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THE ASSESSMENT AND ANALYSIS MODELS FOR DIGITAL DEVELOPMENT OF TERRITORIES

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Chagovets L. O., Chahovets V. V., Butenko T. A., Protsenko N. M. The Assessment and Analysis Models for Digital Development of Territories

The article discusses a comprehensive approach to assessing and analyzing the digital development of Ukrainian territories in the context of recovery, ranging from the development of a city digitalization project and task optimization to the creation of models for evaluating and analyzing various factors of the interconnection between digital and economic development in the country's territories. The study examines the feasibility of using Data Science methods and project management as tools to achieve sustainable digital development of the territories. The development of a strategy for managing digital development in territories, segmented by specific sectors, includes a series of stages and tasks integrated into the basic project model. The article proposes a list of stages and tasks for a city digitalization management project and specifies the corresponding basic model of the organizational structure of the digitalization department. The key components of the management system have been examined: development management, information management, support for digitalization applications, and technical support. A draft digital development strategy has been prepared, and the stages of the project model optimization algorithm are being discussed in terms of time criteria, project cost issues, and the optimization of expenditure items. Since the implementation of complex smart city management projects is adapted to the specific characteristics of economic development in each territorial community, the article also addresses the adaptation of project tasks, illustrated by the development of a model for assessing the state of digitalization across the entire country. The research methodology is based on the development of mathematical models for assessing and analyzing the country's digitization at both the macro and meso levels using Data Science methods, particularly unsupervised agglomerative and iterative machine learning techniques. This approach allowed for the identification of significant disparities in the country's digitization, asymmetry in the development of telecommunications across its regions, and uneven intensity in the implementation of digital technologies in various sectors of Ukraine's economy. The results demonstrate the necessity to improve comprehensive digital development programs and to create new directions for territorial digitalization. These results can be applied in the practice of managing digital development within regional and municipal executive authorities. Implementing the proposed strategic digital development management model will enhance the quality of formulating and making managerial decisions regarding the digitalization of the most critical areas of territorial development in Ukraine.

Keywords: *territory development, IT development strategies, digital development, model, project management, Data Science methods.*
Fig.: *5.* ***Tabl.:*** *4.* ***Formulae:*** *2.* ***Bibl.:*** *32.*

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Чаговець Л. О., Чаговець В. В., Бутенко Т. А., Проценко Н. М. Моделі оцінки та аналізу цифрового розвитку територій

У статті розглядається комплексний підхід до оцінки й аналізу цифрового розвитку територій України в умовах відновлення, починаючи від розробки проєкту цифровізації міста, оптимізації завдань, до розробки моделей оцінки та аналізу різних чинників взаємозв'язку цифрового та економічного розвитку територій країни. У роботі проаналізовано доцільність використання методів Data Science та управління проєктами як інструментів для досягнення сталого цифрового розвитку територій. Розробка стратегії управління цифровим розвитком територій, сегмен-

тованої за конкретними секторами, включає низку етапів та завдань, що інтегровані в базову модель проєкту. У статті пропонується перелік етапів та завдань проєкту управління цифровізацією міста та уточнюється відповідна базова модель організаційної структури відділу цифровізації. Розглянуто ключові компоненти системи управління: управління розвитком, управління інформацією, підтримка додатків цифровізації та технічна підтримка. Розроблено проєкт стратегії цифрового розвитку та обговорюються етапи алгоритму оптимізації моделі проєкту за критерієм часу, питання вартості проєкту, а також оптимізації статей витрат. Оскільки реалізація складних проєктів управління цифровим містом адаптується до особливостей економічного розвитку кожної територіальної громади, у статті також розглядається адаптація проєктних завдань, на прикладі розробки моделі оцінки стану цифровізації по всій території країни в цілому. Методологія дослідження ґрунтується на побудові математичних моделей оцінки й аналізу цифровізації країни як на макро-, так і на мезорівні методами Data Science, зокрема методами не-супервайзерного агломеративного та ітеративного машинного навчання, що дозволило виявити суттєві диспропорції в цифровізації країни, асиметрію в розвитку телекомунікацій її територій та нерівномірну інтенсивність впровадження цифрових технологій у різних секторах економіки України. Здобуті результати доводять необхідність удосконалення комплексних програм цифрового розвитку та створення нових напрямків розвитку цифровізації територій. Результати можуть бути використані в практиці управління цифровим розвитком у регіональних і міських органах виконавчої влади. Застосування запропонованої моделі стратегічного управління цифровим розвитком підвищить якість формування та ухвалення управлінських рішень із діджиталізації найважливіших напрямків розвитку територій України.

Ключові слова: *розвиток територій, стратегії ІТ-розвитку, цифровий розвиток, модель, управління проєктами, методи Data Science.*

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The rapid advancement of global digitalization and digital development processes, which impact individual economic entities, cities, territorial communities, and Ukraine as a whole, is driven by a multitude of factors. Urban executive authorities, facing the instability of external conditions and the emergence of extreme operational environments, are increasingly required to develop resilience against negative influences by continuously integrating the latest technologies into all spheres of human activity. The improvement of digital city management processes is becoming particularly relevant. At the project development stage, numerous tasks related to planning, resource allocation, budgeting, and adaptation of the project to varying conditions of use must be addressed.

The set of models for assessing digitalization developed during the project design phase holds practical significance for the formulation of digital development strategies at both the macro- and meso-levels of the State governance system. Specifically, the parameters of these models may prove useful to analysts, business analysts, and engineers involved in the development of strategic IT consulting systems for regional departments of digitalization and urban digital development.

