Decomposition of management processes in “Smart city”

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Abstract. This article reviews the existing principles of the definition of “Smart city” approaches to the consideration of its elements (from users to physical processes) and their characteristics, approaches to mathematical description of management tasks to processes of socio-cyberphysical systems. The technological concept of creating modern megacities as the final set of functional multi-purpose components and the relationships between them are discussed. Impacts on the physical level, research methods for complex high-tech systems, and analysis of the problems of intellectualization of urban space are the basis for the development of smart cities. Proposed models and methods are widely used in managing the infrastructure of modern megacities.

1. The concept of "Smart city"
Currently, more and more people tend to live in cities, which leads to many problems, such as a large population of megacities, with the resulting problems of waste disposal, lack of resources in limited areas, pollution of the environment, danger to residents in the process of their man-made life, a difficult transport situation, the complexity of the organization of infrastructure in cities. Another set of problems is social problems that are closely related to technological, economic, informational, and so on. The problem is complicated by competing goals and values, social and political complexity, and, most importantly, the presence of numerous and diverse stakeholders who have their own, in scientific terms, target functions.

Today, there are many definitions of the concept of “Smart city”, formulated in the framework of solving various scientific, technical and social problems in different countries, by specialists from different subject areas. This study uses the most formally complete definition formulated by Professor A. A. Volkov as: “Smart city” is a convergent socio-cyberphysical complex that is optimally adaptive to a person, society, and nature [1].

The «Smart city» complex constantly monitors the most important infrastructure objects – roads, other means and infrastructure for ensuring mobility, communication systems, water supply, and power supply of buildings and structures in order to optimize the allocation of resources and ensure safety. Such cities are constantly increasing the number of services provided to the population, providing a sustainable environmental environment that is convenient for citizens to live in. These services are based on data processing and interaction technologies. In this regard, in a number of publications, “Smart city” is also defined by the term “Connected City”. The concept of urban development under study has become quite widespread and is currently being implemented in one way or another in 2,500 cities around the world. It should be noted that it is necessary to analyze aspects of
the design, organization and operation of modern megacities designed to ensure a high quality of life for the General population.

In general, the subject of the methodology of scientific knowledge in the field of technoscience is the methods of obtaining, justifying, presenting and verifying knowledge in the technical and technological Sciences. The most important specific feature of the “Smart city” as an object of scientific research and as an object of management in the broad sense of the word is its complex nature, reflecting the complex structure of scientific knowledge from the point of view of natural science, mathematics, socio-economic and model-projective knowledge [2-6]. Any, including intellectual, device that a person uses in their daily life is a consequence of technological progress, and therefore is based on a certain physical phenomenon. The research process or in other words, the life cycle of real technological systems begins with modeling (building theoretical and material models of future samples of equipment and technology), followed by design, mathematical calculations for constructivity, then-laboratory and field tests for reliability, efficiency, and environmental friendliness; economic calculation for payback, profitability, competitive advantages; as well as social testing for demand and acceptability in terms of meeting the needs of users, etc. The next stage is to ensure the maintenance and safe operation of technological systems, in most cases, all stages of the life cycle are considered, including modernization, re-equipment and disposal. This article discusses the technological concept of the approach to the subject area of smart cities.

2. Levels of management implementation in the “Smart city”

The physical process (in fact, the basic technical essence) of a “Smart city” is a set of construction systems.

Today, a construction system is defined as a finite set of functional components (elements, objects, construction complex) and relations between them, allocated in accordance with a specific goal within a certain time interval [7].

Building systems management processes can be constructed in different ways depending on a large number of factors. In relation to the analysis of the technological implementation of management processes, such a factor is the integration of management systems, which is also due to the degree of their automation.

For fig. 1 an enlarged diagram of the levels of implementation of building systems management processes in the “Smart city” paradigm is presented.

![Diagram of levels of implementation of building systems management processes in the “Smart city” paradigm](image-url)
The scheme has horizontal (I-IV) and vertical (1-5) levels. Horizontal levels characterize the entities being integrated, and vertical levels indicate the degree of integration.

Level I is the level of users, that is, individuals or organized (in one form or another) communities that consume the results of building systems.

Level II is the level of building systems.

Level III is the local management level. In this case, localization of management is understood not as geographical, but as functional localization, that is, the management system can be quite complex, remote, distributed, etc., but perform the functions of managing a specific construction system (or a limited set of construction systems).

