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DEVELOPMENT OF METHODS FOR EVALUATING THE EFFECTIVENESS OF SMART CITIES UNDER THE CONDITIONS OF DIGITALIZATION OF CITY GOVERNANCE

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This paper considers the processes of digitalization of urban management, which forms the prerequisites for solving the problem of the development of the concept of smart cities. As a result, the historical aspects of the formation of the Smart City concept are distinguished. Based on this, elements of the Smart City concept are highlighted at the present stage, such as vision, ecosystem, management, technological background, and financing. Generalization of the results of the study of the processes of digitalization of smart city management has made it possible to distinguish its traditional components, which include transport, energy, utilities, urban environment, security, and "smart" house. In order to ensure effective monitoring of the implementation and development of digital services in the smart city management system, it is proposed to use "city smartophores". The systematization of the Smart City formation experience provided an opportunity to distinguish the relevant models of digitalization of urban governance – decentralized, centralized, and local. The scope of application, initiators, advantages and disadvantages, and prospects for the development of each of them are determined. Unlike other results of the study of the effectiveness of the development of smart cities, it is suggested that the most vivid picture of ensuring a comfortable life in the city is demonstrated by the size of its population. It is proved that it is in the developed cities of any country in the world that there are positive rates of population growth. Quantitative criteria for determining the upper and lower limits of the efficiency of smart city development according to the selected indicator have been developed. The practical application of the results of the study is the possibility of predicting further directions of development of the smart city based on a quantitative assessment of the level of its digital transformation

Keywords: smart city concept, urban management efficiency, digitalization, digital technologies, urban services

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1. Introduction

In the context of strengthening the role of digital technologies in the processes of urban management, there is an increase in the efficiency of management decision-making. This is primarily due to the fact that due to the generation of large information flows using digital platforms, the de-

cision-making process becomes more flexible and adaptive. It is also advisable to note that due to the digitalization of important spheres of life of the urban population, the concept of smart cities is being developed. As a result, "smart" elements are formed and the processes of urban management are accelerated, they become more rational, which increases the degree of comfort and well-being of residents. Along with

the advantages of digitalization of urban governance, there are certain disadvantages. First of all, an important point is to ensure a high level of information security, with the help of which it will be impossible to carry out hacker attacks and gain access to confidential information. No less important problem under these conditions is an uneven distribution or limited access to digital goods, which is an inhibiting factor in the formation of a smart city.

The study of global trends in the digitalization of urban governance proves that there are no unified templates and methods for the development of the concept of smart cities. This is due to the fact that the choice of a certain “smart” direction for the digital development of the city depends on many factors. First of all, a resource factor plays a big role, due to which there are powerful reserves for the introduction of digital technologies into urban management. The concept of a smart city in most cases is considered as a “smart” strategic direction of the city, on the way in which the comprehensive development of mankind will be ensured. The particular relevance of the implementation of the concept of a smart city is acquired under modern socio-economic conditions associated with the acceleration of urbanization processes. Due to the increase in the density of the urban population, there is an excessive impact on medical, educational, housing, communal, and transport infrastructure. Without the digitalization of certain elements of these sectors, it would be impossible to provide quality services to the population. Further trends will only increase the number of digitalized urban operations and accelerate the development of smart cities. In order to achieve targeted landmarks and desired results, it is important to improve existing and implement new digital tools on which the process of forming a smart city depends. Thus, under modern conditions, it is important to ensure the digitalization of urban governance as the basis for the development of the concept of smart cities.

2. Literature review and problem statement

In most scientific studies, the successful development of the concept of smart cities is associated with the strengthening of digitalization processes. Cities invest in digital, data-driven technologies to improve productivity and efficiency by generating vast amounts of information. The use of this data helps governments and local authorities anticipate, respond to, and plan future development scenarios. Access to information in real time helps provide the population with effective productivity-enhancing services that lead to environmental, economic, and social benefits. The decision-making process is also simplified and it becomes possible to involve active representatives of the city in the city administration and improve digital literacy and population culture. Paper [1] discusses and analyzes in detail the current practice of using digital applications, and managed data, which contribute to the smooth functioning of urban systems and solve the problems they face. According to the results of this study, the relevant indicators and criteria of the “smart city” were determined. In addition, a conclusion is drawn about the importance of the concepts of “smart people”, “intelligent life”, and “smart management methods”, which are derived from “smart mobility”, “smart environment”, and “smart economy measures”. In other words, the development of cities opens up opportunities for the introduction of new categories. Consequently, according to this, an important

component of the development of future cities is human, social capital. While study [1] is not limited to geographical scope, then in some works the authors focus on the experience of developing smart cities in individual countries.