On one hand, the development of a city's IT strategy should be viewed as part of the broader vision for the territories' overall sustainable socioeconomic development strategy. On the other hand, it also undoubtedly involves management issues and is closely linked to the efficiency of the governing bodies themselves, utilizing IT to enhance the performance of executive authorities' departments.

Literature review and problem statement. The issues of digital development of the country's territories have been reflected in the works of numerous domestic and foreign scientists. The analysis of the literature has made it possible to identify several key research areas: the assessment of Ukraine's digital development in the pre-war period and the identification of opportunities for postwar recovery [1–4; 8; 9; 19], studies on innovations, e-governance, challenges in public service provision, and the evaluation of digitalization processes [5, 6, 10–16], and research on the interconnections between digitalization, sustainable development, entrepreneurship, and politics, with an emphasis on identifying problematic areas [7; 17; 18; 20–22].

The scientific works have placed analytical emphasis on the following aspects:

1. *The unevenness of digital development of territories, particularly regional disparities and vulnerabilities in the context of war and recovery*. For example, scientists such as Ivanova [1], Samoilovych [2], and Huriev [3] demonstrate that the digital development of regions is highly uneven. Significant differences exist in infrastructure, access to digital services, institutional capacity, and innovative activity. In Ukraine, digital divides are further exacerbated by wartime destruction, population displacement, and shifts in the regional economic structures, all of which complicate the development of a coherent strategy for digital recovery.
2. *The need to improve the methodology for assessing digital development and e-governance*. Authors such as Yakushko [4], Umbach & Tkalec [5], Fesenko et al. [6] argue that existing indicator systems are often fragmented and fail to capture qualitative dimensions such as trust, inclusiveness, and sustainability. They also note that the Smart City and e-governance models require more advanced analytics and deeper data integration. Samoilovych [2] and Chen et al. [7] emphasize that digitalization simultaneously influences economic, social, environmental, and institutional parameters, yet assessment methodologies frequently reduce it to technical or narrowly economic indicators.
3. *Public administration efficiency and e-governance assessment*. For example, researchers such as Ortina et al. [8] and Pasenko et al. [9] highlight the gap between the implementation of digital solutions and their actual economic and social efficiency. They point to a significant challenge: digital tools are introduced, yet they do not always lead to changes in managerial practices or outcomes. A review of the scientific literature (Bushuyev et al. [10]; Du et al. [11]; Ghanbari et al. [12]; Hao et al. [13]; Kaiser Abdullah et al. [14]; Okonta et al. [15]; Yang et al. [16]) indicates that the development of a city's digital management strategy across various sectors must involve a sequence of stages and tasks that should be integrated into a basic project model. Umbach & Tkalec [5] also show that evaluating digital public services faces methodological challenges, particularly in measuring quality, accessibility, and their impact on trust and citizen participation.
4. *Human capital, competences and inclusion*. This issue is addressed by Acerbi et al. [17], who show that even in developed contexts, targeted Upskilling programs are required to support the digital transition and the circular economy. For Ukraine, this need is even more critical in the context of postwar recovery. Chen et al. [7] demonstrate that without efficient governance and adequate digital skills, digitalization does not guarantee sustainable entrepreneurship, as it may instead reinforce inequality and instability.
5. *Data policy, ethical and environmental dimensions*. Gulyás [18] raises concerns about excessive data collection and use, the asymmetry of power between digital platforms, the State, and citizens, as well as the environmental consequences of digital infrastructure. Lola et al. [19] and Gulyás [18] together emphasize a key challenge: as Ukraine integrates into the EU digital market, it must not only achieve technically and regulatory alignment but also account for the ethical, social, and environmental implications of digital policy.

Summarizing the identified problem areas and research directions, we can conclude that the issue of uneven digital development of territories, as well as the methodology for assessing the state of digitalization, remains highly relevant and requires further refinement. The application of project management tools in combination with Data Science and machine learning methods merits particular attention. These approaches offer valuable capabilities for assessing and analyzing the state of digitalization. The models developed on this basis can support the formation of a set of alternative solutions for advancing digitalization at various levels of territorial governance.

The ***aim of the research*** is to develop complex assessment and analysis models of the digital development of Ukraine territories in the context of recovery, which will make it possible to improve the quality of decision-making on digitalization. To achieve this aim, the following objectives were defined:

1. To analyze the feasibility of using Data Science methods and project management as tools for achieving sustainable digital development of territories.

2. To develop a basic model of the city digitalization management project with a clarified organizational structure of the digitalization department, to optimize the project model according to the time

criterion, and to address the issues of project cost and expenditure optimization.

3. Since the implementation of complex digital city management projects must be adapted to the specifics of the economic development of each territorial community, to examine the adaptation of project tasks using the example of developing a model for assessing the state of digitalization across the country as a whole using Data Science methods – in particular unsupervised agglomerative and iterative machine learning methods, and as well as information space reduction techniques.

4. To develop models for grouping territories by their level of digitalization, which make it possible to identify disparities in their digital development and can also be used to improve the quality of forming and adopting managerial decisions on digitalization.

The IT strategy project should consist of a series of interdependent tasks. The interdependency lies in the understanding that certain tasks cannot be performed before others. To optimize the work plan, a network model of the task complex can be used. The project management model can be represented graphically as a network or directed graph, as well as in tabular form. The network representation allows for a clear depiction of the stages and connections between project tasks, recording the optimal order of their execution. This enables the optimization of the network in terms of execution time and resource costs. When the project network is constructed based on task, the early and late task completion times must be calculated for each task (Rodashchuk et al. [23]). The early completion time of the *j* task $t_j(0)$ is calculated as the interval of the longest path from the initial *i* task to the final *j* task ($j = 1, \ldots, N$): $t_1(0) = 0$, $t_N(0) = t_{cr}$; $t_j(0) = \max_i \{t_i(0) + t_{ij}\}$. The late task completion time is the latest time until which the task occurs simultaneously with the completion of the final task: $t_N(0) = t_N(1)$; $t_i(1) = \min_j \{t_j(1) - t_{ij}\}$.

