**Abstract**

**Dissertation work of Togzhanova Kulzhan Ondrisovna on the topic: "Models and methods for the development of dynamic planning systems for the development of Smart city", submitted for the degree of Doctor of Philosophy (PhD) in the specialty 6D070400 – "Computer engineering and software"**

Various players in the investment market, as well as public institutions, began to consider Smart City in the context of the prospects of urbanism and the creation of new zones for cooperation of manufacturers of high-tech products for the needs of urban economy. The city authorities of many large cities, primarily at the municipal level, have announced strategies for investing in Smart City projects. This was dictated by the desire to raise the status of the city, as well as the opportunity to attract long-term investments. The idea of localization of high-tech business within the city infrastructure has also become very promising. At the same time, the companies faced tasks aimed at solving local urban problems, among which water and energy supply, transport and logistics, environmental, as well as information security of residentsd, etc. can be distinguished. Such projects are inextricably linked with the concept of dynamic planning of Smart City development. In turn, such projects are characterized by a high degree of uncertainty and risk. At the same time, the effective development of complex dynamic Smart City systems of various types (socio-economic, technical, etc.) depends on the definition of goals to be achieved. For large projects in the field of urban planning, success often depends on planning and optimal choice of strategies for the development of urban infrastructure, taking into account all factors affecting the system, as well as overcoming various kinds of uncertainties and risks. The main direction of effective solution of these tasks is dynamic planning (DP) of Smart City development.

Dynamic planning today is one of the most effective system tools of modern management and strategic management, analysis and planning of the development of complex systems, in particular, the rapidly developing Smart City. Dynamic planning is an effective method of constructing and developing a rational socio-economic policy, and is also applicable for in-depth analysis and effective development of innovative technologies or large-scale engineering projects.

Dynamic planning has three distinctive features that distinguish it from other types of planning. The first is that when building a plan, the system is considered in time, taking into account the presence of risks and different types of uncertainties and taking into account their changes over time. In addition, it is mandatory to make forecasts about the future effectiveness of the plan and take into account any changes in the environment. Therefore, it is necessary to build a flexible plan and adjust it in accordance with the events that affect the results of the development of the system. The second is that planning is of a long-term nature, since not only short-term goals are considered, but also long-term ones. And the third is that the process of building a plan is evolutionary in nature in order to achieve the best results for the current source data.

Dynamic planning includes various methods of processing quantitative and qualitative information, modeling methods, optimization methods and decision-making at different stages of planning, risk assessment and uncertainty. But the main content of the DP is the construction of well-structured and logically verified dynamic plans, or their elements, different equally plausible and adequate options for the future development plan of the system (in particular, Smart City) and evaluation of the effectiveness of these plans.

The basis of DP is the systematic use of different types of mathematical models, methods of analyzing situations and decision-making, as well as IT-oriented use in conditions of risk and uncertainty. Rapid structural changes in the external environment and in various elements of Smart City are also taken into account to build development plans and forecasts, as well as to solve strategic planning and management tasks. Planning and forecasting the development of Smart City and processes of various types is associated with overcoming various kinds of uncertainties, non-linearities and risks generated by the system itself and the external environment in which Smart City operates. The presence of various types of uncertainties, such as situational uncertainty, inaccuracy and uncertainty of various parameters of the system and the external environment, insufficient information about the system, non–linearity and stochasticity of processes occurring both in Smart City and in the external environment, as well as a large number of risks - all these signs make the problem of solving the tasks of the DP infrastructure of Smart City weak structured and difficult to formalize. Currently, the scientific and applied field of DP Smart City accumulates the latest achievements of the majority of scientific, econometric and information industries and refers to innovative technologies. At the same time, it is an effective tool for planning and forecasting the development of complex dynamic systems at various hierarchical levels. The need for Smart City effective planning growing every year and requires information support in the form of the creation of information and analytical systems with which it is possible to effectively solve the tasks of research and analysis of Smart City by optimizing their structure, identifying and determining the main risks and building effective dynamic plans to select the most likely and appropriate ways of their functioning, development and management.