Thus, in an effort to combine economic growth with improved efficiency, an improved environment, and a more positive image, Polish cities are also using the Smart City strategy. Study [2] identifies the priority areas of major Polish cities regarding the Smart City concept and the extent to which social infrastructure and human capital define development goals. In this regard, the analysis of official documents and websites profiling Smart City strategies in six Polish cities (Warsaw, Krakow, Łódź, Wrocław, Poznan, and Gdansk) and their metropolitan areas was carried out. The obtained data show that Poland’s experience in the development of Smart City is a gradual adaptation process and new forms of urban policy. They reflect the tension between new and more traditional forms of governance and economic, environmental, and social goals. The results of the study prove that institutional changes actually occurred in terms of joint management, digitalization in the provision of services, meeting social needs, and linking Smart City programs with broader urban development goals.

It is worth noting that the transformation into a prosperous “smart city” has become the aspiration of many local self-government bodies around the world. Despite the growing importance, the readiness to transform the “smart city” is still a little-studied area of research. To overcome this gap in knowledge, work [3] identifies key factors influencing the readiness to transform a smart city in the context of Australian cities. The empirical study, conducted by the authors, identifies areas of local government in Australia in terms of “smart city” for quantitative assessment through multiple regression analysis of key factors affecting the level of their urban smartness. The findings and conclusions of this study inform city politicians, managers and experts about their planning policies and practical decisions on the creation of “smart cities”.

Paper [4] explores the digitalization of cities and the development of a “smart city” in the context of Northern society. The study focuses on the views of the city authorities regarding the two largest cities in Finland – Helsinki and Espoo. Both cities invest heavily in the digitalization of cities, as well as build separate “smart” urban areas. The central context of the study is the Scandinavian model of the social state and the role of Finnish cities in society as the most important service providers. At the same time, it is advisable to note that the Scandinavian model of urban management development has specific features that are not characteristic of cities in other countries. This indicates significant limitations of the proposed approach.

The authors of [5] focus on the maturity of transparency in open data ecosystems, which are seen as key to the development and support of citizen-oriented and socially sustainable “smart cities”. To this end, the portals of data of “smart cities” are checked and their compliance with the requirements of transparency of open (state) data is assessed. That allowed the authors of the paper to rank them and determine the level of maturity of transparency at four predetermined levels of maturity – developing, defined, manageable and integrated. In addition, recommendations are provided to determine and improve the current level of maturity and specific features. The conceptualization of the open data ecosystem in the context of the “smart city” has been de-

veloped and its key components have been identified. The author's definition considers the components of a data-oriented and data-driven infrastructure using the approach of system theory. The researchers also identified five preferred types of current open data ecosystems based on preferred components of the data infrastructure. An unsolved part of the problem is a generalized approach and the lack of clear criteria for assessing the ecosystems of smart cities.

Study [6] emphasizes that smart cities use the resources of a new generation of information technology and broadband networks to provide benefits of information and communication. This creates a "smart environment" for urban development, provides effective and flexible support for urban management and operations, and provides more convenient services to the population. The ability to manage and control is a prerequisite for the implementation of the concept of a "smart city". The idea of building cultural heritage management based on the concept of a "smart city" is also given. On this basis, the choice of the program and the effect of the platform are first evaluated, and then the prospect of developing a smart city is put forward, which creates certain difficulties for an objective assessment.

The authors of work [7] emphasize that countries are working on the implementation of the concepts of a "smart city" in different regions. In such cities, it is necessary to use digital technologies in various forms. There are different dimensions that should be taken into consideration when planning and implementing a "smart city". This complexity of measurement, use of technologies and their integration causes risks of implementation of the concept of a "smart city". If such risks are not properly understood and are not taken into consideration in a timely manner, they can create problems in terms of privacy and security. As a result, the functioning of "smart cities" will be ineffective. The study discusses the definition of measurements, tools for assessing the "smart city", available technologies, as well as the parameters of technical and non-technical risk associated with the formation of "smart cities". In addition, current methods of risk assessment and possible improvements are highlighted. It has been found that the dominant digital technologies used in smart city programs are the Internet of Things, artificial intelligence, and blockchain. Paper [7] also provides some areas of research on the design, implementation, and functioning of "smart cities". The problem of the study is the impossibility of timely detection, as well as comprehensive and comprehensive monitoring of various types of risks affecting the processes of urban management.