The project network path is the sequence of activities that connects the initial and final nodes. It is characterized by two indicators: duration and tasks float (Rodashchuk et al. [23]). The path duration is determined by summing the durations of the tasks along the path. The path with the longest duration is called the critical path. It is important to note that a model may have several critical paths, but the total duration of the critical tasks within each path is identical. The tasks on the critical path have no float, i. e.: $R(i) = 0$. The task float represents the amount of time by which a task can be delayed without affecting the overall project duration, or the amount of delay that does not extend the total project time: $R(i) = t_п(i) - t_p(i)$.

Total task float is: $R_{ijtotal} = t_j(1) - (t_i(0) + t_{ij})$.
Late task float is: $R_{ijlate} = t_j(1) - (t_i(1) + t_{ij})$.
Free task float is: $R_{ijfree} = t_j(0) - (t_i(0) + t_{ij})$.
Independent task float is:

$$R_{ijind} = \max\{0; t_j(0) - (t_i(1) + t_{ij} \square\}.$$

Considering the above characteristics of the network model is essential during the rational planning of the task complex. The rational planning of the task complex requires answers to questions such as: when to start and finish individual components of the complex; what obstacles might arise to timely completion of the task complex, and so on. These and other questions can be addressed through optimizing the model according to a given criterion. For instance, if the question arises of how to prioritize critical tasks so that the total time does not exceed the specified limit, optimizing the model according to the time criterion becomes relevant.

Therefore, the problem of developing an optimal model for managing the city's digital development is becoming increasingly pertinent, prompting further research into enhancing the processes of urban digitalization management. The *aim* of this article is to develop a strategic management model for the city's digital development using project management tools and to test this model in the process of analyzing compliance with regional development digitalization requirements and identifying related issues. At this stage, it is advisable to evaluate and analyze the country's digital development using methods of intelligent analysis of multidimensional objects. This approach to management will improve the quality of decision-making related to the digitalization of the most critical areas of urban development.

The *Fig. 1* outlines the stages of the project optimization algorithm based on the time criterion.

1. *Preparation Stage:* This initial phase involves numbering the network tasks, calculating the key characteristics of the model, and determining the critical path of the network. A list of critical tasks is then compiled, identifying those whose durations can be reduced.

2. *Identification of Parallel Tasks:* In this stage, for each critical task, the corresponding parallel non-critical tasks and their total reserves are identified.

3. *Duration Reduction:* The duration of the selected critical task is reduced by an amount that is one unit less than the minimum total reserve of all parallel non-critical tasks. If a critical task lacks parallel non-critical tasks, its duration is reduced by the maximum feasible amount. Should the critical task have parallel critical tasks (in cases with multiple critical paths), the duration of the parallel critical tasks must also be reduced. For the instance serve the tasks (1.3) and (1.4). The *Tbl. 1* exemplify such tasks.