Therefore, the task remains urgent, the interest of investors in the development of technology to support decision-making during the dynamic planning of the development of Smart City, and the synthesis of sound plans for the development of Smart City.

**Connection of work with scientific programme.** The research and dissertation work of the doctoral programme is carried out in accordance with the state program "Digital Kazakhstan", approved on December 12, 2017 by the Decree of the Government of the Republic of Kazakhstan No. 827.

**The purpose** of the study is to develop models, methods and information technologies to support decision–making during dynamic planning of Smart City development.

To achieve this goal, it is necessary to solve the following tasks:

1) analyze ways to improve the efficiency of the decision-making process during the dynamic planning of Smart City development;

2) to develop a modified method of hierarchy analysis (MMHA) that will allow the formation of consistent pairwise comparison matrix indicators (PCMI) in individual factors of dynamic planning of Smart City development;

3) to supplement the method of effective project risk management during the DP of Smart City development, taking into account the parameters of project risk modeling in a multi-project environment;

4) develop and test a software product (decision support system) during the review of the tasks of the Smart City DP based on group decision-making methods.

**The object of research is decision**–making processes for dynamic planning of Smart City development.

**The subject of the research** is methods and models for the decision support system (DSS) during the DP of Smart City development.

**Research methods.** In the course of the study, taking into account the specifics of the subject area and the formulated tasks of the dissertation, the following methods were used: hierarchy analysis method (for the formation of coordinated PCMI of dynamic planning of Smart City development in individual factors, creation of a consistent matrix of factor comparisons and determination of a global criterion based on factor-indicator estimates of the DP of Smart City development); methods of game theory (for solving the problem project risk management software during the development of Smart City); computer modeling methods (for computational experiments); methods and models for designing DSS (for automated generation of sets of solutions during the evaluation of options for the development of Smart City (for the tasks under consideration); paradigm, principles and methods of object-oriented programming for the development of DSS as a whole and its individual modules.

**Scientific novelty:**

for the first time, a modified method of hierarchy analysis (MMHA) is proposed by forming consistent matrices pairwise of paired comparison matrix indicators (PCMI) in individual factors, creating a consistent matrix of comparisons of factors and determining a global criterion based on factor-indicator estimates;

the methodology of formalization of the main steps of building dynamic Smart City development plans has been developed, which, unlike the existing ones, is supplemented by the stage of decomposition of the solution of the problem of ranking factors into a hierarchy and creating a multi-layer model for assessing the parameters of Smart City development;

the method of effective project risk management has been developed during the dynamic planning of Smart City development, and also takes into account the parameters of project risk modeling in a multi-project environment, and unlike existing solutions, project risk management is described as the risks of investment loss during the dynamic planning of Smart City development, based on the use of the mathematical apparatus of multi-step degree games, and quality games with multiple terminal surfaces.

**Practical value.**

The software solution and the main forms for the DSS module, which is implemented in the C# MMHA language, are described. The program implementation of the MMHA is carried out by forming consistent PCMI in individual criteria (or factors), creating a consistent matrix of comparisons of factors and determining a global criterion based on factor-indicator estimates. During the testing of this module, using the example of the task of assessing the level of energy efficiency of Smart City development plans, it is shown that the use of the proposed method and, in general, the DP methodology, allows you to streamline, algorithmize and adjust the procedure for expert evaluation of various factors and improve the quality of the results obtained for the formation of the decision-making process during the DP development of Smart City. A software solution and the main forms for the DSS module are proposed, which implements a model in C# when assessing the risks of investment loss during the DP development of Smart City. In contrast to existing solutions, the proposed model and its software implementation provide specific recommendations when assessing the risks of investment loss during the DP development of Smart City. The module is implemented on the basis of using the mathematical apparatus of multistep degree games, and quality games with multiple terminal surfaces. It is shown (for example, evaluating a project related to the energy efficiency of Smart City development plans) that with an unsatisfactory risk forecast, flexible adjustment of the parameters of the investment process is possible in order for the parties to achieve an acceptable financial result.