Level IV is the integrated management level. Integrated management refers to the functional integration of management of many (ideally, all) building systems of a given object (city, district, urbanized territory).

Consider the levels that characterize the degree of integration.

Level 1 is the level of manual control systems, that is, the level that assumes the complete absence of automated (and/or automatic) control systems.

Level 2 is the level of automatic or automated systems that do not allow the user to adjust the rules (laws, algorithms) implemented by the control system. In fact, this level implements cyber-physical building systems.

A cyberphysical construction system is a finite set of functional components (elements, objects, construction complex, computing resources integrated into included physical processes) and relationships between them, allocated in accordance with a specific goal within a certain time interval [7].

Level 3 is the level of automatic or automated systems that allow the user to adjust the rules (laws, algorithms) implemented by the control system. In fact, this level implements the simplest case of socio-cyberphysical building systems.

Level 4 is the level of partially integrated automatic and automated systems, that is, at this level, the functionality of local control systems is preserved, but it integration with external cyber-physical construction systems is already provided.

Level 5 is the level of integrated automatic and automated systems, that is, at this level, the functionality of local control systems is fully delegated to integrated control systems that implement socio-cyberphysical integration.

It can be noted that the intellectual development of a complex of technical solutions for the organization of urban space convenient for life implies a synergistic effect of mutual influence and interpenetration of all spheres of life of citizens and technogenic infrastructure. The principles of self-organization and cognition are inherent in society, and therefore cities are associated with the processes and phenomena of nature; they are provided with means of communication, management, and information; they use the principles of organization, feedback, expediency, and probability. The evolution of urban structure development is conceptually universal, in terms of its focus on future development. Based on the "signal-response" functional approach, a hypothesis is formed about the internal composition and structure of technogenic systems, implying the self-organization of the socio-cultural system.

The synergetic approach allows us to balance the problems of development of intellectual systems of different nature, including man-made ones, in relation to complex and highly complex systems [8], the laws and principles of their self-development. The key is the philosophical concept-system, and the synergetic method is initiated with synergetics, Cybernetics, General systems theory, computer science, or in modern formulation and practical application – information and communication technologies. "Synergetics is one of the leading directions of modern science, representing a natural-science vector of development of the theory of nonlinear dynamics in modern culture" [9]. Note that one of the characteristic features of systems, including synergistic ones, is the presence of feedback. In control theory feedback is a communication subsystem on the output in comparison with some job on
the input, the relationship characterizes the impact of the environment on the system and the response, the link allows you to manage.

In a broad sense, synergetics is interpreted as a General theory of self-organization and development that forms a new type of thinking and worldview. Synergetics is considered as spontaneous formation of regular structures in open, nonlinear, stable systems [10, 11]. Studying the theory of development of thermodynamics of nonequilibrium processes, I. R. Prigogin elevated synergetics to the status of a General scientific discipline [12]. Models of modern synergetics develop according to one or another scenario, assume that the system chooses one or another path of development, postulating the phenomenon of randomness [13]. At the same time, synergetics is material and controlled by the cybernetic mind.

The development of urban development strategies based on the theory of alternatives, Wiener-Shannon information theory, cyclical development, and situational research methods allows us to test a number of new strategies for scientific research, provided that the system is open; it is far from equilibrium and the presence of disturbances. The tools of the synergetic approach are probabilistic, stochastic (random-probabilistic) methods, mathematical and cybernetic modeling methods. The technical significance of synergetics and cybernetics is the development of the trend of cybernetization and Informatization of all spheres of life, which we see at the present time due to the development of the intellectual sphere of production and social life.

The basis for creating hierarchical high-tech systems with complex interaction of elements is based on social, environmental and economic priorities for the development of production systems. Methods of searching for new technical solutions using morphological analysis as a tool of the system approach in scientific research are justified by F. Zwicki [14]. A. I. Polovinkin investigated the physical principles of operation of various devices [15, 16] when developing search design methods, designing and optimizing the selection of a set of technical solutions. Issues of intensification of technological processes at the physical level and the choice of optimal effects are studied in the works of G. A. Kardashev [17] and Mikhailov P. E. [18], Shatalov A. L. [19].

In [20], the author proposes generalized principles for building control systems that lead to the possibility of intensification as an improvement of the existing technological process. The proposed principles of hierarchy, openness, selectivity, and consistency are confirmed by studies of existing automated control systems and analysis of technological components of production chains, as well as the selection of optimal additional physical effects [17, 19].

