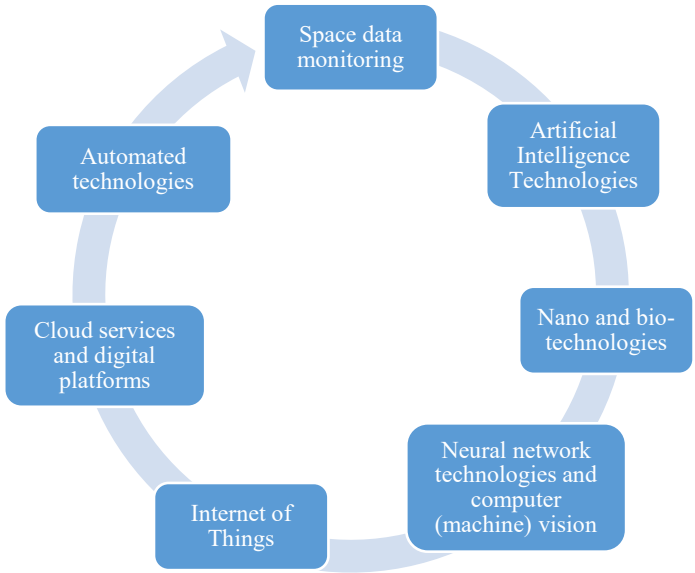

Fig. 1. Key digital technologies used in forestry production.

The use of space data monitoring allows obtaining the necessary data on the state of the forest fund for prompt decision-making based on the current situation. It is mainly used in forest management and forest inventory for large forest areas. The main tools when using space data monitoring are geoinformation analysis methods and visualization tools.

Modern forest industry enterprises are interested in switching to a digital path of development, this is due not only to the use of individual digital technologies at a specific production site, but also the entire range of information and communication technologies (ICT), including the ability to transfer the production process to an innovative and information level of development [2,9,14]. It is important to note that the transition to digital technologies allows for the automation of not only the entire production, but also the necessary business processes separately. The use of modern information and communication technologies allows for the output of high-quality information on the course of each business process, taking into account the identified deviations. Analysing the dynamics of the use of information and communication technologies in the forest industry complex, we can note the focus on the implementation of digitalization of not only individual processes in the production system, but also on the construction of a unified data system [7,10,13]. The formed system takes into account all the necessary analytical data for their further processing, with the aim of forming and adjusting the program of innovative development and forming an innovative infrastructure of forest industry enterprises, with the possibility of digitalizing key business processes.

Figure 2 presents a model of key conditions for the application of information and communication technologies in the structure of innovative digital optimization of business processes.

