Description of a complex technical system of urban electric transport from the standpoint of synergistic methodology

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Abstract. City electric transport is considered from the standpoint of a synergistic methodology in order to search for modern approaches to solving the actual problem of increasing its efficiency. The properties of the urban electric transport system are identified in their unity and interdependence in terms of synergetics. Methodological interpretations of these properties from the standpoint of an actually existing system of urban electric transport will allow determining its theoretical synergetic model.

Introduction
Improving the efficiency of urban electric transport (UET), primarily energy, is a prerequisite for the modernization and innovative development of the transport system of modern cities, to ensure that the transport needs of the population are met, and also to integrate urban agglomerations into a single transport system. These processes require new methodological approaches to the description of the GET, as a complex technical system with a huge number of internal and external relations with their heterogeneity and structural diversity.

The modern methodological space of science has been enriched with synergetic ideas about the phenomena of reality as complex systems. Such a view of the world, born of the efforts of a number of outstanding scientists of the new time, is reflected in the concept of “Synergetic”, which was developed and formulated as a new scientific paradigm by the German mathematician Hermann Hacken [1]. An attempt to interpret all these methodological bases from the standpoint of a real-life organization of the urban electric transport system will serve to develop innovative solutions to the actual problem of increasing its efficiency.

Materials of theoretical study
The modern city, its production and non-production technologies, where the UET system occupies a central place and is of unifying importance for many, is one of the most problematic objects of synergistic research [2, 3] in the context of the growing urbanization of public life. In the domestic scientific literature [3, 4], attempts are made to describe transport systems in terms of open complex systems and synergetics, and also to determine which theoretical and practical problems can be solved from the standpoint of innovative, positive development of urban transport systems. The most relevant from the standpoint of systemic synergetic methodology seems to be the definition in terms of
synergetics of the following properties of the UET system in their unity and interdependence (Figure 1).

1. **The complexity of the organization of the system.** This is one of the most important properties of the system, determining all other qualities and manifestations of its order [5, 6].

   The UET system is complicated by the presence and quantity of various types of rolling stock, means of communication, sources and methods of energy supply, production and repair facilities for transport units, etc. It is complicated not only by its technical and technological content, but also by its complex social infrastructure that provides the functions of the transport system, including the human, personnel, professional, and educational factors. The complexity has a number of necessary characteristics.

   ![Figure 1 - Synergistic properties of the UET system](image)

   a) **Level of difficulty.** It consists in a variety of parts included in the system. A systematic approach to urban transport has been significantly developed and presented in the scientific literature [4, 5], there remains the problem of determining the specific level of complexity of this system, which is crucial for its positive innovative development based on the properties of self-organization and self-development. In the UET system of a modern large city there are types of transport that compete with each other, for example, by their availability, comfort, etc.

   b) **The nature of the complexity,** consisting in the fact that parts of the system and their space-time relationships are not the same, are significantly different, they coexist as “the unity and struggle of opposites”. The search for specific ways to optimize such a dialectic unity is the second problem of the complexity of the UET system. The transport system of a city, having a certain level and nature of complexity, may not have in its composition any elements, for example, sufficient energy sources, repair facilities for the production of vehicles and means of communication, institutions preparing personnel, etc. [7-9].

   c) **Integrity** - a sufficient number of parts included in the space-time relationship. It characterizes the organization as a system capable of displaying the qualities of order. The more complex the system
is in its level and nature and, if it is integral in its composition, the more pronounced are the qualities inherent in complexly organized ordered systems. Determining the sufficient integrity of the UET system for its innovative development is the third problem of its complexity.

2. The openness of complex systems. This is a property of systems that determines their dependence on external resources and the ability to perceive these resources in the interests of the emergence and development of their internal qualities and their manifestations. The system UET is open to relationships with other technological systems of the city. Moreover, it plays the role of connecting many technologies of the city into a single technological system, ensuring the flow of people - the main energy potential of society in a single stream of raw materials, means and products of their production and non-production activities. However, the whole set of non-transport technologies of the city has an impact on its transport part. These relationships can be conducive to or impede the processes of positive mutual development of city technologies. The relationship of the transport system with other technologies of the city as a source of innovative development is the central problem of the technological development of the city as a whole [10, 11].

