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CHOOSING AN INVESTMENT STRATEGY FOR SMART CITY PROJECTS BASED ON A GENETIC ALGORITHM

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ABSTRACT

This paper presents a genetic algorithm (GA), which is adapted to solve the problem associated with obtaining a predictive assessment of benefit from different areas of investment in Smart City projects. The application of the proposed GA provides potential investors with predictive assessments of the prospects of the selected investment strategies at the stage of assessing the attractiveness of individual projects related to the development of Smart City. This is achieved by identifying significant growth drivers for the benefit from investment in the Smart City, as well as tracking points of growth and structural changes in the urban economy. The application software was developed based on the GA described in the paper. A series of computational experiments on the selection of rational strategies for investors in Smart City projects was conducted. Based on the data of computational experiments, a conclusion about the operability of the proposed GA in the task of forecasting the attractiveness of investment strategies in Smart City development projects was made.

Keywords: *Investment Strategy; Projects; Smart City; Genetic Algorithm; Decision Support*

1. INTRODUCTION

As shown by analytical studies of the past few years [1, 2], the trend to increase the number of investment projects in the technology of "Smart Cities" (hereinafter referred to as Smart City), remains relevant. And the very area of investment in Smart City technology is becoming increasingly attractive for both large companies, such as Siemens AG (Germany); ABB Group (Switzerland), Cisco Systems, Inc. (USA), Schneider Electric (France), etc., and for individual independent investors. This is due, not least of all, to rapid urbanization and the widespread implementation of information technology (IT) into urban infrastructure.

According to [3, 4], the Smart City concept in one form or another has been implemented in about two and a half thousand cities around the world. However, the Swedish IT company Easy Park singles out only 500 "smart" cities in its own famous Smart City Industries index.

However, this Smart city concept has not been implemented in many places, according to an important number of sceptics. Basically, it is a set of individual elements of the "Smart" city: Wi-Fi points; the use of smartphone apps; various sensors and detectors; automated parking meters; waste management services; tracking stolen bicycles and the like.

Easy Park IT company conducted a study in 2019, according to the results of which a list of the "smartest" cities on the planet is given [4]. The main criteria for evaluating cities were: 4G, 5G mobile communications system; a large number of wireless network access points (eg, Wi-Fi, LoRa); smart phones and tablets as a universal means of service management; "Smart Parking"; car sharing services (short-term car rental); optimized traffic system; online access to public services; waste

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recycling; active social attitude of citizens; clean energy sources.

Currently, the issue of choosing a rational (optimal) strategy for investment in IT in the management of urban economy is of particular importance for the many municipalities, which set ambitious goals for the development of digital technology to improve the quality of life of citizens. According to many experts [5, 6] in the field of infrastructure development of municipal systems, it is information and communication as well as geographic information systems that can dramatically improve the quality of life of urban residents, in particular through the integration of digital technologies and a new generation of electronic devices in a variety of products and services in the field of electricity and water supply, environmental monitoring, transport logistics, security, health, waste recycling, etc., see Fig. 1.

The processes of investment in Smart City technology and systems, in particular in IT, belong to the category of risky enough [6, 7]. It is necessary to use the potential of computer technology and application software in such tasks, according to many experts involved in the theoretical development of the problem of investment. It is the application software that can take on a significant part of the routine work associated with the enumeration of multiple options in the analysis and selection of a rational strategy for investors. However, the question remains of filling this kind of application software with appropriate algorithmic and modelling components for analysts. At the same time it is necessary to strike a balance between the accuracy of calculations when choosing a rational investment strategy and calculating speed. Let us note that genetic algorithms can provide such a balance in the context of the problem to be solved.