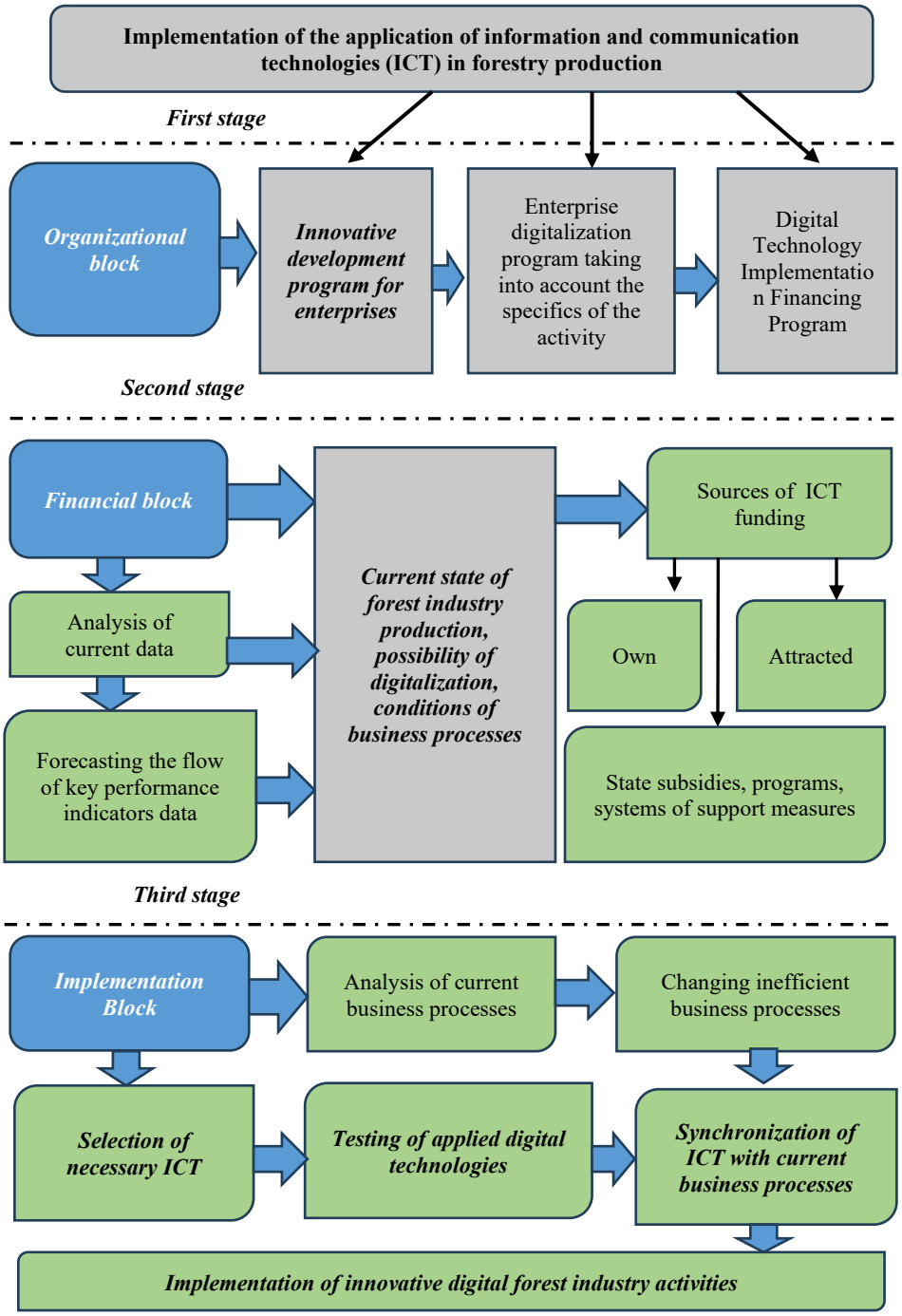

Fig. 2. Model of key conditions for the application of information and communication technologies in the structure of innovative digital optimization of business processes.

As can be seen from the presented model, which includes three main stages, in order to implement the digitalization of forest industry enterprises, it is necessary to develop appropriate programs, identify sources of financing for the transition to digital production.

At the final stage, inefficient business processes are cut off, the latest digital technologies are studied and tested, and information and communication technologies are directly implemented in the activities of enterprises.

2 Material and methods

There are a sufficient number of methods that determine the level of technological development of a manufacturing enterprise, but they all take into account only the basic indicators of digitalization, without taking into account the crisis and sanctions, as well as the influence of various factors, including geopolitical ones.

The most optimal for industry enterprises included in the forestry complex will be the use of indicators of the methodology for assessing the level of technological development, based on the analysis of statistical indicators and taking into account the importance of scientific research and development, the degree of development of technological innovations (Methodological recommendations for conducting a statistical assessment of the level of technological development, the order of the relevant department in the field of economic development) [4,11,15].

This methodology is based on an integral indicator for assessing the level of technological development based on statistical data. We propose an improved integral indicator based on this methodology, taking into account the specifics of forest industry production.

$$S_{fc} = \sum_{j=1}^{g}(And_j + Idc_i) \times b_j \quad (1)$$

where S_{fc} - is an integral indicator for assessing the level of innovation and technological development for each type of production;

g - is the number of aggregate groups of criteria;

j - is the number of the group of analysed criteria (j = 1, …, g);

A_{ndj} - is an indicator of technological development in the context of a specific forest industry sector of production;

I_{dci} - is an indicator of financing digital costs;

b_j - is a coefficient that determines the weight of the j-th criterion on the final value of the formed integral indicator for a separate type of production.

