The development of the digital transformation of socio-economic and ecological systems

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ABSTRACT

Information about the development of digital transformation is crucial for the state's operational and strategic management. The paper aims to find issues of the state's digital transformation development based on assessing the dynamics of the digital transformation of its socio-economic and ecological systems. The paper adds a set of relevant quantitative and relative indicators for evaluating the digital transformation of socio-economic and ecological systems through comparison methods. Dynamic indicators have been designed and used to analyze how the digital transformation of socio-economic and ecological systems changes over time. They base on the mean of the growth rate of each indicator from the proposed set. The paper evaluated the dynamics of the digital transformation of socio-economic and ecological systems for Ukraine for 2018-2021. The results mainly indicate an improvement in developing the digital transformation of socio-economic and ecological systems. However, the dynamic indicator which characterizes the quantitative aspect of the digital transformation of socio-economic systems slightly decreased, indicating its issues. It is suggested to maintain the current pace of Ukraine's digital change while eliminating found issues.

Keywords: Digital transformation, socio-economic system, ecological system, indicators, sustainable development, Ukraine

Mathematics Subject Classification: 91-02, 91B76

Journal of Economic Literature (JEL) Classification: O11, O13, Q55

Computing Classification System: A.1

1. INTRODUCTION

In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development (United Nations, 2015), a comprehensive and global plan to achieve economic prosperity, environmental sustainability, and social inclusion. This Order contains seventeen goals in the field of sustainable development. The ninth goal among them is the creation of sustainable infrastructure, the promotion of comprehensive and sustainable industrialization and innovation, and the digital transformation of socio-economic and environmental systems.

Currently, many states in the world need help developing digital transformation. Therefore, forming such a management model in these countries, which would reorient local business entities from traditional to computerized production, becomes an urgent issue. The current crisis phenomena in the global economy confirm the thesis about transitioning to a new economy focused on innovative development and digital transformation.

Even though studies on digital transformation as a factor of sustainable development reach a significant number, the central part of them is aimed at developing appropriate tools and means of activating digital transformation and revitalizing the innovative development of states. The digital transformation of socio-economic and ecological systems is of great importance on this path, as the success of achieving the relevant goals of sustainable development of the entire country depends on this. So, the country's digital transformation is closely related to the availability of appropriate internal capabilities and resources in the socio-economic and ecological systems.

The development of the digital transformation of socio-economic and ecological systems depends on the quality of transformation management. The results of digital transformation management are reflected in competitiveness. Therefore, to make successful management decisions, it is necessary to have a high-quality tool kit for evaluating the dynamics of digital transformation of socio-economic and ecological systems in the form of an appropriate indicators and criteria system. The general problem is contained in the complexity of assessing due to the specifics of individual territorial socio-economic and ecological systems, their different sizes, and their features. This paper aims to seek issues associated with the development of the state's digital transformation by assessing the dynamic changes of digital transformation taking place in its socio-economic and environmental systems.

2. LITERATURE REVIEW

The review aims to explore the different aspects of the development of digital transformation in socio-economic and ecological systems. The effectiveness of regional socio-economic systems is greatly influenced by innovations and digital transformation, which play a pivotal role in shaping their development as a fundamental component of the systems (Omelyanenko et al., 2022; Hao and Zhang, 2021). Solid comprehension of digital transformation is essential to maintain competitiveness amidst the constantly changing landscape in the future (Banović–Ćurguz, 2018; Tkalenko et al., 2019). The state of digital transformation aims to offer more empirical evidence for governments to enhance their digital transformation policy and meet the country's development demands in the contemporary era (Dung et al., 2021). Organizations must improve their digital abilities to benefit from digital transformation impact while balancing economic, environmental, and social effects (Gomez-Trujillo and Gonzalez-Perez, 2022; Padua, 2021). In the present socio-economic context, businesses have a crucial responsibility to prioritize digitalization as a response to the risks posed by conventional manufacturing methods and regulations mandated by stakeholders and governments (Pasqualino et al., 2021). Industrial revolutions explain the process of development of digital transformations. The future digital transformation within the 'Fourth Industrial Revolution' can support a circular economy (Pellegrini et al., 2018; Türkeli and Schophuizen, 2019). Implementing digital transformation favors the sustainability aspect of the environment and society (Junge and Straube, 2020). The achievement of the United Nations Sustainable Development Goals may be improved through digital transformation (Ufua et al., 2021; Andersson and Mattsson, 2018; Babay and Erragcha, 2023). Digital changes can help us overwhelm economic, social, and environmental challenges to reach sustainable development (Dayıoğlu and Turker, 2021; Prokhin, 2020; Melnyk and Dehtyarova, 2022; Moroz and Dyma, 2020; Larios-