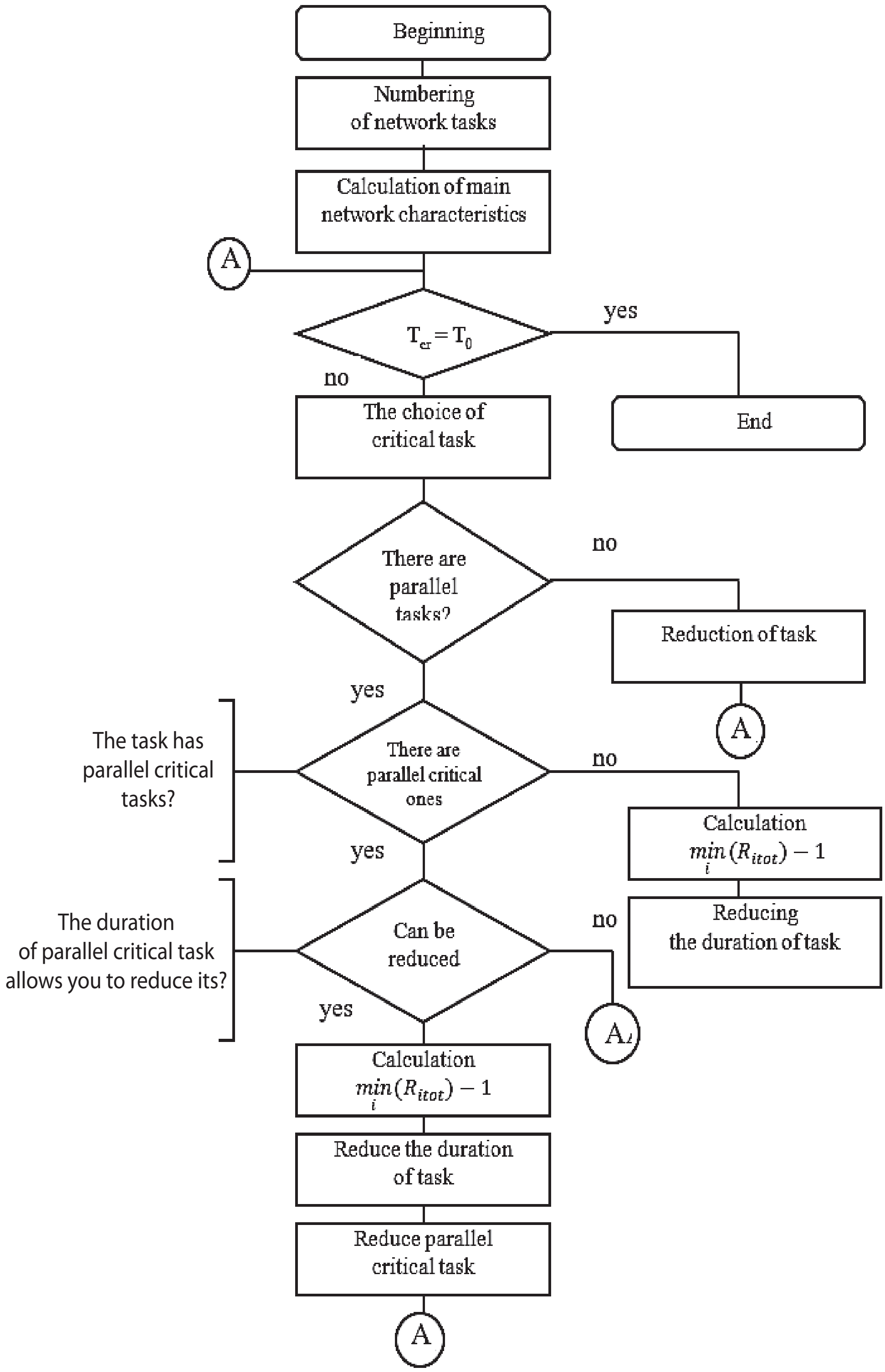

Fig. 1. Algorithm of project optimization according to the time criterion

Source: compiled by the authors.

As a consequence of these reductions, the total duration of the critical path may be shortened by the same amount as the duration of the critical activity itself. After these actions are executed, new parameters for the model are calculated.

To quantitatively substantiate the assessment of the current level of digitalization of territories, cluster-based mathematical models are constructed. An appropriate tool for developing such models is business intelligence methods, in particular methods of multidimensional statistical analysis techniques, which today form part of the broader group of Data Science and machine learning methods. Let us examine the features of these methods and their potential for building mathematical models for assessing and analyzing of the level of digitalization.

To construct models across the full spectrum of machine learning, it is advisable to apply unsupervised learning methods – grouping or clustering methods, including unsupervised hierarchical agglomerative methods and iterative methods such as k-means. There are also less common unsupervised learning methods, among which dendritic clustering, spherical clustering, fuzzy subtractive clustering and distinguished clustering methods. The main problem faced by the researcher when performing clustering is the choice of the optimal number of clusters. The iterative k-means method does not involve examining all possible clustering configuration; instead, it partitions the data according to a predefined number of clusters. This constitutes a fundamental distinction between iterative methods and hierarchical clustering. The optimal number of clusters may be identified using both by a priori methods and empirical techniques such as the elbow method. When constructing models for grouping territories by the level of digital development, and in order to substantiate the feasibility and number clusters, it is proposed to apply Ward's agglomerative method, one of the most widely used clustering methods. Its advantage lies in its ability to form homogeneous clusters of regular shape. The method is based on minimizing the within-group variance. At each step, two clusters are merged so as to minimize the objective function (the sum of squared within-group variances). At the same time, the sum of squared distances of observations to the centers of other clusters increases. To reduce the risk of obtaining a suboptimal local solution rather than a global partition, a dendrogram is constructed. Subsequently, the iterative k-means method is applied to verify the optimal number of cluster members. A series of experiments is conducted with different partitioning options, and the results are compared using clustering quality metrics: the between- and within-group variance criterion, which indicates the strength of the partition, and the F-criterion, which assesses the overall statistical adequacy of the clustering. The iterative process continues until the final partition replicates the configuration obtained at the previous stage.

Thus, the application of the methods considered makes it possible to construct a model for assessing the level of digital development across territories. This, in turn, provides an opportunity to generate a set of alternative decision-making options for digitalization in different territories, taking into account their specific development characteristics.

Research results. As result of the conducted research, it was found that formation a strategy for managing the city's digital development across individual sectors should involve a sequence of stages and activities that are integrated into a basic project model. The developed project for the city's digital development is presented in the *Tbl. 1*.

Overall, the digital development management model should be implemented through the creation of a corresponding basic organizational structure for the digitalization department. It should consist of the following key management system components:

- *Development Management:* Addressing tasks related to strategy development, planning, and analysis.
- *Information Management:* Solving tasks using database management systems and content management systems.
- *Support for Digitalization Applications:* Tasks related to the development, support, and integration of platforms and digital applications.
- *Technical Support:* Ensuring the efficient operation of hardware and the Service Desk.

Given that the management level was identified as strategic, the overall task complex established the project's timeline – over one year. To determine the project's task complex duration, we constructed a linear chart – a Gantt chart, as shown in *Fig. 2*.

The determination of task durations by strategic phases (see Tbl. 1) allowed us to establish the project's total duration at 125 days, which corresponds to the critical path time in the network model. Additionally, we identified the tasks that constitute the project's critical path.

Considering the characteristics of the network model discussed above is essential for rational planning of the digital development management task complex. This process requires addressing questions such as when to initiate and conclude individual components of the IT strategy, as well as identifying potential obstacles that may impede the timely completion of the task complex.

These inquiries, among others, can be addressed through optimization of the model according to a specified criterion. For instance, if the question arises regarding how to prioritize critical tasks to ensure that the overall duration does not exceed a predetermined limit, it becomes pertinent to optimize the model based on the time criterion.

The algorithm is applied iteratively until the overall project duration conditions are satisfied. In the case of the project under consideration, the maximum duration reduction achieved was 20 days.