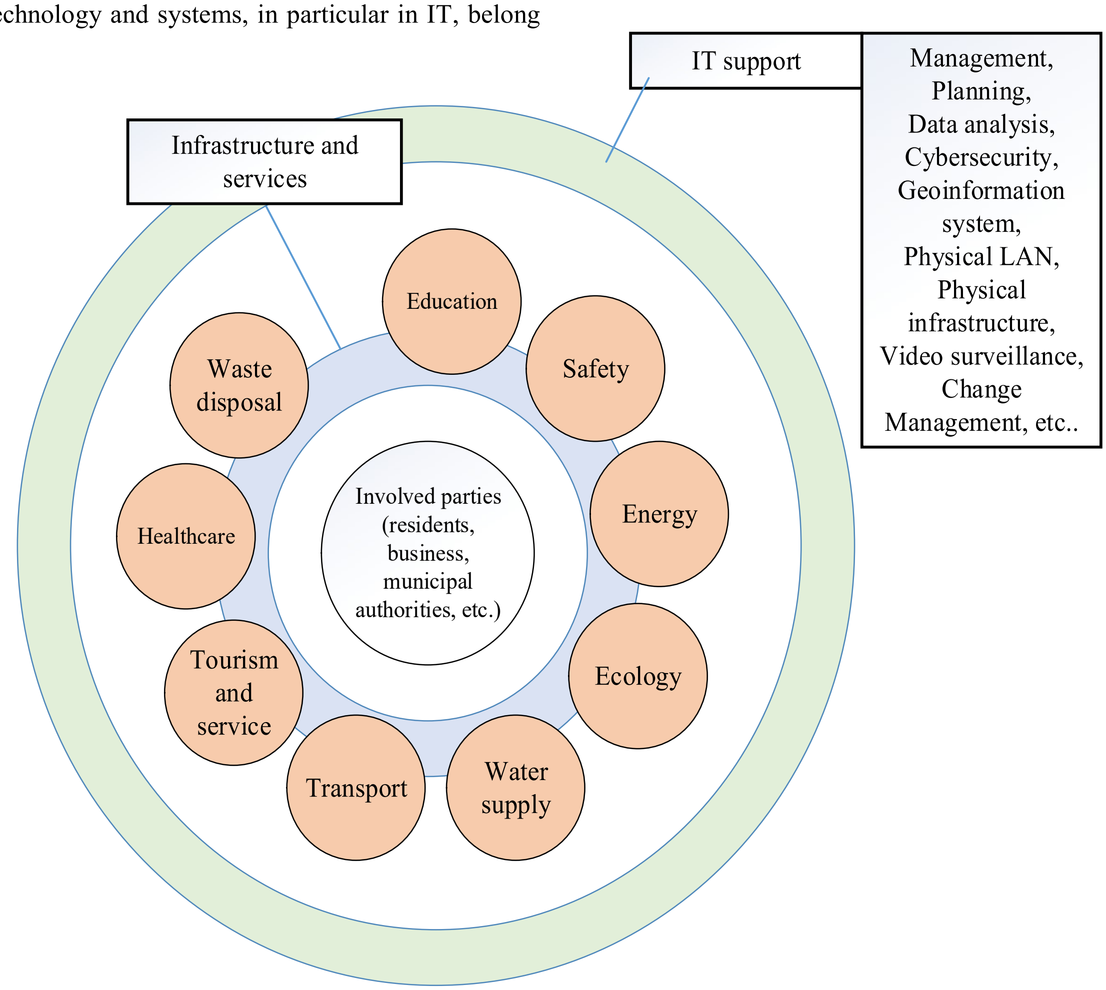

Figure 1: Outlines of investors' interests in applied tasks solved in the development of Smart City

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Many types of existing application software on the market for analyzing investment projects, including those related to Smart City, do not allow to optimize procedures related to finding different investor strategies [8]. Therefore, the task of synthesizing new models and corresponding algorithms used in the decision support for the search for rational investor strategies is still relevant. This will allow to adequately describe the real processes of investing in Smart City projects resulting from the increasing level of competitiveness of various players in this market.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

Over the past few years, many researchers have devoted their work to the problem of selecting effective investor strategies for projects related to Smart City, such as [9–11].

As shown in [9, 11], the successful development of Smart City can be based on the integration of all technological components of the Smart City infrastructure into an integral whole.

As shown in [12, 13], the formation of the Smart City concept is associated with the creation of strategies aimed at solving the problems caused by the growth of urban population and rapid urbanization. However, these studies were rather descriptive and did not contain specific algorithmic and mathematical methods for achieving the goals by investors in Smart City projects.

Various papers show that the Smart City concept accepts the priority role of artificial intelligence systems [14], ICT [15], social and environmental potential [16] as a resource for the development and competitiveness of a dynamically developing city.

As shown in [3, 4], Smart City investments become a link in the task of creating a comfortable living environment, and contribute to improving the intellectual and educational skills of the population. And besides that, there is a growing interest in innovation and productivity of businesses and organizations within this environment.