3. Order parameter in the system. This is the criterion by which order arises and manifests itself — an organization-system is formed with certain properties that correspond to this criterion. In addition, the order parameter or regulation is an external condition and an internal factor in the emergence and subsequent independent development of a complex system. For the UET system, the order parameter is various kinds of positive effects on the life of a city, for example, on “convenience for life” [12]. Order (complex system) and order parameter are born simultaneously. In the chaos of events, the random movement of particles in certain conditions “seizes” the parameter according to which the motions acquire the space-time order and thus the order parameter is realized, fixed in the properties and manifestations of the system. Based on the value of the UET system for people's livelihoods, its innovative development cannot be focused only on random events of choosing the order parameter [13]. Finding the optimal order parameters in the UET system is an urgent task for the technological development of modern cities as a whole at all stages of this process.

4. Self-organization and self-development. This formation of the relations of parts of the system suddenly arising, in accordance with the original order parameter, into a space-time organization that corresponds to this parameter, with subsequent complication of the organization, the establishment of new order properties in its new parameters. This is due to the appearance in the system of internal, intrinsic to it, mechanisms and development resources and, of course, due to its openness to perception of external resources and exchange with them [14]. The transport systems of modern cities have a centuries-old history of their origin and development. Now there is no need to talk about the spontaneous generation of the UET system, especially in large cities, in which the development of electric transport is a pressing social problem - in them transport systems have already been “born” and formed in one form or another. The existing organization of the city’s transport needs to be improved. Based on the principles of self-development, transport, the transport system, the UET system develops in the direction of improvement, and therefore positive development, thanks to the means inherent in it — internal mechanisms that are different from other technological systems. But this is not only the case - with all the openness towards the surrounding technological environment and considerable dependence on it, the mechanisms and processes of self-development of the UET system are active, largely independent and independent of external influences. However, they can lead to development and to an unfavorable result, both for the system itself and global, socially significant. The problem of analyzing the processes of self-organization and self-development of the UET system consists in knowing the specifics of the internal mechanisms of development and determining the parameters of the order in which development should occur. The result of self-development (positive or negative) depends on a number of other crucial properties of the transport complexly organized system [6, 15].

5. Instability of a complex system. In everyday terminology, instability is perceived as a negative quality of any phenomenon. Relatively complex systems with the properties of openness, self-organization and self-development instability is defined by the terms “nonequilibrium”, “non-
equilibrium states”, which are also understood as positive properties of systems that provide them with the necessary variability, ability to easily adapt to changing conditions of existence and development. UET systems, the more complex in their composition, nature and integrity, the more they are non-equilibrium. Such a state may have various manifestations, the essence of which requires definition and specification. This may be existing fluctuations and the emergence of new characteristics of the complexity of the transport system. This may be the instability and coexistence of different, possibly contradictory, order parameters; the emergence of new parameters that require selection and consolidation. The non-equilibrium state of the UET arises for internal reasons related to the complexity of the system, and for external reasons related to the processes of the entire technological system of the city, requiring the satisfaction of new order parameters. In this non-equilibrium state, the UET system is faced with the choice of a new path of self-organization and self-development based on existing or emerging additional internal resources. The problem arises of determining and studying the mechanisms and conditions for choosing this path, which depends on the problem associated with the following property of the transport systems [3].

6. Ambiguity of directions and development processes. This is the possibility of different lines, directions of development of the system in its given non-equilibrium state. In terms of synergetics, this phenomenon of bifurcation is a split line of development, possibly of more complex splitting. Bifurcation arises in connection with the instability and variability not only of the states of the system itself, but to a greater degree of the environment of its existence. It is regarded as a non-linear development at each moment of growing imbalance, its probabilistic and unpredictable nature, at the same time as the ability of the system to choose the direction of development itself, the most adequate to its internal properties and therefore more efficient. The lines of development of the UET system may be different due to changes in the characteristics of its internal complexity associated with changes in the scale of the city, its production and non-production technologies, socio-economic tasks and processes, and other characteristics. In any case, development should proceed along a positive line in its social and humanitarian significance. This is expressed in the problem of finding mechanisms for providing some kind of “stability in instability” - ensuring sustainable positive development of the city and its technologies in general, taking into account the non-equilibrium properties of its technologies as complex open systems [16]. The solution to this problem is largely due to the property of the system, manifested in its high sensitivity and reactivity.