Project costs consideration: the formulation of the project budget is a complex and multifaceted task

Table 1

Stages and tasks of the digital city management project

Stages	Task Description	Duration (days)
Stage 1. Project Preparation		
1.1	Conducting negotiations with senior management of the department	7
1.2	Initial agreements	20
1.3	Appointment and coordination of the working groups necessary for the project	14
1.4	Refinement of the work plan	7
Stage 2. IT Audit and Analysis		
2.1	Defining the goals and role of IT in sectoral development processes	5
2.2	Surveying department managers and executives	20
2.3	Preparing and conducting a roundtable with leadership to identify priority areas for the city's digitalization development	5
2.4	Collecting information to assess the state of digitalization within departments and the city's digital development	14
2.5	Analysis of compliance with city and regional digitalization requirements, identification of issues:	24
2.5.1	development of a model for assessing the state of city and regional digitalization	3
2.5.2	assessment of interdependencies among indicators of sustainable digital city development	3
2.5.3	evaluation of the impact of key components of digital city development indicators	5
2.5.4	assessment of the overall level of digital development across city sectors	2
2.5.5	analysis of compliance with sectoral digitalization requirements, identification of issues	6
2.5.6	determination of directions for the city's digital development	5
2.6	Readiness assessment for changes	10
2.7	Preparation of the audit report	7
2.8	Preparing and conducting a roundtable with leadership to identify priority areas for the city's digitalization development	5
Stage 3. Formation and Evaluation of Digital Development Alternatives for the City		
3.1	Formation of a portfolio of IT projects for digital development and business support	10
3.2	Detailing the composition of digital development projects and prioritizing their implementation according to selected indicators	5
3.3	Creation of a registry of expected economic effects from the results	10
3.4	Evaluation of all types of resources needed for IT project implementation	15
3.5	Approval of the IT project portfolio for digital development	20

Source: compiled by the authors.

that necessitates evaluation from several perspectives. On one hand, the budget must account for expenditures related to the project management system; on the other hand, it must encompass the costs associated with executing specific project tasks that comprise the development program. During the execution of tasks related to forming the IT project portfolio, all projects submitted within the context of the announced competition for small business projects in the field of information business are reviewed.

To establish the primary component of the budget for the digital development management department, both direct and indirect costs must be assessed. The principal categories of expenditure include:

- *Development Costs:* These encompass consultancy fees, costs for server equipment, networking equipment, printers, software installation, system software, transactional systems, database management systems, application development, and training for the project team.

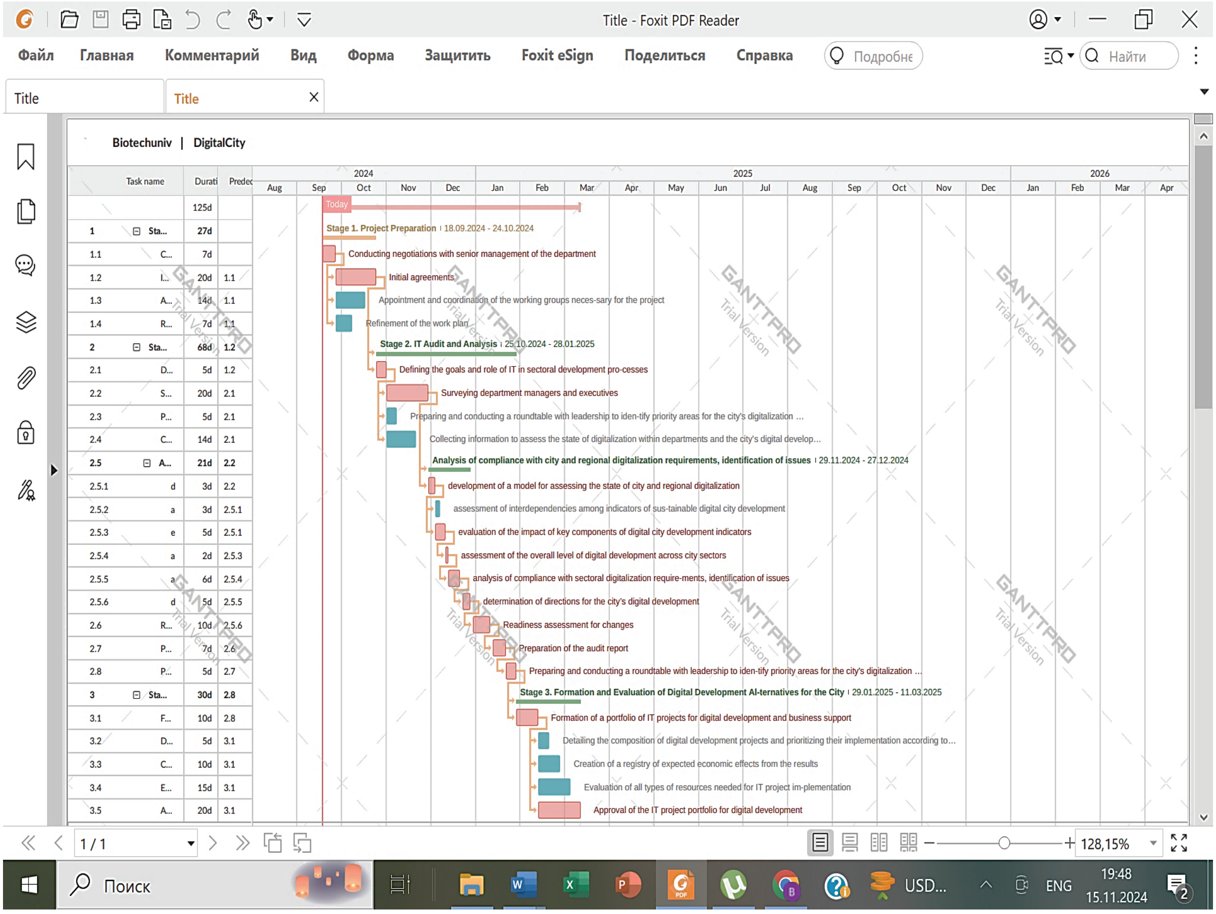

Fig. 2. Project calendar for strategic management of the city's digital development

Source: compiled by the authors.