Personal contribution of the applicant. All the results of the dissertation work, which are submitted for defense, are received by the doctoral student personally. Among the main results: a modified method of hierarchy analysis (MMHA), which was achieved by forming consistent MPSI in individual factors, creating a consistent matrix of factor comparisons and determining a global criterion based on factor-indicator estimates; supplemented with a method of effective project risk management during dynamic planning of Smart City development, as well as modeling project risk in a multi-project environment; a model for the DSS in assessing the risks of investment loss during the dynamic planning of Smart City development.

**Approbation of the results of the dissertation.** The main provisions of the dissertation and the results of the research were reported and discussed at scientific seminars of the department and at conferences:

1. XV International Scientific Conference of Students and Young scientists "GYLYM JANE BILIM – 2020" (Kazakhstan, Nur-Sultan, L.N. Gumilev ENU, 2020).

2. International scientific and practical conference "Gylym zhane innovatiyalar: zhanyktar, manseler men zhetikter" (Kazakhstan, Almaty, 2020)

3. XI International Scientific and Technical Conference "Energy, Infocommunication technologies and Higher Education" dedicated to the 45th anniversary of the formation of Gumarbek Daukeev AUES, (Kazakhstan, Almaty, AUES, 2020)

4. International Congress "Innovative Technologies in Logistics, Transport and Education". (Kazakhstan, Almaty, ALT, 2021)

Publications. The main results of the dissertation work have been published in printed works, including 2 articles in journals included in the Scopus database; 4 articles in journals recommended by the CQASES of the Ministry of Education and Science of the Republic of Kazakhstan; 6 publications in the materials of international conferences and scientific journals.

**The structure and scope of the dissertation.** The dissertation consists of an introduction, four sections, a conclusion set out on 127 pages and contains 38 figures, 8 tables, 124 sources used and 3 appendices.

In the introduction, the relevance of the study was determined and the problems associated with the topic were shown, the degree of scientific development of the topic was studied, the object and subject of the study, the goal were established, tasks were formulated and the main provisions submitted for defense were presented.

The first chapter analyzes previous research and information technologies for dynamic planning of Smart City development, analysis of information systems to support decision-making on the development of urban infrastructure, analysis of previous research in the field of modeling risks affecting the development of complex systems, as well as multi-criteria and multi-purpose methods of analysis and decision-making in the process of dynamic planning of complex systems development. Also in this chapter the basic concepts of the dissertation research are given, an explanation is given. The problem of effectively solving the problems of dynamic planning and decision-making, as a new tool of modern information technology planning and forecasting, for the development of Smart City, as well as the insufficient level of scientific and methodological research of these issues, makes it relevant to conduct new in-depth research in this area. The statement of the research problem is given.

The formulation of TP tasks may differ in the following characteristics: the presence of links between tasks, the type of Smartcity development plan under construction (operational or early), the presence of various types of uncertainties and risks, the type of target functions and limitations.

*When building a dynamic Smart city development plan at various stages, it becomes necessary to solve the following main tasks:*

1. Tasks of information analysis. At this stage, the information is analyzed and the goals of building the plan (main and auxiliary) are determined, and their ranking is performed.

2. Tasks of constructing the structure of a dynamic plan (composition and number of stages). In addition, the possible variants of the plan are defined in detail, their structure and time limits for the plan.

3. Tasks of determining and accounting for uncertainties and risks of Smart city development.

4. Dynamic plan modeling tasks. The structure and parameters of the Smart city development plan are modeled.

5. Forecasting of the main planning indicators.

6. Making decisions and choosing the optimal variant of the Smart city development plan, taking into account all criteria and evaluating the effectiveness of the plan.

The second chapter defines the main tasks and stages of dynamic planning of Smart City development.