Hernandez, 2023; Bieser and Hilty, 2018; Wuppertal Institute, 2021). The primary challenge of digital transformation will involve a new model of financial advancement, addressing the issue of joblessness and ensuring the integration of the novel technological system with society's information and social infrastructure (Devezas, 2021). The digitalizing socio-economic systems provide analysis, assessment, and monitoring readily available to the regional participants engaged in sustainable territorial growth. These resources are instrumental in creating suitable development plans, proficiently administering them, evaluating their effectiveness, and determining their outcomes (Popa, 2022). On the other hand, the process of digital transformation cannot be considered entirely positive because it has various effects on different aspects, such as the economy, the environment, society, technology, and institutions, along with their interconnections (Rijswijk et al., 2021; Behera, 2021; Parra-López et al., 2021). To address this issue, Rijswijk et al. created a framework that enables us to understand how the aspects of a system are interconnected. They identified the requirements that must be met to achieve a successful digital transformation of such a system (Rijswijk et al., 2021). For assessing digital transformation, researchers use the "technology-environment-organization" model. New approaches to evaluating digital transformation are also evolving (Bin et al., 2021; Koblianska et al., 2020). The issue is that most existing digital transformation strategies concentrate on the product, process, and process cluster levels. At the same time, the United Nations Sustainable Development goals primarily address the economy-wide level (Pauliuk et al., 2022).

3. METHODS AND GENERATION OF THE DATA

The strategies of development of digital transformation on the economy-wide level require appropriate tools for its assessment. Considering the vector of scientific research in the form of existing indicators and criteria for assessing digital transformation of socio-economic and ecological systems, and based on the importance of researching the dynamics of digital transformation due to the specific nature of each state, the paper adds a set of relevant indicators and criteria. Based on these, assessing the digital transformation of socio-economic and ecological systems is possible. By counting the fact that systems tend to change over time, it becomes possible to evaluate the dynamics of digital transformation. This, in turn, makes it possible to develop recommendations for managing the state's digital transformation.

It is proposed to evaluate the dynamics of the digital transformation of socio-economic systems using two groups of annual indicators. The first group includes absolute indicators; the second is relative indicators.

The first group of annual indicators (absolute indicators)

1. I_i – number of government institutions that have access to the Internet, un.
2. I_d – number of state institutions that provide the opportunity to use the tools of electronic democracy, un.
3. E_t – number of enterprises carrying out electronic trade, un.
4. A_p – the amount of products sold through e-commerce, thnd. USD.
5. E_i – number of enterprises that have access to the Internet, un.
6. E_w – number of enterprises with their website, un.
7. E_c – number of enterprises that use computers, un.
8. E_{bd} – number of enterprises conducting "Big Data" analysis, un.
9. E_{in} – number of enterprises providing invoices in electronic form, un.
10. E_{bb} – number of enterprises using broadband Internet access, un.

The second group of annual indicators (relative indicators)

1. P_i – part of public institutions that have access to the Internet in the total number of institutions, %.
2. P_t – part of enterprises that carry out electronic trade, %.
3. P_{tw} – part of enterprises that carry out electronic trade through websites or web applications in the total number of enterprises, %.
4. P_p – part of the number of products sold through electronic trade, %.
5. P_{bd} – part of enterprises conducting "Big Data" analysis, %.

6. P_s – part of enterprises employing specialists in information and telecommunication technologies in the total number of enterprises, %.
7. P_{3D} – part of enterprises using 3-D printing in the total number of enterprises, %.
8. P_{fa} – part of enterprises using fixed Internet access, %.
9. P_{ow} – part of enterprises that have their website, %.
10. P_{cc} – of enterprises purchasing cloud computing services in the total number of enterprises, %.

All indicators should increase yearly, which will characterize the positive dynamics of the digital transformation of socio-economic systems. The first group better represents the quantitative side of digital transformation, and the second group better represents the qualitative side. Indicators can be determined both on an administrative basis and for individual territories. By comparing the values of indicators among themselves and by changes over time, it is possible to determine how digital transformation is carried out.