The principles are considered as the basis for building automated systems of hierarchically interconnected management if the system has a technological resource for modernization, i.e. the possibility of increasing economic efficiency, environmental safety, equipment modernization and intensification of technological processes. It is shown that the introduction of additional control physical actions into the existing technology allows to significantly intensify a number of processes [17-19]. The selectivity of the choice of the type of physical impact is determined by the goal, for example, reducing the time, the longest stage, or/and ensuring the specified quality of the product [21]. Coordination of the physical impact for a particular process or its individual stage is a crucial factor in overall efficiency.

The theoretical basis for the study of methods and basic principles of managing complex technological systems is decomposition methods implemented in control systems taking into account the behavior of both interconnected subsystems and elements of other levels of the hierarchy. Generalization of the concept of "management" at all stages of the life cycle of a technical system leads to the need to include additional control physical influences as one of the target factors of intensification [17]. It is noted that with an integrated approach, the tasks of "automation" and “intensification” merge into one complex problem to be solved.

The formulated principles are not exhaustive, but their relationship justifies the use of methods of hierarchically interconnected management, as well as the inclusion of physical influences among the controlling factors. Hierarchical structures can be observed in all complex systems: biological, technical, technological, as a result of their natural development.
The technological and structural complexity of modern cyber-physical systems is implied a priori. The conceptual approach to building a model of a cyberphysical system involves the study of the balance of requirements for various fields of application of this type of system, especially in the study of social and technological systems in the construction industry. Prior to the simulation analysis involves the study of legal norms, and resource potential of the region, the dynamics and the structure of its industrial potential, natural and environmental factors, infrastructure, an analysis of the size and structure of the population of the region and so the Phase modeling is important in the process of effective intellectual management involves integrating various practical perspectives. The design of the elements that make up the «Smart city» complex must be performed after analysis, forecasting, and modeling of balanced subsystems.

3. Formalization of the control problem

The multivariance of the structure of complex technological systems and the autonomy of individual stages lead to the possibility of setting the optimization problem in terms of explicit decomposition. Technological processes for each of their subsystems are focused on achieving certain indicators, the values of which are determined either on the basis of its optimization, or on a priori information about the process. Automated control methods must provide the optimal or specified value of technological parameters accepted as a technological component of the optimal control criterion (1). For example, for energy-intensive heat treatment processes with a significant influence of economic indicators of production, we can offer an additive structure of the criterion of optimality of local problems

\[ a_i = a_{1i} \cdot f_{1i}(\bar{x}, \bar{u}) + a_{2i} \cdot f_{2i}(\bar{x}, \bar{u}), \]

where \( f_i \) – is the optimization criterion for the \( i \)-th subsystem; \( f_{1i}(\bar{x}, \bar{u}), f_{2i}(\bar{x}, \bar{u}) \) – technological and economic components of the optimization criteria; \( a_{1i}, a_{2i} \) – weighting factor.

The structure of the criteria allows us to take into account raw materials and energy costs, as well as losses due to deviations of the parameters of processed materials from the regulatory values, when solving the optimization problem. The weighting factors make it possible to determine the significance of the components of the optimality criterion for each subsystem. The main components of heat treatment costs are fuel and air consumption. Material costs are determined by the amount of raw materials, operating costs necessary to obtain heat treatment products of the specified quality, taking into account irreversible losses.

The decomposition methods are based on the transformation of the original optimization problem to a separable form, followed by its structural decomposition into a number of subtasks of the lower level of the hierarchy (local tasks) and the coordination problem of the upper level. The selected local problems (2) and the coordination problem of this type are solved together in the framework of an iterative procedure for inter-level data exchange, during which the values of variables selected during the solution of the coordination problem are passed to the local problems as specified constants. The obtained solutions of subtasks are sent to the coordination task, with the subsequent evaluation of their value for optimality by the global task criterion. If necessary, the values of the coordinating parameters are corrected and passed to the local tasks again. The procedure is completed by determining the optimal values of the variables of the coordination problem, which together with the corresponding solutions of local problems determine the desired solution.

\[ \max_{x,y,u} \sum_{i=1}^{N} f_i(x_i, u_i, y_i), \]

\[ y_i = g_i(x_i, u_i), \quad h_i(x_i, u_i, y_i) \geq 0, \quad x_i = \sum_{j=1}^{N} c_{ij} y_j \quad i = 1,2, \ldots, N. \]