To solve the problems of effective dynamic planning of Smart City development and decision-making, an analysis of the external environment (analysis of the current situation) in which planning objects function is necessary. The external environment is defined as a set of economic, social and political factors and subjects that directly or indirectly affect the ability and ability to achieve goals in planning]. To orient oneself in the external environment in order to solve the tasks of dynamic planning of Smart City development, it is necessary to clearly define the main characteristics of the external environment (situation). The following main characteristics of the external environment can be determined]:

1. Complexity – the number and variety of factors that will affect the planning process of Smart City development;

2. Multiple relationships between factors, that is, the force with which a change in one parameter (factor) affects the change in other parameters of the Smart City development plan;

3. Dynamism – the speed at which changes in the external environment (changes in the situation) occur, and the speed of impact on the Smart City development plan, which is being developed initially;

4. Uncertainty (weak structuring).

The identification and processing of such information characteristics and the analysis of information to describe the environment indicates that it is necessary to apply a systematic approach and consider the external environment as a system or a set of systems that affect the Smart City development plan being developed. It is within the framework of this approach that it is customary to represent any objects in the form of a structured system, to highlight the elements of the system, the relationships between them and the dynamics of the development of the elements and the entire system as a whole. Therefore, the analysis and processing of information used to study the external environment and accumulate the necessary information for further use at various stages of dynamic planning of Smart City development should be considered as a necessary component of dynamic planning.

A sequence of solving dynamic planning problems has been developed. The mathematical formulation of the problem of dynamic planning of Smart City development is presented. The main steps of building dynamic plans for the development of Smart City are formalized. The proposed classification of the types of multicriteria selection tasks and mechanisms of multicriteria selection. The methodology and procedure of selection in the tasks of dynamic planning and decision-making on the development of Smart City have been developed. It is also shown that in order to ensure the effective solution of the tasks of dynamic planning of Smart City development, it is necessary to develop and use the following types of information technology: analysis and evaluation of information;

modeling of dynamic plans; forecasting; decision support. Based on the systematic use of methods: data analysis; modeling; forecasting; decision-making, a method of synthesis of information technology has been developed to solve the problems of dynamic planning of Smart City development. A methodology for using information technology for various types of Smart City development planning tasks is proposed. An example of decomposition in solving the problem of ranking factors into a hierarchy and creating a multi-layer model for evaluating the parameter of Smart City development is considered. As such a parameter, the energy efficiency of objects is considered and the process of ranking factors is described. The method of hierarchy analysis is modified by forming consistent matrices of paired comparison indicators in individual factors. It is shown that the use of the proposed methodology allows you to streamline, algorithmize and adjust the procedure for expert evaluation of different factors and improve the quality of the results obtained for the formation of the decision-making process during the dynamic planning of Smart City development.

In the third chapter of the dissertation, a method of effective project risk management in the course of dynamic planning of Smart City development, as well as modeling of project risk in a multi-project environment, is proposed.

The problem of risk management is extremely broad and important, because it arises in a variety of areas of human activity. Moreover, the concept of risk is defined differently depending on the scope of application, and it is in project activities (strategic planning, dynamic planning, project management and operational adjustments to the progress of its implementation) that a wide variety of types of risks arise.

In turn, the project type of management is becoming more and more popular, which is due to the dynamic development in the field of information technology, since, in fact, activities in this area are unique, products are updated quickly, effective coordination of available resources is necessary to achieve the goal, and time limits are clearly defined for each product – whether it is for an information system (IS) or for a specific object of informatization (OI). In particular, we are talking about software or hardware projects for local tasks of energy and water distribution management, environmental monitoring, road conditions, etc. in Smart City.

That is why the problems of research and risk management in the dynamic planning of Smart City development and related project activities are important and relevant from both theoretical and practical points of view.

Simulation modeling was performed to test the effectiveness of the method. Examples of effective resource allocation between two IT development projects for Smart City in a multi-project environment are considered. It is established that the described method is advisable to use for the distribution of non-renewable resources between projects operating in a multi-project environment in a competitive environment.