To assess the digital security of forest industry enterprises, the study formed a set based on systems of linear regression equations, which, in turn, characterize the insufficiency of the use of information and communication technologies (ICT) in a particular industry [2,6,12]. At the same time, it can be clarified that the number of systems and industry directions coincide, which correspond to the required xij and are equal to the calculated n, and each digitalization indicator of the i-th direction corresponds to the i-th industry direction.

Using the indicators of the methodology for assessing the level of technological development, built on the basis of the analysis of statistical indicators and taking into account the importance of scientific research and development, the degree of use of technological innovations, we will develop a corresponding model focused specifically on forest industry enterprises.

The model of the integral indicator for assessing the level of security of innovative development in the context of the transition to import-substituting products, taking into account the crisis and sanctions, has the form, with the following ratio:

$$S_{fc} = \sum_{j=1}^{g}(And_j + Idc_i) \times b_j = 0 \leq 1 \geq 1{,}5 \quad (2)$$

To calculate this model, a coefficient of optimality of indicators of a group of forest industry enterprises was developed, which is calculated using the formula:

$$Kdr_{fc} = \frac{\frac{Pdr_{fin}}{Pdr_{init}}}{P_n} \quad (3)$$

Where, Kdr_{fc} is the optimality coefficient of the digital resource usage indicators of the forest industry enterprises group;

Pdr_{fin} is the final value of the digital resource usage indicator in the reporting period;

Pdr_{init} is the initial value of the digital resource usage indicator in the first analysed period;

P_n is the number of analysed periods.

$$Kfd_{fc} = \frac{\frac{Pfd_{fin}}{Pfd_{init}}}{P_n} \quad (4)$$

Where, Kfd_{fc} is the optimality coefficient of the digitalization financing indicators of the forest industry enterprises group.

$Pfdf_{in}$ is the final value of the digitalization financing indicator in the reporting period;

Pfd_{init} is the initial value of the digitalization financing indicator in the first analysed period.

The following elements for applying the model of the integral indicator for assessing the level of technological development based on statistical data are the indicator of the level of efficiency of ICT application and the indicator of the level of ICT financing.

ICT application efficiency level indicator:

$$I_{ael} = \frac{1+Kdr_{fc}}{n} \times P_{fin} \quad (5)$$

Were, I_{ael} – ICT application efficiency level indicator;

N – number of useful life periods of digital technologies.

ICT financing level indicator:

$$I_{le} = \frac{1+Kfd_{fc}}{n} \times P_{fin} \quad (6)$$

Were, I_{le} – Indicator of the level of ICT financing.

The number of useful life periods of digital technologies is on average 10 years, therefore n=10.

3 Results and Discussion

Next, according to the presented coefficients and indicators, we will form the indicators and criteria necessary in the future for conducting correlation analysis for 2023 - the last reporting period (P_{fin}).

Table 1. Range of required data for correlation analysis for the last reporting period.