Unlike the previous ones, paper [8] deals with the most updated concepts of "smart cities". The problem of sustainable urban development is highlighted. An overview of the transformation from "smart cities" to "smart countries" has been provided. The study proposes an intelligent management system that will increase efficiency in the application of smart e-Government and Smart City projects in all areas. An integrated operational center is presented – a new concept of operational intelligence that can digitize, control, predict, act, make better and faster decisions, and interact with its citizens. The concept of the "smart city" management system ("smart region", "smart country") proposed by the authors will make it possible, if implemented, to make breakthrough changes, increase the efficiency of management and functioning of the city or region. At the same time, the proposed mechanism is directly dependent on the overall

level of digitalization of countries, and therefore cannot be a universal tool for measuring the effectiveness of the development of smart cities.

In studies [9, 10], attention is paid to the processes of urbanization as a prerequisite for the creation of "smart cities". The authors of [9] contributed to the development of a scientific program for the digitalization of cities in relation to alternative practices at the grassroots level, by reviewing and structuring data on urban space production and management. The results of that study conceptualize the version of mass digital urbanism, which is located at the intersection of the public urban movement and digital sovereignty. In addition, the lack of empirical work and critical reports on the consequences of the relevant initiatives in the restructuring of urban space production and reconfiguration of urban management are emphasized. It is worth noting the problem of the lack of methods for assessing digital sovereignty.

In [10], studies of "smart urbanism" mainly focus on the production of digital knowledge. As a response to previous work, this article explores the potential and limitations of digital devices that produce the knowledge needed to manage the urban environment. Based on four case studies in Europe, the paper explores which types of knowledge become privileged and what knowledge is overlooked when digital devices are used to inform city governance. The authors found that non-digital knowledge is easy to eclipse but it remains vital for effective and inclusive urban environmental management. The results suggest that digital technologies need to be developed in such a way as to be attentive to the different types of knowledge (digital and non-digital) that may be necessary for effective and inclusive urban management. At the same time, the problem of establishing the impact of the level of development of digital technologies on the availability of digital and non-digital knowledge, as well as the relationship of the latter with the effectiveness of urban management, remains unresolved.

Summarizing the review of literary sources creates the basis for formulating certain limitations of existing studies to ensure the digitalization of urban governance, as the basis for the development of the concept of smart cities:

- first, in the studied works there is no characteristic of the elements of the concept of a smart city;
- second, the cited studies contain separate criteria and indicators for the development of smart cities, which do not demonstrate their comprehensive monitoring.

3. The aim and objectives of the study

The aim of this study is to develop methods for assessing the effectiveness of smart cities by deepening the digitalization of urban governance. This will create the basis for the comfortable living of the population in the city and increase the level of its social and economic development.

To accomplish the aim, the following tasks have been set:

- to analyze the prerequisites for the emergence and elements of the structure of the concept of smart cities that affect the efficiency of urban management;
- to investigate the processes of digitalization of urban governance and offer a comprehensive system for monitoring the development of digital services in smart cities;
- to analyze existing models of digitalization of urban management and formation of smart cities;

– to investigate individual criteria and indicators with which it is possible to measure the effectiveness of the development of smart cities.

4. The study materials and methods

The theoretical basis for the study is the conceptual provisions of the regional economy, as well as the processes of digitalization of the urban economy, scientific developments in the areas of assessing the effectiveness of smart cities in the context of the introduction of digital technologies. Methodical developments were also used to ensure the adoption of transparent management decisions, optimize urban management, and plan the strategy of the socio-economic development of cities.

For the study, structural and system methods were used in distinguishing elements of the structure of the smart city concept, as well as the components of a smart city. Methods of analysis and synthesis, deduction and induction were used in the preparation of the table of the smartphore of cities. Structural-logical and comparative methods are used in the analysis of models of digitalization of urban management and the formation of smart cities. To distinguish the criteria and indicators for measuring the effectiveness of the development of smart cities, methods of generalization, systematization, formalization, and algorithmization are used.

For information and analytical support of the conducted research, data from open statistical and literary sources were used.