As shown in [12, 14], new IT that includes the widespread use of smartphones, the growing popularity of online transactions and P2P technologies will enable Smart City municipalities to interact effectively with citizens.

As shown in [17, 18], a sufficiently effective approach in solving such class of problems is the use of game theory. First of all, we are referring first to such a branch of game theory as multistep quality games with multiple terminal surfaces [17]. However, it should be noted that complex application game models are characterized by both high-dimensionality of the space of control parameters and of the criteria space. Moreover, if we consider a group of investors in Smart City development projects as a coalition, then the components of the vector performance indicators of the evaluation of such a coalition are characterized by nonconvexity and gaps. When considering complex investment projects, the game model in its pure form makes it rather difficult or impossible to use conventional game models, as well as well-known optimization methods. As a result, new approaches to solving this class of problems are required. For example, based on the use of genetic algorithms.

In [19, 20] the possibilities of using genetic algorithms (GA) for solving problems related to the choice of investor strategy are considered. In these papers, GA supports a population (a group of chromosomes) that is a contender for an optimal solution. Through probabilistic operators, the authors of these studies sought to obtain the populations best suited to the conditions set for a particular task. However, the GA data represented, in fact, simple operations of exchanging and copying parts of chromosomes. This approach does not always help for such a subject area as the procedure for investing in complex projects.

In many studies [2, 8, 9, 17, 18] the authors show that the prerequisite for effective implementation of economic performance management mechanisms of cities is a qualitative assessment of the return on investment in the development of Smart City innovative technologies and industries. Such information can provide municipal authorities with data for a more detailed determination of the points of growth of the urban economy. Moreover, it becomes possible to monitor unfavourable trends for the development of the urban economy. In [8, 9], the authors showed that most municipalities developed mainly short-term forecasts of urban infrastructure development. The lack of predictive assessments of the dynamics and prospects of development of various investment projects for Smart City, rational or optimal options for the development of various projects and areas (see Fig. 1), can generally lead to the

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Table 1 – Coding variables for the task of finding a rational investment strategy in Smart City

No.	Parameters	Designation
	Growth of the benefit on investment in the Smart City economy	PrG
	Investment areas (indicators)	X_i
1	Energy	X_1
2	Water supply	X_2
3	Transport	X_3
4	Ecology	X_4
5	Safety	X_5
6	Tourism and service	X_6
7	Healthcare	X_7
8	Waste disposal	X_8
9	Education	X_9
10	Smart housing and communal services	X_{10}
11	Smart lighting	X_{11}
12	Integrated automation	X_{12}
13	Smart parking	X_{13}
14	Social services	X_{14}
15	Remote infrastructure management	X_{15}
16	Smart city management	X_{16}

wrong choice of priority areas of urban infrastructure development. Or difficulties associated with the wrong strategy for the placement of funds for investment projects can be generated. This implies the need to strengthen the potential of the forecasting function, for example, based on the use of GA.

As shown by the analysis of the mentioned publications [8, 10, 11], the authors in most cases did not offer any real recommendations in the search for rational strategies for the investment of such large projects.

The above has led to the problem associated with the need to develop new GA-based models for intelligent information systems (IIS) [12] in the task of determining the rational strategies for financial investment in Smart City projects. Analysis of publications on this topic confirmed the relevance of further development of GA (hereinafter referred to as GA) in the task of selecting the rational strategies of investors in the Smart City development projects.

As follows from the analysis of the works' materials [1, 8, 14, 15, 17], it was found that with the development of information technology (IT), all major cities started to consider the possibilities of IT potential use to simplify the municipal infrastructure management systems, as well as to use it in other areas of urban life. Therefore, the IT investment sphere for Smart City is potentially one of the most attractive for investment projects implementation.

3. GOALS AND OBJECTIVES OF THE STUDY

The goal of this work is to adapt a genetic algorithm for the task of obtaining a predictive assessment of benefit from different areas of investment in Smart City projects.

To achieve the goals of the study, the following tasks should be solved:

1) Adapt the GA for the specified task by identifying significant growth drivers for the benefit from investment in the Smart City projects, tracking points of growth and structural changes;

2) to develop and test in the course of computational experiments application software based on an adapted GA for the selection of rational strategies for investors in Smart City projects.