To assess how the digital transformation of socio-economic systems is changing over time, it is proposed to calculate indicators for dynamics of digital transformation of socio-economic systems, which are particular dynamic indicators for each of the first and second indicators groups. The optimal after-change direction of these indicators is growth.

Dynamic indicators are calculated based on the relative growth of the annual indicators of the first and second groups according to the formulas:

$$D_{1i} = \sqrt[N-1]{\prod_{n=1}^{N-1}\left(\frac{A_{1i\{n+1\}}}{A_{1i\{n\}}}\right)}, \quad (1)$$

$$D_{2i} = \sqrt[N-1]{\prod_{n=1}^{N-1}\left(\frac{R_{2i\{n+1\}}}{R_{2i\{n\}}}\right)}, \quad (2)$$

where: D_{1i} – dynamic indicators of digital transformation of socio-economic systems for the first group of indicators (absolute ones);

D_{2i} – dynamic indicators of digital transformation of socio-economic systems for the second group of indicators (relative ones);

A_{1i} – i-th indicator of the first group (absolute indicator);

R_{2i} – i-th indicator of the second group (relative indicator);

N – number of years for which the analysis is carried out;

n – designation of the year number.

The first and second groups of the proposed indicators are designed in such a way as to be sufficiently compact and straightforward while at the same time covering the main areas of digital transformation of socio-economic systems. Relative indicators are more comparable, while the scale of their components' absolute values has little effect on the indicators. The indicators are universal enough, which allows their use for different countries, provided that their peculiarities are considered.

It is proposed to evaluate the dynamics of the digital transformation of ecological systems using the following system of two groups of annual indicators. The third group includes absolute indicators; the fourth is relative ones.

The third group of annual indicators (absolute indicators)

1. E_a – expenses for protecting atmospheric air and climate, thnd. USD.
2. E_t – return water treatment expenses, thnd. USD.
3. E_w – wastes management expenses, thnd. USD.
4. E_p – expenses for protecting and rehabilitating soil and water objects, thnd. USD.
5. E_b – expenses for the protection of biological diversity, thnd. USD.
6. E_r – radiational protection expenses, thnd. USD.
7. E_s – expenses for scientific and research work on nature protection, thnd. USD.
8. E_h – total energy production by hydroelectric power stations, thnd. t.o.e.
9. E_{eb} – total energy production from biofuels and wastes, thnd. t.o.e
10. E_s – total energy production from wind and solar energy, thnd. t.o.e

The fourth group of annual indicators (relative indicators)

1. R_{ep} – the ratio of enterprises carrying out electronic trade and emissions of pollutants into the atmospheric air by stationary sources.
2. R_{se} – the ratio of the volume of products sold through e-commerce and the total final energy consumption.
3. R_{im} – the ratio of the number of enterprises that have access to the Internet and emissions of pollutants by mobile sources.
4. R_{ce} – the ratio of enterprises using computers to the total primary energy supply.
5. R_{ge} – the ratio of the number of government institutions with Internet access and energy consumption.
6. R_{gd} – the ratio of the number of state institutions that provide the opportunity to use the tools of electronic democracy and the amount of generated wastes of I-III hazard classes.
7. R_{ad} – the ratio of enterprises analyzing "Big Data" and releasing greenhouse gases into the atmosphere.
8. P_{hyd} – part of energy production by hydroelectric power stations, %.
9. P_{bw} – part of energy production from biofuel and wastes energy, %.
10. P_{sol} – part of the wind and solar energy production, %.

To assess how the digital transformation of ecological systems is changing over time, it is proposed to calculate indicators for dynamics of digital transformation of ecological systems, which are particular dynamic indicators for each of the third and fourth indicator groups. The optimal after-change direction of these indicators is growth. Dynamic indicators are calculated based on the relative growth of the annual indicators of the third and fourth groups according to the formulas:

$$D_{3\mathrm{i}} = \sqrt[N-1]{\prod_{n=1}^{N-1}\left(\frac{\mathrm{A}_{3\mathrm{i}\{n+1\}}}{\mathrm{A}_{3\mathrm{i}\{n\}}}\right)}, \quad (3)$$

$$D_{4\mathrm{i}} = \sqrt[N-1]{\prod_{n=1}^{N-1}\left(\frac{R_{4\mathrm{i}\{n+1\}}}{R_{4\mathrm{i}\{n\}}}\right)}, \quad (4)$$

where: D_{3i} – dynamic indicators of digital transformation of ecological systems for the third group of indicators (absolute ones);

D_{4i} – dynamic indicators of digital transformation of ecological systems for the fourth group of indicators (relative ones);

A_{3i} – i-th indicator of the third group (absolute indicator);

R_{4i} – i-th indicator of the fourth group (relative indicator);

N – number of years for which the analysis is carried out;

n – designation of the year number.