5. Results of research on ensuring the digitalization of urban management as the basis for the development of the concept of smart cities

5.1. Results of analysis of preconditions for the emergence and structure of the concept of smart cities

The processes of transformational transformation of social relations, as well as the rapid development of digital technologies, led to the emergence of a new type of urban management – the Smart City concept. In addition, urbanization is a no less important prerequisite for the creation of Smart City. According to experts, the share of the urban population of developed countries in the world in 2025 will be more than 80 % [11].

The European Smart City concept provides a long-term vision of the future, emerging from promising areas of development, in accordance with global challenges. In turn, global challenges are associated with the complication of the socio-economic sphere, the acceleration of technological development, in particular, digitalization, as well as the aggravation of the climate crisis [12, 13].

Exploring the historical aspect of the formation of the Smart City concept, it is worth noting that the active use of the term “smart city” coincides with the beginning of the 19th century [14]. However, at the very beginning, the

conceptual foundations of the “smart city” provided only for the use of information technology, in order to create a virtual space of the city [15]. The next stage in the development of the Smart City concept is associated with the active use of intelligent technologies to improve the efficiency of urban management [16].

At the present stage, the Smart City concept includes vision, ecosystem, management, technological background, and financing (Fig. 1).

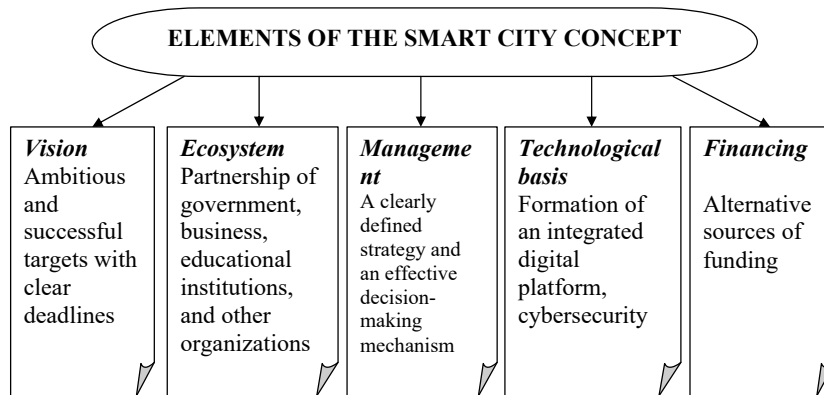


Fig. 1. The structure of a smart city concept

Note: compiled on the basis of [17]

It is worth noting that among the target guidelines of the Smart City concept, the main thing is to create comfortable living conditions for all, without exception, citizens of the city. This, in turn, provides for energy optimization, development of smart infrastructure, improving the quality of health care, education, security level, and digitalization of the housing and communal sector [18]. As alternative sources of funding, it is possible to turn to the use of public funding (crowdfunding) or “green” funding. As a result of the successful implementation of the Smart City concept, there is a gradual increase in the share of “smart” residents of the city, which, as a result, leads to an increase in socio-economic development.

5.2. Studying the processes of digitalization of smart city management

The formation of smart cities and effective urban management would not be possible without the development of digital technologies. Digitalization of urban governance involves the transfer to the digital environment of functions and activities (business processes) that in the past were performed by people and organizations [19].

Smart City is an innovative city that implements a set of technical solutions and organizational measures. These measures are aimed at achieving the maximum possible efficiency of resource management and service provision, in order to create sustainable favorable living and stay conditions, and business activity of present and future generations [20, 21].

Traditionally, the components of smart cities include:

- transport (intelligent transport systems, infrastructure payment systems, smart parking, information notification, environmentally friendly transport);
- energy (“smart” electricity consumption meters, control of final electricity consumption, electric transport infrastructure, renewable generation);

- utilities (“smart” meters of water and heat consumption, control of water and heat consumption, management of unforeseen situations, innovative methods of water purification, monitoring of the operating time of utility machines);
- urban environment (control of air pollution level and noise level, “smart” lighting, “smart” waste disposal, road surface monitoring, urban planning and land use management, social services);
- security (“smart” video surveillance, communication of citizens with emergency services, systems for recognizing car license plates and shots from firearms for operational actions of special services);

– “smart” house (remote management of the building and apartment, “smart” devices, “smart” programs, energy-efficient design of buildings) [22].

In order to monitor the implementation and development of digital services in the smart city management system in Ukraine, it is proposed to use the so-called “smartophores of cities”, the elements of which are given in Table 1. In the “smartophores of cities”, there are three colors in accordance with the development of operations: services are indicated in green, in which certain operations are available, yellow – operations in work, and red – operations are absent.