Digitalization criteria by industry (x_{ij})	**(dr_{fc})**	**(I_{ael})**	**Criteria for the implementation of digitalization financing by industry (y_i)**	**(Kfd_{fc})**	**(I_{le})**
An indicator of the number of forest industry enterprises using Internet resources to retrain personnel in digital technologies, $x1_{ij}$	0.158	45.158	Funding for costs associated with training in the use of information and communication technologies in the forest industry, ($y1_i$)	0.309	2380.60
Forestry, $x1.1_{ij}$	0.131	25.905	Forestry, $y1.1_i$	0.410	1200.78
Woodworking industry (WI), $x1.2_{ij}$	0.219	5.608	Woodworking industry, $y1.2_i$	0.127	186.76
Pulp and paper industry (P. and P.I.), $x1.3_{ij}$	0.212	6.663	Pulp and paper industry, $y1.3_i$	0.179	470.52
Furniture industry, $x1.4_{ij}$	0.235	7.412	Furniture industry, $y1.4_i$	1.522	1012.84
Number of forest industry enterprises that have the necessary training software, $x2_{ij}$	0.588	119.598	Acquisition of the latest production equipment based on the use of modern digital technologies in the forestry industry, ($y2_i$)	0.210	452545.37
Forestry, $x2.1_{ij}$	0.597	66.761	Forestry, $y2.1_i$	0.227	29163.79
(WI), $x2.2_{ij}$	0.575	21.735	(WI), $y2.2_i$	0.113	73060.44
(P. and P.I.), $x2.3_{ij}$	0.609	22.522	(P. and P.I.), $y2.3_i$	0.208	219112.18
Furniture industry, $x2.4_{ij}$	0.518	8.654	Furniture industry, $y2.4_i$	0.451	150066.74

Based on the generated indicators and criteria presented in Table 3, we will conduct a correlation analysis based on the optimality coefficient of indicators (Kdr_{fc}) and the indicator of the level of efficiency of ICT application (I_{ael}) (Figure 3).

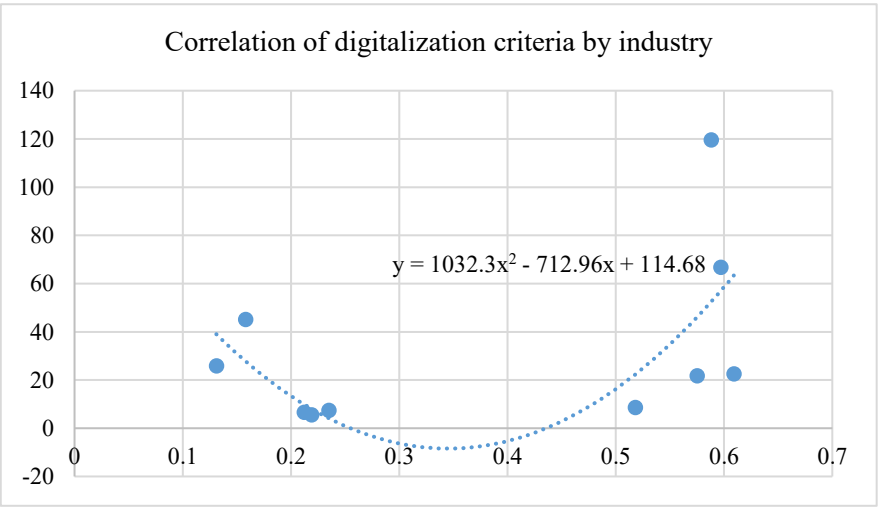

Fig. 3. Results of the correlation analysis of the digitalization criterion in the forestry industries.

As can be seen from Figure 3, in general, the level of digitalization in the forestry industry is insufficient, but is within the acceptable values, closer to 1. A weak correlation dependence is observed, which tends to a non-linear form. The equation of the digitalization criterion for the forestry industries is: y = 1032.3x2 - 712.96x + 114.68. On average, the level of digitalization is at the level of 21 points out of 100 possible.

Next, we will consider the results of the analysis of correlated data on the level of digitalization financing in the forestry industries. The correlation analysis was carried out on the basis of financial and economic data obtained for the last reporting period (2023) for the analysed industries. The optimality coefficient of indicators (Kfd_{fc}) and the ICT financing level indicator (I_{le}) were correlated - Figure 4.