The third and fourth groups of proposed indicators are designed to be sufficiently compact and straightforward while at the same time covering the main areas of digital transformation of ecological systems. Relative indicators are more comparable, while the scale of absolute values of their components has little effect on indicators. The indicators are universal enough, which allows their use for different countries, provided that their peculiarities are considered.

Each group of indicators contains ten indicators for evaluating the dynamics of the digital transformation of socio-economic and ecological systems. The dynamics of digital transformation itself are evaluated using the dynamic indicators for each group, respectively. That is, the dynamic indicators are calculated for each of the 40 indicators for assessing the dynamics of the digital transformation of socio-economic and ecological systems.

The positive criteria for evaluating the dynamics of digital transformation of socio-economic and ecological systems is a value greater than 1 for each dynamic indicator. This means that if the dynamic indicators of digital change of socio-economic and ecological systems are more than 1 after calculation, the digital transformation of socio-economic and ecological systems according to the corresponding indicator is in the right direction and indicates positive dynamics, i.e., change over time. If the values of the dynamic indicators are equal to 1, there are no positive changes over time but no negative changes over time. In this case, the dynamics of digital transformation of socio-economic and ecological systems demonstrate constancy over time. Suppose the value of

dynamic indicators of the digital transformation of socio-economic and ecological systems is less than 1. In that case, this means a regression of digital transformation over time, and the systems need quick intervention to preserve the possibility of quality digital transformation in the future.

The proposed method is necessary during the digital transformation for its operational, strategic management, and implementation, which will allow having the required information about the state territorial system. The method is based on calculating 40 dynamic indicators D_{1i}, D_{2i}, D_{3i}, and D_{4i}, which can be reduced to 4 aggregate indicators D_1, D_2, D_3, *and* D_4. The principles of this aggregation are as follows.

Initially, there are four groups of absolute and relative indicators; each group contains ten indicators, a total of 40. Half of them are absolute; half are relative. Groups 1 and 3 consist of absolute indicators, and groups 2 and 4 – of relative. Groups 1 and 2 characterize the digital transformation of socio-economic systems, and groups 3 and 4 represent the digital transformation of ecological systems.

For each of the 40 absolute and relative indicators, their dynamic indicators D_{1i}, D_{2i}, D_{3i}, and D_{4i} are calculated according to each of the four groups. Since each group has its own ten dynamic indicators, they can be aggregated into one dynamic indicator for each group.

Aggregation occurs by applying weighting factors. Since each group has ten indicators and each has the same weight, their weights are 10% or 0.1. The formula for finding aggregated dynamic indicators:

$$D_j = \sum_{i=1}^{10}(0{,}1 \cdot D_{ji}), \tag{5}$$

where: D_j – the aggregated dynamic indicator of the digital transformation of systems for the *j*-th group of absolute indicators.

Criteria for evaluating the dynamics of digital transformation of socio-economic and ecological systems for aggregated dynamic indicators:

$$D_j > 1. \tag{6}$$

If this condition is fulfilled, the digital transformation of socio-economic and ecological systems according to the corresponding dynamic indicator is in the right direction. It indicates improving dynamics, i.e., changing over time.

In the paper, the proposed method for evaluating the dynamics of the digital transformation of socio-economic and ecological systems is carried out on the example of Ukraine for 2018-2021.

4. RESULTS

The results of calculations of all dynamic indicators of the digital transformation of socio-economic and ecological systems for Ukraine for 2018-2021 are presented in Tables 1 and 2. The estimates were made based on the data from the State Statistics Service of Ukraine (The official site of The State Statistics Service of Ukraine, 2023).