7. High sensitivity and reactivity. This is a property of a system that has a complex organization, to react to the smallest influences from the external environment and to the smallest changes in the internal environment, at the same time, it is the ability to give large reactions to these small external or internal changes. In technical terms, this means the following: for small information "at the entrance" to the system, it gives great information - a great result of the response at the output. This property has both a positive side and a negative one, consisting in the fact that a small, but unpredictable, possibly negative, effect can be caused by small impacts on the system [6]. Due to its material “cumbersome” and organizational complexity, the urban transport technical, technological system can be perceived as an inert enough education - sensitive only to strong influences from the general factors of the social life of the city, its general technological basis, and not capable of fast and complete response. on these impacts. However, the methodological approach suggests that a certain level and certain characteristics of the complexity of the UET system provide it with high sensitivity and reactivity to the smallest external influences and changes in internal processes, not to mention the effects of large and strong ones. The methodological approach reveals in this the problem of finding criteria for the complexity of the UET system and the influencing factors that can serve to identify both the positive and negative sides of the state of its hypersensitivity and reactivity. This has not only a theoretical and methodological meaning, but also a practical one, which consists in the need for balanced decision-making on introducing changes to the UET system, often of an administrative-voluntaristic nature. One of the conditions for studying this problem is to refer to the properties of the system, which determine the unity and purposefulness of its response to external influences.
8. **Unity, focus and effectiveness of response.** This is a special property associated with the presence in the system of coherence mechanisms, in a technical language, the coherence of its parts in their space-time relationships and actions. Consistency - the coherence of the parts of the UET system, which are part of its complex organization, is one of the most realistic, practical problems of innovative, positive development of urban transport. Its deepest methodological essence consists not only in the coherence of one part with another, but also the coordinated unity of the space-time actions of the entire set of parts as a whole. The most important thing in this problem is the theoretical search, definition and practical implementation of such coherence. The system is coherent in the relationship of its parts, many times more efficient than non-coherent. Coherence gives unexpected, emergent results [18].

9. **Propensity for loss of order resources.** This is a property of the system associated with its internal complexity and openness towards the external environment. In the language of physics, a complex system is “dissipative,” that is, prone to dissipation, loss of its resources — “energy, matter, and information” when interacting with other systems. Thus, it loses the level and nature of its organization - the resources of its order. In everyday terminology, dispersion, loss has a negative meaning. Relatively complex systems, a dissipative property means dispersion and loss of resources that go beyond the established order, are not fixed in order, and free up space for acquiring new resources from outside to form a new order with its new parameter. For the innovative development of the GET system this is a favorable condition [3]. It is the replacement of obsolete resources with new ones - in engineering, technology and in the organization of the system. Such a methodological approach requires a theoretical and practical definition of dissipation criteria, its characteristics positive or negative if they lead to the loss of valuable resources due to their disorder, disorganization.

10. **Transitions of the system to fundamentally new states.** These are the processes of transition of the system to states that are radically different by their internal organization, properties, and their external manifestations, which take place under the influence of various factors. In modern scientific methodology, they are referred to as "phase" states of physical and chemical material objects. Depending on the nature of the system and the influences exerted on it, new phase states can be very diverse. On this methodological basis, a practical, real definition of variants of phase states of UET systems with different technological characteristics and development trends is needed. Such states can be certain types of the UET system, characterized by special, significantly different properties. In these states, it is important to determine the real mechanisms of transitions, the corresponding attractors, given the need to acquire positive development directions based on a synergistic view of the development of transport systems in the global unity of all the technologies of life in a modern city.

**Conclusion**

The above properties of the UET require careful study in theoretical and practical terms from the standpoint of a real organization of the city’s transport system, which ultimately will make it possible to obtain a model of an open, complexly organized technical system of UET. This is a serious theoretical and methodological problem, practical approaches to the solution of which require the use of modern information and analytical technologies [18, 19]. The model should be fairly simple, but not as simple as possible, in order not to reduce the synergistic essence and complexity of a truly existing UET system. The authors of this article did not disclose all the properties of the UET as a complexly organized technical system, but a start has been made to rethink the principles of organization, development and management of the UET system in the context of the dialectics of the relationship between its external target management, on the one hand, and the internal properties of self-organization - on the other [3, 6].

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