Table 1

Digital services for monitoring in “smartophores of cities”

Service	Operational monitoring
1	2
1. E-government	
1. 1. Electronic document management	green yellow red
1. 2. Electronic bidding	
1. 3. Property management system	
1. 4. Map of MAFs	
1. 5. Map of advertising structures	
2. Openness and transparency of local government	
2. 1. Electronic appeals on the city hall website	green yellow red
2. 2. Electronic appointment	
2. 3. Open budget	
2. 4. Participation budget	
2. 5. Budget on the map	
3. Provision of electronic administrative services	
3. 1. Electronic administrative services	green yellow red
3. 2. Electronic entry to the CNAP	
3. 3. Cabinet of the Ministry of Internal Affairs in the CNAP	
3. 4. Resident’s office on the city hall website	
3. 5. Map of the resident	
4. Communal sphere	
4. 1. Single call center	green yellow red
4. 2. Road condition map	
4. 3. Map of housing applications	
4. 4. Choosing Online Utility Contractors	
5. Transport	
5. 1. GPS of public transport	green yellow red
5. 2. GPS of public transport	
5. 3. Traffic and traffic control center	
5. 4. Electronic ticket	
5. 5. Electronic scoreboard of traffic at stops	
5. 6. Payment for parking by contactless cards	
5. 7. Fare payment by contactless cards	
6. Safety and comfort	
6. 1. Street video surveillance	green yellow red
6. 2. Video surveillance with face recognition	
6. 3. Calling the police online	
6. 4. Chargers on streets and bus stops	
6. 5. Bicycle paths	
6. 6. Walkways for the disabled	
6. 7. Garbage cans with filling sensors	
7. Medicine and education	
7. 1. Electronic registry	green yellow red
7. 2. Electronic patient card	
7. 3. Electronic registration in kindergarten	
7. 4. Innovations in education	

Continuation of Table 1

1	2
8. «Smart» energy	
8. 1. Energy monitoring	green yellow red
8. 2. Automatic regulation of heat carriers	
9. Modern tourist	
9. 1. Electronic guides for tourists	green yellow red
9. 2. QR codes for tourists	

Note: compiled on the basis of [23]

The smartphore of a city demonstrates a clear picture of the digitalization of urban governance in the relevant areas. This creates conditions for the further application and development of smart technologies in the city. It seems expedient to carry out the practical implementation of the proposed monitoring on the example of large cities of Ukraine – Kyiv, Dnipro, and Lviv (Table 2).

It is worth noting that with the development of digital technologies and their introduction into the city management system, the list of services can be expanded.

At the present stage, significant opportunities have been created for the development of smart cities at different levels. In particular, these processes are facilitated by the actions and steps of leading mobile operators. For example, Vodafone contributes to the formation of Smart City using digital technologies such as the Internet of Things, Big Data, Mobile ID, and Cloud [24]. In turn, Kyivstar also actively uses the Internet of Things, Big Data, Cloud, Internet of Things, and M2M [25]. Thus, these trends help to more effectively perform daily tasks in the field of urban management.

Table 2

Smartphores of Kyiv, Dnipro, and Lviv

Service	Kyiv	Dnipro	Lviv
1	2	3	4
1. E-government			
1. 1. Electronic document management	green	green	green
1. 2. Electronic bidding	green	green	green
1. 3. Property management system	green	green	yellow
1. 4. Map of MAFs	green	green	red
1. 5. Map of advertising structures	green	yellow	yellow
2. Openness and transparency of local government			
2. 1. Electronic appeals on the city hall website	green	green	green
2. 2. Electronic appointment	yellow	green	green
2. 3. Open budget	green	green	green
2. 4. Participation budget	green	green	green
2. 5. Budget on the map	yellow	green	green
3. Provision of electronic administrative services			
3. 1. Electronic administrative services	green	green	green
3. 2. Electronic entry to the CNAP	green	green	green
3. 3. Cabinet of the Ministry of Internal Affairs in the CNAP	yellow	green	green
3. 4. Resident’s office on the city hall website	green	yellow	green
3. 5. Map of the resident	green	yellow	green
4. Communal sphere			
4. 1. Single call center	green	green	green
4. 2. Road condition map	yellow	green	red
4. 3. Map of housing applications	green	yellow	yellow
4. 4. Choosing Online Utility Contractors	yellow	red	red
5. Transport			
5. 1. GPS of public transport	green	yellow	green
5. 2. GPS of public transport	green	green	green
5. 3. Traffic and traffic control center	yellow	yellow	green
5. 4. Electronic ticket	yellow	yellow	yellow
5. 5. Electronic scoreboard of traffic at stops	yellow	yellow	green
5. 6. Payment for parking by contactless cards	green	red	green
5. 7. Fare payment by contactless cards	green	red	red