- *IT Renewal Costs:* These refer to expenditures for equipment, software, staff training, and related business trips. System Maintenance Costs: This includes technical support expenses for equipment (server rooms), software maintenance costs, the number of end-users, the number of IT specialists required for system upkeep, as well as expenses for maintaining remote offices.
- *Data Storage and Processing Costs:* This pertains to expenses for organizing data storage, creating backups, and system recovery.
- *System Upgrading Costs.*

In the proposed project, ten specialists and analysts of the department are involved. Given the number of workstations, the average age of PCs (3.5 years), and the department's policy of moderate development when each workstation costs UAH 21.600, we can calculate the annual costs associated with upgrading the PC fleet as follows. The resulting calculation is UAH 106.920 per workstation.

As an option for drafting the budget articles, we will calculate the annual costs for the support of the information infrastructure using the ratio:

$$S_t = S_{ti} + S_{tj};$$

$$S_{ti} = \frac{N_i \cdot C_i}{T_i} + R_i \cdot (N_i \cdot C_i);\ S_{tj} = \frac{N_j \cdot C_j}{T_j},$$

where *St* – total infrastructure maintenance cost;

S_{ti} – the annual cost of supporting equipment of the *i*-th category;

S_{tj} – the annual cost of software support of the *j*-th category;

N_i – number of equipment units of the *i*-th category;

C_i – the purchase price of a unit of equipment of the *i*-th category;

T_i – duration of the life cycle of equipment of the *i*-th category;

R_i – cost factor for equipment of the *i*-th category;

T_j – the duration of the *j*-th category software life cycle;

N_j – the number of software units of the *j*-th category;

C_j – the purchase price of a software unit of the *j*-th category.

The calculation of the cost of the infrastructure of the department's information system maintenance is given in *Tbl. 2.*

Table 2

Calculation of the cost of information infrastructure maintenance

No.	Index	Costs, UAH
1	Number of equipment units (PCs)	10
2	Cost per equipment unit	86.400
3	Total equipment cost	864.000
4	Equipment lifecycle	5 years
5	Equipment maintenance cost	172.800
6	Probability of equipment failure per year	30%
7	Average repairing cost per unit of equipment (% of price)	10%
8	Equipment repair cost	25.920
9	Number of licenses	10
10	Cost per license	1.350
11	Total license cost	13.500
12	Software lifecycle	3 years
13	Software maintenance cost	18.000
14	Total maintenance cost	1.083.600

Source: compiled by the authors.

The implementation of complex projects for digital development managing is adapted to the economic development characteristics of each region. Therefore, as an example of the adaptation of project work, we will consider the development of a model for assessing the state of digitalization in a region, which falls under Stage 2 – IT audit and analysis.

The matrices of output indicators were formed taking into account researches (Gorelova et al. [24]; Zubchenko et al. [25]) and certain objective constraints related to the periodicity and specificity of reporting by the State Statistics Committee. Based on the analysis of statistical information from open sources, two sets of evaluative indicators were developed.

Group No. 1 – indicators for assessing the state of telecommunications development in the region:

x47 – percentage of the population that used Internet services (% of the total population of the region);

x48 – number of cable television subscribers (persons per 1.000 of the total population);

x49 – number of mobile communication subscribers (per 100 persons of the total population);

x50 – volume of services provided in telecommunications and postal communication (amount in UAH per 1.000 of the total population);

x51 – number of domestic and international outgoing phone calls by region;

x52 – sending of money transfers and pension payments, amount in UAH per person;

x53 – income from the provision of international postal and communication services, total amount in UAH per person.

Group No. 2 consists of a set of indicators assessing the activity of using digitalization tools – the population's engagement with Internet services:

x54 – population that sent (received) e-mail, % of the total population;

x55 – population that interacted with government authorities, % of the total population;

x56 – population engaged in learning and education, % of the total population;

x57 – the population that read/downloaded newspapers and magazines online, % of the total population;

x58 – population that downloaded movies, images, music; watched television or video; or listened to radio or music; played video or computer games or downloaded them, % of the total population;

x59 – population that downloaded software, % of the total population;

x60 – population that made phone calls via the Internet/Volp (Skype, iTalk, via web camera), % of the total population;

x61 – population that was engaged in communication (hobbies), % of the total population;

x62 – population that used banking services, % of the total population;

x63 – population that searched for information related to health issues for themselves and for others;

x64 – population that ordered (purchased) goods and services via Internet;

x65 – population that obtained information about goods and services not previously mentioned in this list.

The analysis of the telecommunications development state was conducted and published in one of the previous studies (Chagovets et al. [26; 27]; Chahovets et al. [28]). Its results allowed for the conclusion regarding the possibility of forming three stable clusters of regions based on high, medium, and low levels of telecommunications development: "The analysis of cluster center values led to the conclusion that the first cluster of regions is characterized by the highest values across all indicators of the group. The second cluster has a moderate share of the population using Internet services, the volume of services provided in telecommunications and postal communication, and the lowest value for the number of cable television subscribers. The third cluster is characterized by the lowest values for all indicators, except for cable television subscribers" (Chahovets et al. [28]).