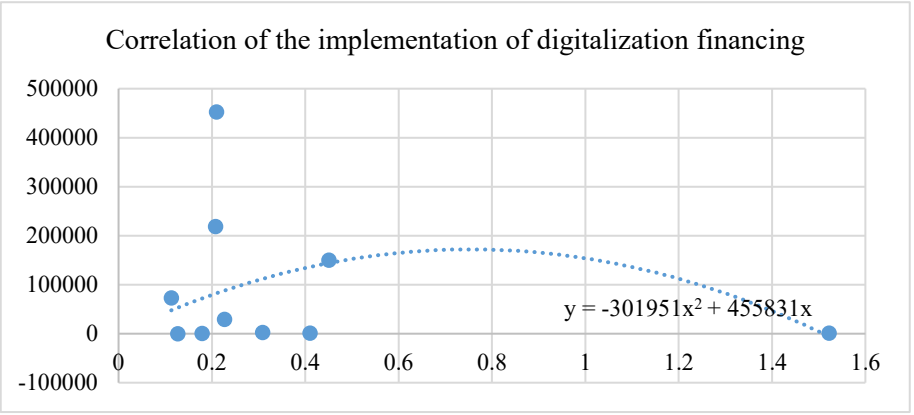

Fig. 4. Results of the analysis of correlated data on the level of implementation of digitalization financing in the forestry industry.

Having correlated the data on the level of implementation of financing in the digitalization of forestry enterprises, it can be seen that there is an inverse correlation, which shows that with a decrease in financing, the correlation coefficient can tend to 0 or have a negative value, which is unacceptable in the current conditions. The graph shows a polynomial trend line, which demonstrates the immutability of financial processes, i.e. the analysed indicators are in the range [0; 1]. Tables 2 and 3 present more detailed results of the correlation analysis of the optimality coefficients for the studied forestry industries for 2020-2023, based on the indicators and criteria formed in Table 1. The analysis used data from logging enterprises, woodworking industry, pulp and paper and furniture enterprises. The calculation took into account the optimality coefficient of indicators (Kdr_{fc}) and the indicator of the level of efficiency of ICT use (I_{ael}).

Table 2. Results of the correlation analysis of the optimality coefficients (digitalization level) for the studied forestry industries for 2020-2023.

Periods / Variables	2020	2021	2022	2023	Periods / Variables	2020	2021	2022	2023
$DR\ x1_{ij}$	0.432	0.243	0.159	0.158	$y1_i$	61.154	44.745	36.390	45.158
$x1.1_{ij}$	0.404	0.205	0.122	0.131	$y1.1_i$	39.593	25.915	19.070	25.905
$x1.2_{ij}$	0.488	0.317	0.262	0.219	$y1.2_i$	6.101	5.270	5.552	5.608
$x1.3_{ij}$	0.481	0.308	0.260	0.212	$y1.3_i$	7.404	6.277	6.802	6.663
$x1.4_{ij}$	0.529	0.373	0.225	0.235	$y1.4_i$	8.259	7.824	5.637	7.412
$DLP\ x2_{ij}$	0.589	0.452	0.719	0.588	$y2_i$	47.904	50.378	126.500	119.598
$x2.1_{ij}$	0.582	0.443	0.741	0.597	$y2.1_i$	25.789	26.837	72.254	66.761
$x2.2_{ij}$	0.563	0.417	0.672	0.575	$y2.2_i$	8.438	8.500	21.567	21.735
$x2.3_{ij}$	0.685	0.572	0.734	0.609	$y2.3_i$	10.614	12.422	23.405	22.522
$x2.4_{ij}$	0.500	0.333	0.648	0.518	$y2.4_i$	3.300	2.933	9.392	8.654

Digital Resources (DR) and Digital learning programs (DLP).

As can be seen from Table 2, the value of the optimality coefficient, reflecting the number of forestry enterprises using Internet resources to retrain personnel in digital technologies ($x1_{ij}$), tends to decrease, if the coefficient value in 2020 was 0.432, then in 2023 it was 0.158. At the same time, the indicator reflecting the number of forestry enterprises with the necessary training software ($x2_{ij}$) has practically unchanged dynamics, if in 2022 the coefficient value was 0.719, then by the end of 2023 it was already 0.588, in comparison with 2020 we see that there are no changes. As for the indicator of the level of efficiency of ICT use, it can be seen that there is also a decrease in most values, which can be caused by an insufficient number of organizations using training programs at forestry enterprises. The results of the correlation analysis for all analysed periods (2020-2023) are presented graphically in Figure 5:

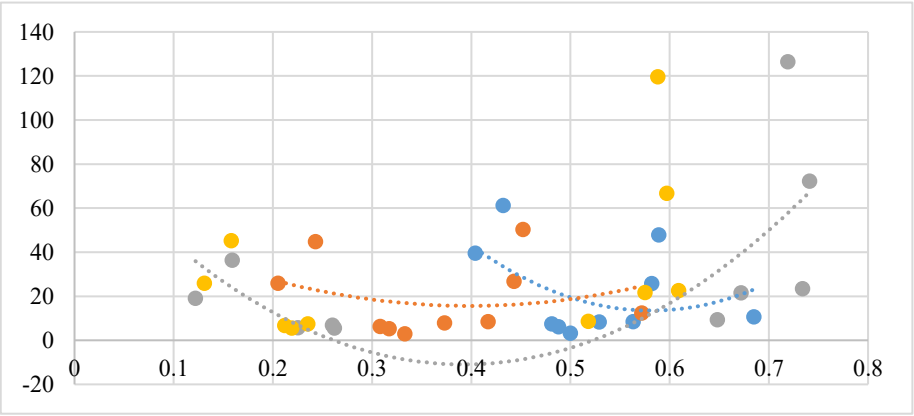

Fig. 5. Results of the correlation analysis of the digitalization criterion for all analysed periods.

Based on the results of the correlation analysis of the digitalization criterion for all analysed periods, presented in Figure 5, one can see a linear correlation dependence, which is at the lower acceptable limits for most indicators, closer to «0», which is accompanied by a low connection between the variables, but generally within the acceptable range [1;1].

Table 3. Results of the correlation analysis of the optimality coefficients (the level of implementation of digitalization financing by industry) for the forestry complex for 2020-2023.

Periods / **Variables**	**2020**	**2021**	**2022**	**2023**	**Periods** / **Variables**	**2020**	**2021**	**2022**	**2023**
Financing $x1_{ij}$	0.806	0.741	0.226	0.309	$y1_i$	3420.31	4549.82	1304.041	2380.604
$x1.1_{ij}$	0.350	0.133	0.106	0.410	$y1.1_i$	392.27	187.97	194.452	1200.789
$x1.2_{ij}$	0.484	0.312	0.189	0.127	$y1.2_i$	376.39	321.70	235.990	186.766
$x1.3_{ij}$	0.870	0.827	0.159	0.179	$y1.3_i$	1447.74	2016.09	327.064	470.521
$x1.4_{ij}$	5.450	6.934	1.926	1.522	$y1.4_i$	3712.69	8714.19	1190.692	1012.842
Equipment $x2_{ij}$	0.469	0.292	0.245	0.210	$y2_i$	491993.55	404148.18	435230.66	452545.37
$x2.1_{ij}$	0.886	0.591	0.324	0.227	$y2.1_i$	69918.80	58971.12	35935.903	29163.799
$x2.2_{ij}$	0.189	0.126	0.228	0.113	$y2.2_i$	52159.98	49399.79	130132.63	73060.445
$x2.3_{ij}$	0.322	0.215	0.138	0.208	$y2.3_i$	148286.57	136240.87	109182.21	219112.18
$x2.4_{ij}$	1.306	0.871	0.658	0.451	$y2.4_i$	276059.89	223937.62	199877.13	150066.75

Table 3 presents the results of the correlation analysis of the optimality coefficients, reflecting the level of implementation of digitalization financing and the introduction of information and communication technologies in the studied forestry industries for 2020-2023. The calculation took into account the optimality coefficient of the indicators (Kfd_{fc})

and the indicator of the level of ICT financing (I_{le}). The criteria are divided into 2 main blocks, expressed by indicators ($y1_i$) and ($y2_i$).