Continuation of Table 2

1	2	3	4
6. Safety and comfort			
6. 1. Street video surveillance	green	green	green
6. 2. Video surveillance with face recognition	yellow	yellow	green
6. 3. Calling the police online	green	green	red
6. 4. Chargers on streets and bus stops	green	yellow	yellow
6. 5. Bicycle paths	yellow	yellow	yellow
6. 6. Walkways for the disabled	yellow	yellow	yellow
6. 7. Garbage cans with filling sensors	yellow	yellow	red
7. Medicine and education			
7. 1. Electronic registry	green	green	green
7. 2. Electronic patient card	yellow	green	red
7. 3. Electronic registration in kindergarten	green	green	yellow
7. 4. Innovations in education	yellow	red	red
8. «Smart» energy			
8. 1. Energy monitoring	yellow	yellow	green
8. 2. Automatic regulation of heat carriers	yellow	yellow	green
9. Modern tourist			
9. 1. Electronic guides for tourists	yellow	yellow	green
9. 2 QR codes for tourists	green	yellow	yellow

5. 3. Analysis of models of digitalization of urban management and formation of smart cities

Taking into consideration the world experience in the formation of Smart City, it is possible to distinguish the relevant models of digitalization of urban governance (Fig. 2).

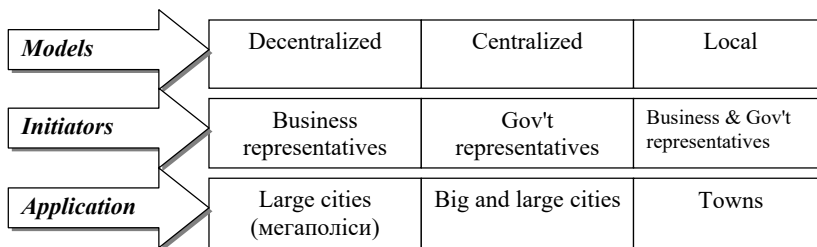


Fig. 2. Models of digitalization of urban governance

Note: compiled on the basis of [26–30]

The decentralized model of digitalization of urban governance is the implementation by various stakeholders of a large number of projects in the field of their competencies and powers. A sphere of implementation of such programs can be projects on energy efficiency, intellectualization of elements of transport infrastructure, water supply systems, etc. Subject to the active role of the authorities in creating the necessary conditions and with a sufficient degree of business interest, a transformational period will take place. The gradual transition takes place from separate, even large, projects to the implementation of more systematic projects and to the creation of sectoral digital platforms. As a result, the management of the life cycle of all sectors of the city's development is improved. In the future, the interoperability of information systems and digital platforms operating in the city can be ensured. An example of the implementation of such a model of digitalization in world practice is the city of Songdo (South Korea) [31].

With a centralized model, digitalization of urban governance is possible solely through leadership, coordination, and control by state authorities. Under such conditions, a

leading role in the planning and management of the processes of intellectualization and digitalization of urban development can be assigned to a profile agent in a municipality or regional government, often in conjunction with a state corporation. To coordinate and support specific projects, a

special organization can also be established, which will be entrusted with the functions of the project office. Digitalization on a structural basis of individual subsystems of urban economy and all urban infrastructures is guided by a single decision-making center. The formation of a single environment of urban digital services takes place based on a single digital platform. The main characteristic of digitalization is the reduction of the share of services provided to residents directly by the city, and an increase in the total number of services available to

citizens and businesses by delegating them to businesses and technology companies. This means the implementation of a fundamentally new approach to the issue of data ownership and their openness to various entities. Examples of the implementation of such a model of digitalization in a world practice are the cities of Rio de Janeiro (Brazil) and Barcelona (Spain) [32].

The local model of digitalization of urban governance is implemented in the format of a public-private partnership. At the same time, participants seek to increase the efficiency of various infrastructure sectors of the city, subject to limited resources. A feature of the model is the implementation of pilot projects, which allows partner companies to demonstrate under real conditions the possibility of applying their solutions in the urban environment. A promising direction of this model is the creation of effective physical infrastructure and primary digital infrastructure with minimal costs, due to the positioning of the city as a "living laboratory" for working out technological solutions. In addition, it is possible, by virtue of scale, to carry out under an experimental or commercial mode the complete digitalization of

individual subsystems of the urban economy. An example of the implementation of this model of digitalization is the city of Antwerp (Belgium) [33].