Similar to the analysis presented above, to ensure the homogeneity of the sample and comparability of the input population objects, the indicators of the second group assessing the activity of using digitalization tools were converted into relative terms. The values of the indicators were assessed as percentages of the total population. This enabled a comparative analysis of diverse territories in terms of population size, excluding the Autonomous Republic of Crimea, the city of Sevastopol, and the city of Kyiv. Further clustering of territories was carried out based on spatially dynamic sampling data for five years before the full-scale invasion, using the hierarchical Ward agglomerative method and the iterative k-means method.

A visual analysis of the resulting dendrogram graphs, as shown in *Fig. 3*, across different periods allowed for the conclusion regarding the possibility of dividing the population of territories into two clusters.

Analyzing the results of the dendrogram reveals an imbalance in the clusters concerning their composition. Specifically, the first cluster includes almost all territories except for Kirovograd and Zaporizhzhya, which entered the second cluster.

This division was observed throughout the entire study period. The computation of statistical characteristics from the conducted analysis of variance for iterative clustering: between-group and within-group variance statistics (Akinosho et al. [29]; Martyniuk et al. [30]; Mykhailov [31]; Shved et al. [32]), a F-test with degrees of freedom (2, 21), confirmed the significance and adequacy of the grouping model as a whole, along with the statistical significance of the grouping indicators at a 95% confidence level (see *Fig. 4*).

The final analysis of the k-means centroids graph for interpreting the formed clusters indicated that the imbalance in cluster composition is due to different emphases on the use of digital technologies in the socioeconomic life of the territory (see *Fig. 5*).

It is determined that members of cluster number 1 contains 22 cases (*Tbl. 3*).

Table 3

Members of cluster 1 and distance from respective cluster center

Territory	Distance	Territory	Distance
Vinnytsia Region	0.513894	Odesa Region	0.866424
Volyn Region	0.617471	Poltava Region	0.755264
Dnipropetrovsk Region	0.573917	Rivne Region	0.906067
Donetsk Region	0.705369	Sumy Region	0.903002
Zhytomyr Region	0.397688	Ternopil Region	0.553460
Zaporizhzhia Region	0.532734	Charkiv Region	0.625671
Ivano-Frankivsk Region	0.839089	Cherson Region	0.512215
Kyiv Region	0.792344	Khmelnytskyi Region	0.650395
Luhansk Region	0.650816	Cherkasy Region	0.468712
Lviv Region	0.534241	Chernivtsy Region	0.546237
Mykolaiv Region	1.237622	Chernihiv Region	0.641004

Source: compiled by the authors.

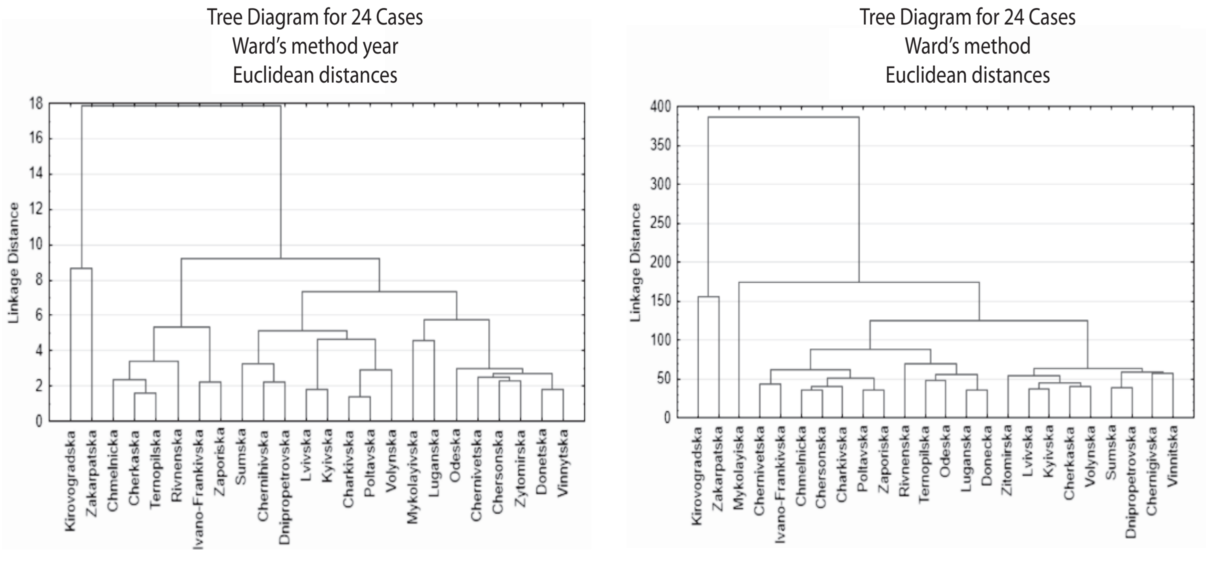

Fig. 3. Dendrogram chart based on the spatial-dynamic sample

Source: compiled by the authors.

Variable	Analysis of Variance Between SS	df	Within SS	df	F	signif. p
x54	4,33113	2	18,66887	21	2,43598	0,111840
x55	10,04980	2	12,95020	21	8,14837	0,002403
x57	8,14755	2	14,85245	21	5,75995	0,010133
x58	18,16603	2	4,83397	21	39,45890	0,000000
x59	16,76222	2	6,23778	21	28,21571	0,000001
x60	14,16457	2	8,83543	21	16,83313	0,000043
x61	5,63939	2	17,36061	21	3,41080	0,052154
x62	14,74806	2	8,25194	21	18,76586	0,000021
x63	16,20892	2	6,79108	21	25,06133	0,000003
x65	6,50008	2	16,49992	21	4,13644	0,030579

Fig. 4. Analysis of variance for grouping

Source: compiled by the authors.