Input vector \( x_i = (x_{i1}, \ldots, x_{ik}) \), output vector \( y_i = (y_{i1}, \ldots, y_{il}) \), control vector \( u_i = (u_{i1}, \ldots, u_{im}) \), performance criterion \( f_i(x_i, u_i, y_i) \), mathematical description of system elements \( y_i = g_i(x_i, u_i), i = 1, \ldots, N \), technological limitation \( h_i(x_i, u_i, y_i), i = 1, \ldots, N \), adjacency matrix \( c_{ij} \).
The explicit decomposition method, called the variable pinning method, uses the values of related inputs and outputs of subsystems of a complex technological system to coordinate local tasks $x_i$ and $y_j$, $i, j = 1, 2, \ldots, N$, which are considered to be formally broken. In the global coordination task, the inputs and outputs are always set in compliance with the continuity condition.

Note that linear trend and autoregressive models with a reliability level close to 90% according to the Fischer criterion are used as forecasting models, as well as integral models. The implementation of the conceptual approach involves a step-by-step solution of the problem, which, within the framework of the given approach, can be formulated as ensuring the maximum level of comfort of the population's standard of living, taking into account various social, industrial, environmental factors, safety and security factors.

Effective, sustainable smart cities arise as a result of dynamic processes for coordinating the activities of many entities that have their own goals, activities, and resources on an open innovation platform. Synergies should be coordinated based on the stage of development and social opportunities. A balanced approach to ensuring a high quality of life and security of citizens requires the creation of a conceptual hierarchical system of economic and mathematical models. Hierarchical systems allow you to combine Autonomous cyber-physical systems that operate at the level of subsystems that may have been created earlier and are already functioning. Hierarchical systems for managing complex structures require the development of intelligent methods and algorithms that provide solutions to local management problems and global coordination problems.

The two-level scheme for making a control decision corresponds to the structure of Fig. 2. Here CTS$_i$ – modified complex technological systems corresponding to $i$ situations; CB – coordinating body, CS – a control system that solves a modified control problem.

**Figure 2.** Scheme for making a control decision when decomposing in time

For example, as part of the development of intelligent transport systems, there is a constant exchange of real-time data between vehicles, road transport infrastructure, control centers and information services. Information messages, danger messages are generated in global networks, but the information reaches the consumer under the control of cooperative systems-a new type of service. Data exchange protocols in cooperative systems, as well as the messages themselves, should be standardized for broad integration of various services, and the accuracy and reliability of cooperative services should be ensured. The motion control system is expanded in the direction of virtual and cloud solutions.

Intelligent street lighting management involves managing the lighting network, accounting for electricity, planning energy costs, servicing Troubleshooting activities, and so on. Improving energy efficiency and reducing energy costs is achieved by reducing budget spending on the construction and repair of outdoor lighting networks, operational monitoring of electrical equipment and lines of
outdoor lighting, improve the reliability and efficiency of their work while ensuring regulatory
indicators in the illumination of urban spaces, and the use of phase control lamps, local control of
lamps and their capacity, budget planning network operations.

Each production facility has high safety requirements, this applies to the safety of the process itself
and the prevention of the consequences of failure or damage to the equipment on the surrounding
infrastructure. Pre-project analysis of cyber-physical systems is carried out in accordance with the
requirements of reliability and security in order to minimize defects and the possibility of parallel use
of one or more alternative control structures. Management processes must be flexible, as they require
high reliability and cyber security requirements.

Step-by-step solution of the formulated tasks makes it possible to increase the level of satisfaction
of citizens with the quality of implemented intellectual and technological solutions.

4. Conclusions
As a result of the analysis of problems of intellectualization of urban space justified methods of study
of complex high-tech systems, the peculiarities of the development of cyber-physical systems, the
possibilities of intensification of technological processes. In addition to the direct application of new,
including energy-saving technologies, these are: the use of physical and chemical influences; creating
environmentally friendly infrastructure elements, improving the design of man-made systems based on
the use of physical and mathematical modeling, automation, and design of heat and mass transfer
processes in particular.

In the study of open technogenic systems, it is possible to justify the synergistic effect, identify
factors for improving the efficiency of subsystems, selectively selecting significant relationships,
optimal control actions at the physical level, and additional information effects on elements of
decomposed systems, taking into account intra-level and inter-level relationships.

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