Each of the presented models closely correlates with the evolutionary generations of the Smart City concept. While for the first phase (generation) the main interested entities are business representatives, for the second – the main role is assigned to the city authorities. For the third, principal is the emergence of various partnerships and the transition of citizens to an active position, their independent connection to the processes of management and intellectualization of the city.

5. 4. Results of studying the effectiveness of the development of smart cities

The effectiveness of the development of a smart city can be determined by any indicator. However, the most vivid picture of ensuring a comfortable life in the city is demonstrated by the size of its population. The hypothesis is confirmed by the fact that in the developed cities of any country in the world there is a positive rate of population growth, at a time when the inhabitants of depressed regions intend to leave.

At the same time, it is proposed to consider the upper and lower limits of the efficiency of the development of a smart city. The upper limit of the efficiency of the development of a smart city by its population is proposed to be determined through the digital reserve for the development of a smart city. In other words, the upper limit is the maximum population of a smart city, which can be provided with high-quality digital services on its territory at a certain standard of living. Accordingly, the more the population will be able to live within the city, the lower the level of service for citizens, and vice versa [34].

This restriction is of particular importance when considering a smart city as a socio-economic system, in particular the availability of digital and intellectual resources. The lower limit of the efficiency of the development of a smart city is proposed to be assessed using a break-even point corresponding to the population of the city, in which the total costs of maintaining and developing a smart city will be equal to its income.

In the event that the total costs of functioning and development of a smart city exceed its revenues, it will become unprofitable and will not be able to function and develop sustainably without external support.

The formal representation of the definition of the upper and lower limits of the efficiency of smart city development by population is as follows:

$$P_U: TC=kGRP; DR \rightarrow 0, \tag{1}$$

$$P_L: TC \leq kGRP; DR > 0, \tag{2}$$

where P_U is the population with zero reserve for the development of a smart city (upper limit);

DR – a reserve for the development of a smart city; development of the city;

P_L – the population of a smart city when it reaches the lower limit of development efficiency;

TC – total costs for the maintenance and development of a smart city;

$kGRP$ is a part of the gross regional product that goes to compensate for the costs of maintaining and developing a smart city.

The above indicators for calculating the upper and lower limits of the efficiency of smart city development in individual large cities of Ukraine could be represented in the form of Table 3.

Table 3

Indicators for calculating the upper and lower limits of the efficiency of smart city development by individual large cities of Ukraine in 2020

Indicator	Kyiv	Dnipro	Lviv
Population, thousand people	2,566.95	1,053.95	725.3
Total costs for maintenance and development of the smart city, UAH million	62,645.77	14,736.85	10,847.7
Part of the gross regional product allocated to compensate for the costs of maintaining and developing a smart city, UAH million	82,568.4	43,236.5	36,942.7

The obtained data show that none of the cities studied has reached the upper limit of population, that is, there are reserves for the development of smart cities.

In addition, the effectiveness of the development of large smart cities can be determined using the Smart City Index, which is designed to demonstrate where the greatest integration of high-tech smart solutions into the daily lives of citizens is observed [35]. For example, in 2021, the “smartest” city in the world was Singapore, the second place was taken by Zurich, the third – Oslo, the fourth – Taipei, the fifth – Lausanne. The city of Kyiv took the 82nd place, while the positive point is the fact of improving its position 16 points above the level of 2020 [36]. The Smart City Index provides for their division into four levels – from AAA to D. In addition to the overall rating, the level of urban development by infrastructure and technologies is determined. Thus, these rating criteria can also be used to make decisions on the further development of smart cities.

6. Discussion of results of the study of ensuring the digitalization of urban management as the basis for the development of the concept of smart cities

The study of the impact of digitalization of urban management on the development of the concept of smart cities makes it possible to draw a general conclusion about the structure, models, criteria and performance indicators of digital transformation. In contrast to the studies reviewed [2–4, 9, 10], which are aimed at a certain geographical aspect or specific prerequisite, systematic consideration of the processes of digitalization of urban management (Fig. 1) makes it possible to determine the multicomponent composition of a smart city. At the same time, in order to achieve the goal of further development of smart cities, it is important to harmoniously combine the functions of long-distance and local interaction [37, 38]. It is worth noting that the successful implementation of these areas is facilitated, first of all, by the activation of the state-corporate sector, which creates the basis for balanced urban development [39, 40].