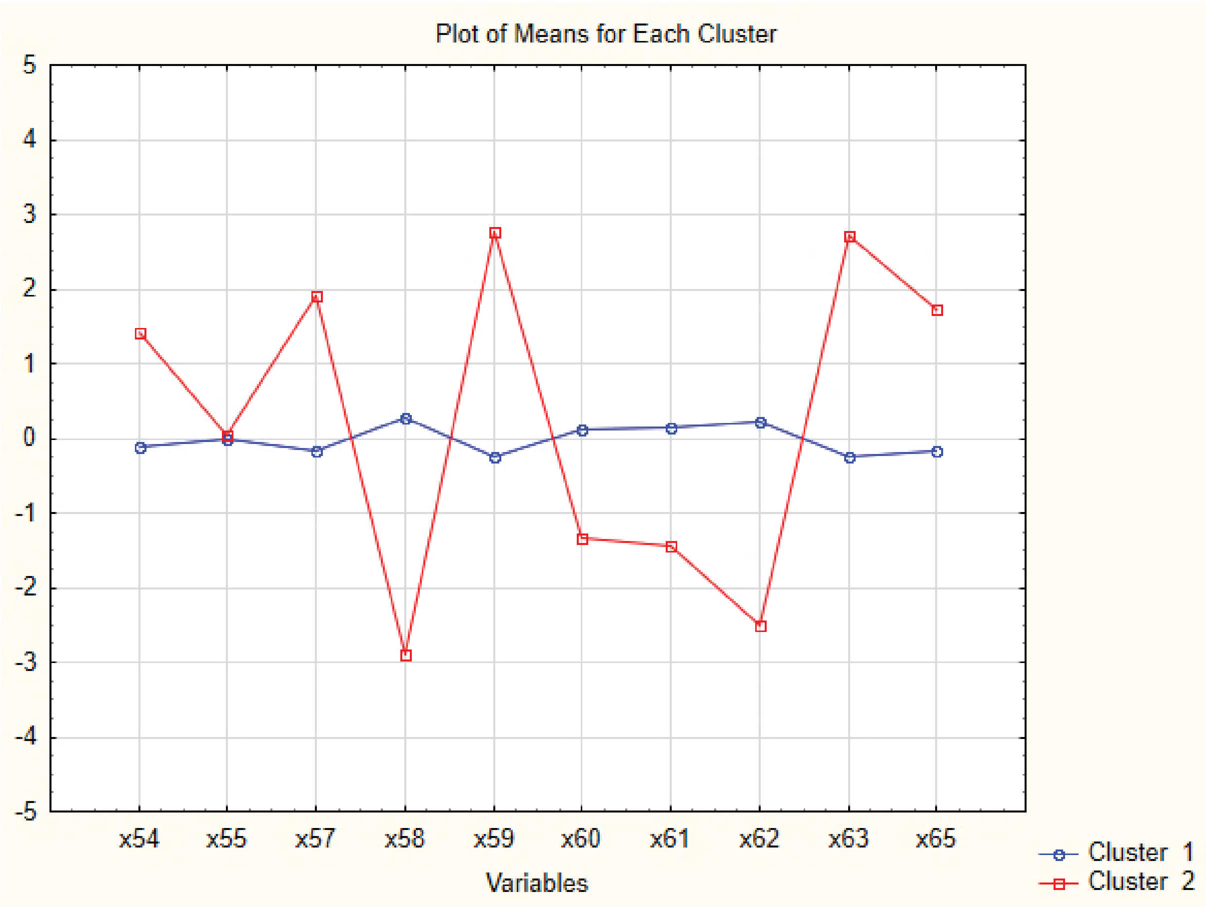

Fig. 5. Average graph based on clustering

Source: compiled by the authors.

Members of cluster number 2 contains 2 cases and distances from respective cluster center is shown in *Tbl. 4.*

Cluster 1 reflects the active use of digitalization tools in the business sphere, characterized by high levels of Internet use for banking services, online trade, and entertainment. In contrast, the positioning of regions in Cluster 2 is determined by the use of digital tools primar-

Table 4

Members of cluster 2 and distance from respective cluster center

Territory	Distance
Zakarpattia Region	1.235852
Kirovohrad Region	1.235852

Source: compiled by the authors.

ily for everyday Internet communication, such as reading, searching for health related or product information, and for interaction with government authorities.

CONCLUSIONS

Thus, the studies indicate that a comprehensive approach to assessing and analyzing the digital development of Ukraine's territories in the context of recovery is essential. This includes the development of city level digitalization projects, the formulation of optimization tasks, and the creation of models for evaluating and analyzing various factors that shape the relationship between digital and economic development across the country. Such an approach deserves particular attention, as the resulting models can support more informed and efficient decision making.

The constructed mathematical models for assessing the digitalization of the country at both macro- and meso-levels, based on intelligent data analysis using methods of information space reduction, allowed for the identification of significant disproportions in the country's digitalization, asymmetries in the telecommunications development of its territories, and uneven intensities in the adoption of digital technologies across various sectors of the Ukrainian economy. The findings demonstrate the need for improving comprehensive digital development programs and creating new directions for the digitalization of cities in the country.

The results can be used in the management practices of digital development within territory and municipal executive authorities. The application of the proposed strategic management model for the digital development of cities, constructed using project management tools, will enhance the quality of decision-making related to the digitalization of the most critical areas of urban development. ■

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