Table 1: Dynamic indicators D_{1i}, D_{2i} of digital transformation of socio-economic systems of Ukraine for 2018-2021

Indicator D_{1i}	Value	Indicator D_{2i}	Value
$D_{1\,1}$	0.837	$D_{2\,1}$	0.999
$D_{1\,2}$	0.836	$D_{2\,2}$	1.030
$D_{1\,3}$	1.010	$D_{2\,3}$	1.429
$D_{1\,4}$	1.242	$D_{2\,4}$	1.923
$D_{1\,5}$	1.009	$D_{2\,5}$	1.026
$D_{1\,6}$	1.019	$D_{2\,6}$	0.991
$D_{1\,7}$	1.009	$D_{2\,7}$	1.048
$D_{1\,8}$	0.979	$D_{2\,8}$	0.998
$D_{1\,9}$	1.016	$D_{2\,9}$	0.997
$D_{1\,10}$	1.010	$D_{2\,10}$	1.013
$\boldsymbol{D_1}$	**0.997**	$\boldsymbol{D_2}$	**1.146**

Table 2: Dynamic indicators D_{3i}, D_{4i} of digital transformation of ecological systems of Ukraine for 2018-2021

Indicator D_{3i}	Value	Indicator D_{4i}	Value
$D_{3\,1}$	1.108	$D_{4\,1}$	1.078
$D_{3\,2}$	1.020	$D_{4\,2}$	1.282
$D_{3\,3}$	1.068	$D_{4\,3}$	0.989
$D_{3\,4}$	1.220	$D_{4\,4}$	1.053
$D_{3\,5}$	1.200	$D_{4\,5}$	0.827
$D_{3\,6}$	0.787	$D_{4\,6}$	0.871
$D_{3\,7}$	1.012	$D_{4\,7}$	0.897
$D_{3\,8}$	0.938	$D_{4\,8}$	0.973
$D_{3\,9}$	1.110	$D_{4\,9}$	1.150
$D_{3\,10}$	1.808	$D_{4\,10}$	1.861
$\boldsymbol{D_3}$	**1.127**	$\boldsymbol{D_4}$	**1.098**

Table 1 shows that 70% of the values of dynamic indicators of digital transformation of socio-economic systems for the first group (absolute) indicators demonstrate compliance with the criteria. This means that the digital transformation of socio-economic systems has an improvement or change over time in the corresponding indicators. However, 30% of the values of dynamic indicators are less than 1, indicating regression in digital transformation according to these indicators.

For the second group (relative) indicators, 60% of the values of dynamic indicators of the digital transformation of socio-economic systems demonstrate compliance with the criteria. However, 40% of the values of dynamic indicators are less than 1, indicating regression in digital transformation according to these indicators.

Table 2 shows that 80% of the values of dynamic indicators of the digital transformation of ecological systems for the third group (absolute) indicators demonstrate compliance with the criteria. This means that the digital transformation of ecological systems has an improvement or change over time in the corresponding indicators. However, 20% of the values of dynamic indicators are less than 1, indicating regression in digital transformation according to these indicators.

Among the dynamic indicators of the digital transformation of ecological systems for the fourth group (relative) indicators, 50% of the indicator values comply with the criteria. Accordingly, 50% of the indicator values do not meet the criteria. This group of indicators has the lowest level of compliance with the criteria.

However, the values of aggregated dynamic indicators are the most significant. The results of the calculations of four aggregated dynamic indicators D_1, D_2, D_3, *and* D_4 for Ukraine gave the following values, respectively: 0.997; 0.146; 0.127; 1.098 (Tables 1, 2). This shows that only the value of the aggregated dynamic indicator of digital transformation of socio-economic systems D_1 for the first group (absolute) indicators don't match the criteria.

5. DISCUSSION AND CONCLUSION

The study results show that the digital transformation of Ukraine's socio-economic and ecological systems during 2018-2021 had some issues.

The value 0.997 for the first aggregate dynamic indicator responsible for the quantitative side of the digital transformation of socio-economic systems indicates its declining dynamics. This deterioration occurred due to the decrease in some absolute indicators of the digital transformation of socio-economic systems, such as the number of government institutions that have access to the Internet, the number of government institutions that provide the opportunity to use e-democracy tools, the number of enterprises that conduct "Big Data" analysis. This indicates the need to make efforts to improve mentioned indicators.

At the same time, the second, third, and fourth aggregate dynamic indicators of the digital transformation of socio-economic and ecological systems show growth in 2018-2021, which allows us to conclude that the digital transformation of socio-economic and ecological systems of Ukraine principally improved.

For the following years, Ukraine needs to maintain the pace of digital transformation of socio-economic and ecological systems as it was during the period and make efforts to eliminate the mentioned issues.

The practical use of the study is its possible application for making management decisions for the development of the digital transformation of the state.

Opportunities for future research in this direction lie in identifying specific factors influencing the development of the state's digital transformation.

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