Applying the smart city’s digital development monitoring approach is a fairly simple practical tool that requires no extra effort and can be used at any time. The assembly of the smartophore of cities (Table 1) demonstrates a certain

level of digitalization of the smart city both in each direction and according to a specific criterion separately. At the same time, it is advisable to pay attention to the development of a system of statistical indicators that make it possible to determine the impact of digitalization on the effectiveness of urban management [41].

Analysis of models of digitalization of urban management and formation of smart cities (Fig. 2) has made it possible to single out the initiators and the scope of each of them, as well as to determine their prospects. It is worth noting that these models are integrated with each other, so in its pure form almost do not occur. Examples of application of models of digitalization of urban management are also given.

The logical continuation of our study was determining the effectiveness of the development of smart cities. Since the effectiveness of the development of a smart city can be determined by any indicator, it was hypothesized that the population is the most relevant one. This hypothesis was substantiated in detail. Thus, the upper population limit of the smart city (1) and the lower population limit of the smart city (2) were determined. In addition, it is proved that the effectiveness of development can be determined on the basis of rating criteria.

The scientific results of our study of ensuring the digitalization of urban management, as the basis for the development of the concept of smart cities, are a kind of basis for increasing the level of efficiency. This will make it possible to determine the steps for the further introduction of digital tools in the field of urban economy, creating comfortable and safe living conditions for the population.

The practical significance of the study is proven by the ability to determine the level of digital transformation of a smart city without undue difficulty, as well as to predict further directions of its development. The proposed methodical approaches are easy to use and do not require unique data.

After analyzing the content of the concept proposed by authentic authors, it is advisable to distinguish certain shortcomings. In particular, the study focuses on such indicators of the development of a smart city as the population, the level of technology development and urban infrastructure. At the same time, other indicators of the development of a smart city are not taken into consideration. This indicates a certain limited approach but gives grounds for further research in this area.

The development of further research initiated by this paper implies further deepening of the theoretical and methodological approaches to the development of the concept of smart cities in the context of digitalization. In particular, further research should be directed to the construction of a multicomponent system-structural model of a smart city. This proves to distinguish a large number of interrelated criteria, build an economic and mathematical model of smart cities and predict further development strategy.

7. Conclusions

1. It is determined that digital transformation has led to the emergence of a new type of urban management – the concept of Smart City. It is established that an important prerequisite for the creation of a Smart City is urbanization processes. It is proved that the creation of Smart City is associated with global challenges. Historical aspects of the formation of the Smart City concept are distinguished, providing for three phases of its development, starting from the XXI century. It is determined that at the present stage the smart city concept includes vision, ecosystem, management, technological background, and financing. Each element of the concept under study is substantiated in more detail.

2. It was established that the creation of smart cities became possible only with the development of digital technologies, as a result of which functions that were previously performed by people and organizations were transferred to the digital environment. The traditional components of smart cities are distinguished, including transport, energy, utilities, urban environment, security, and “smart” house. It is proposed to use the smart cities methodology to monitor the implementation and development of digital services in the smart city management system. This procedure is systematized in nine directions. It is substantiated that this is a prerequisite for the further application and development of smart technologies in the city.

3. The world models of digitalization of urban management and the formation of smart cities – decentralized, centralized, and local – have been characterized. The initiators and conditions of application of each of them are determined. The prospects of each model of digitalization of urban governance are substantiated. Examples of cities, the development of which took place according to these models, are given. It is noted that each of the presented models closely correlates with the evolutionary generations of the Smart City concept.

4. Our results created the basis for determining the effectiveness of the development of smart cities. It is established that the effectiveness of the development of a smart city can be determined by any indicator. Despite this, a hypothesis has been put forward, which is further substantiated that the most vivid picture of ensuring a comfortable life in the city is demonstrated by the size of its population. It is proposed to establish the upper and lower limits of the efficiency of smart city development based on a reasonable indicator of population. In addition, the effectiveness of development is recommended to be determined using the Smart City Index, which demonstrates which cities have the most integrated high technologies of smart solutions in the daily lives of citizens. It is determined that the proposed methods of efficiency assessment can be used to make decisions on the further development of smart cities.

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