A model is proposed for the computational core of the decision support system (DSS) when assessing the risks of investment loss during the dynamic planning of Smart City development. Unlike existing solutions, the proposed

model provides specific recommendations when assessing the risks of investment loss during dynamic planning of Smart City development, based on the use of mathematical apparatus of multistep degree games and quality games with multiple terminal surfaces. With an unsatisfactory risk forecast, flexible adjustment of the parameters of the investment process is possible in order for the parties to achieve an acceptable financial result.

It is shown that a distinctive feature of the considered approach is the use of tools based on solving a bilinear multistep game of both quality with several terminal surfaces and a game of degree solved in the class of mixed strategies. Computational experiments were carried out using the Maple mathematical modeling package.

The practical significance of the results obtained lies in the fact that the DSS has been developed. The DSS implements a risk assessment model based on the application of methods of the theory of multistep games. The developed DSS makes it possible to reduce the discrepancies between the data of forecasting the risks of investment loss during the dynamic planning of Smart City development and the real return on investment.

In the fourth chapter, practical aspects of the software implementation of a multi-module decision support system were considered during the consideration of dynamic planning tasks based on group decision-making methods.

When designing a decision support system to solve the problems of dynamic planning of Smart City development and management decision-making, it is necessary to combine into a single system all functional modules that provide the planning and decision-making process.

The chapter presents the structure of the DSS for solving the problems of dynamic planning and decision-making made during the analysis of individual Smart City development projects. The developed DSS consists of several subsystems and provides for modular-block construction. Such a DSS architecture made it possible to implement it quite flexible, which makes it possible, if necessary, to supplement the already implemented solution with new functional modules focused on performing computational and analytical tasks that arise during the dynamic planning of Smart City development. The minimalistic interface of the DSS makes the process of communication between the users of the DSS and the internal elements of the system simple and intuitive, and provides input and output of information for the decision maker (DSS).

The interface for the DM is separated from the data storage subsystem. Such an organization of data storage and retrieval during the calculation provides an opportunity to choose the optimal data management system for a specific practical task and removes the need for future structural transformation of the DSS when introducing new, more modern DBMS.

The main subsystem of the DSS, through the selection menu of the corresponding module, ensures the implementation of the analysis process and the solution of a specific task in accordance with the general structure of solving multi-purpose tasks. At the same time, for the implementation of certain procedures, the corresponding modules that are part of the subsystem of functional modules are

connected and applied. Such modules are designed to implement the developed methods and approaches used in the process of multi-purpose decision-making, and provide for the possibility of further improvement and development of this software product without the need to adjust other elements of the DSS.

The architecture of the developed DSS is easily modified to solve other decision-making tasks, as well as to the possibilities of using other methods of multi-purpose optimization and decision-making.

The main form of a multi-module DSS for the tasks of dynamic planning of Smart City development, designed as an MDI application. All modules are implemented in C# in the Visual Studio 2019 programming environment.

The software solution and the main forms for the DSS module, which is implemented in C, are described# :

- modified hierarchy analysis method. The software implementation of the modified hierarchy analysis method carried out by forming consistent matrices of paired comparison indicators in individual criteria (or factors), creating a consistent matrix of comparison factors and determining a global criterion based on factor-indicator estimates;

- a model for assessing the risks of investment loss during the dynamic planning of Smart City development.

Unlike existing solutions, the proposed model and its software implementation provide specific recommendations when assessing the risks of investment loss during dynamic planning of Smart City development. The module is implemented on the basis of using the mathematical apparatus of multistep degree games, and quality games with multiple terminal surfaces. It is shown (for example, evaluating a project related to the energy efficiency of Smart City development plans) that with an unsatisfactory risk forecast, flexible adjustment of the parameters of the investment process is possible in order for the parties to achieve an acceptable financial result.

In conclusion, the main results and conclusions of the dissertation research are presented. The level of reliability and the results of testing. The validity and reliability of the study correspond to the reasoned responsibilities of the task, the analysis of criteria and the state of research in this area, a large number of experiments conducted and their successful implementation in practice.