Assessing the results of the analysis of the correlation of the level of digitalization financing by industry, it can be noted that it is worth paying attention to the indicators ($x1.2_{ij}$) and ($x1.3_{ij}$), where there is a significant decrease in the optimality coefficient of the indicators (Kfd_{fc}), fivefold and threefold, respectively. In the first analysed period, the value of the variable ($x1.2_{ij}$) was 0.484, and in 2023 it was already 0.127. The value of the variable ($x1.3_{ij}$) in 2023 was 0.179, compared with the value of 0.870 in the initial period. Considering that the optimality of the coefficient values should correspond to the ratio $0 \leq 1 \geq 1.5$, there are quite serious deviations that need to be paid attention to. This is primarily due to a decrease in the ICT financing level indicator (I_{le}), which reflects the optimality of the implementation of tasks on the introduction of information and communication technologies in the activities of forestry enterprises. Figure 6 presents the results of the analysis of the correlation of the criterion for implementing digitalization financing by industry.

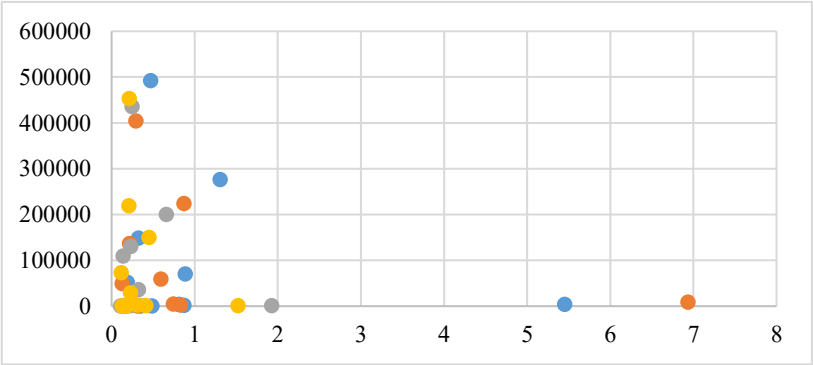

Fig. 6. Results of the correlation analysis of the criterion for the implementation of digitalization financing by industry for all analysed periods.

Having correlated the necessary data taking into account the level of financing for the implementation of information and communication technologies and the implementation of digitalization, it can be seen that the indicator of the level of financing is characterized by a weak correlation with elements of nonlinear correlation, in which a weak connection between the variables is carried out, tending to «0», for all analysed periods. The highest level of correlation is observed with variables ($y2_i$) and ($y2.3_i$), caused by the introduction of the latest production equipment based on the use of modern digital technologies. The largest increase is noted in the pulp and paper industry, with a level of 219112.18, according to the results of 2023, but in comparison with the same base period (2020), a significant increase is observed, where the value of the variable ($y2.3_i$) was 148286.57.

4 Conclusion

The study modelled the key conditions for the use of information and communication technologies in the structure of innovative and digital optimization of business processes. Based on the constructed model, the analysis of the effectiveness of the implementation of information and communication technologies and the assessment of the level of digitalization in the forestry industries were carried out. It is worth noting that in general, in the forestry industry, organizations pay significant attention to the implementation of digitalization of production processes. Also, forestry enterprises make a personal contribution to the transition to an innovative and digital path of development. The most successful, according to the optimality coefficient of the indicators of the use of digital resources of the group of forestry

enterprises in digitalization (Kdr_{fc}), can be noted as enterprises engaged in furniture production with a variable ($x1.4_{ij}$) with an index of 0.235, with (I_{ael}) = 7.412. Pulp and paper enterprises are characterized by the largest variable ($x2.3_{ij}$) with an index of 0.609, with (I_{ael}) = 22.522. The remaining industries are characterized by lagging and lower indices and variables. At the same time, the digital capacity is distinguished by logging production, with a low coefficient index (Kdr_{fc}) a high value (Iael) is observed, with ($x1.1_{ij}$) = 25.905 and with ($x2.1_{ij}$) = 66.761.

Acknowledgments

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