4. MODELS AND METHODS

Based on the data from [1,2,6,8], as well as analytical reports [3,4], we will identify areas of investment (indicators) that affect the growth of the benefit on investment in the Smart City economy.

The names of these areas of investment (indicators), as well as a list of variables put in line with each of the areas that investors are interested in, are shown in Table 1.

It is assumed that each investment area can contribute to the growth of production in a conditional Smart City.

We will assume that PrG in Table 1 is a parameter characterizing the growth of the benefit on investment in the Smart City economy. The parameter PrG is accepted in monetary terms and is considered as a variable dependent on X (areas of investment in Smart City technology).

The genetic algorithm should enable the implementation of the following procedures during data processing:

calculate the increase PrG ;

define threshold values PrG ;

convert values PrG into binary form;

convert indicator values X_i into binary form;

determine the error rate for the classified sequence PrG ;

determine the list of areas of investment in Smart City technology that can ensure the greatest growth of its economic indicators. At the same time it is necessary to minimize the error rate for PrG.

The value of the parameter PrG – the growth of the benefit on investment in the Smart City economy – can be generally determined on the basis of the models presented in [17,18]. The above papers consider in detail the solutions of differential equation system for a bilinear dynamic quality game with multiple terminal surfaces. This solution made it possible to determine the initial forecast data on the growth of the benefit on investment in the Smart City economy.

Figure 2 shows the Investor preference set. This set is formed by points on the terminal surface. Also, in order to find a rational strategy, it is necessary to further investigate the information concerning the financial resources of the participants in the investment project.

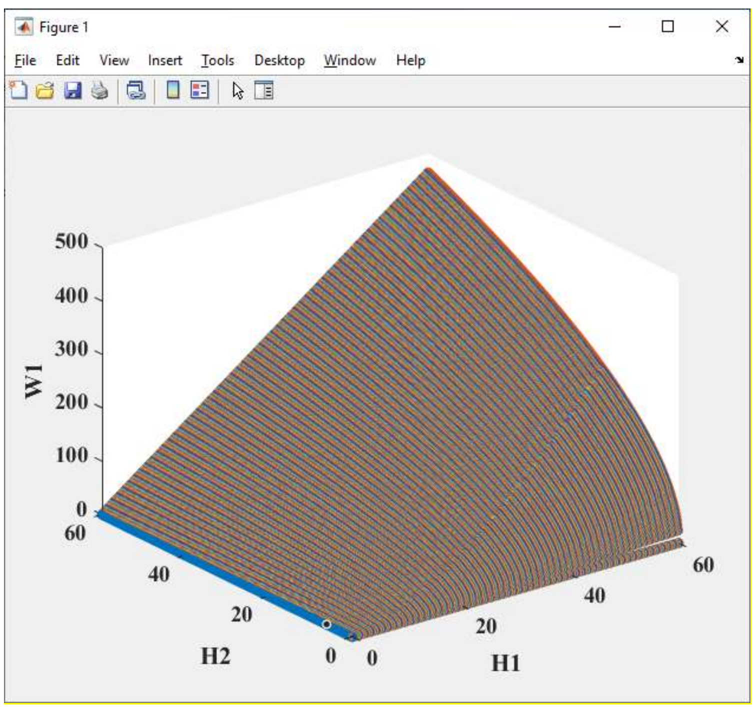

Figure 2: Investor preference set [17, 18]

We apply binary coding in order to present the predictive assessments for a certain time period. So if the result of solving a bilinear dynamic quality game with multiple terminal surfaces shows an increase in profits for investors in the Smart City economy, then the binary code indicator is assumed to be 1. If the growth forecast is zero or negative, the indicator is assumed to be 0. An example table with binarization results is shown below.

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Table 2 – Binarization results of growth indicators of benefit from investment in the Smart City economy

Area (see Table 1)	**The projected value of the growth of benefit from different areas of investment in Smart City economy in certain areas**	**Indicator**
1	+25 (example of calculated value based on models [17,18])	1
2	–10	0
…	…	…
16	+5	1

Let us perform encoding for variables. As an example, let us consider a chromosomal filament containing two genes, X_1 and X_2, from Table 1. These are, respectively, areas of investment in energy and water projects for Smart City. We will assume that each gene is 16 bits long. Therefore, the chromosomal filament will contain 32 bits, see Fig. 3.

X1

1	0	0	0	1	0	1	1	0	1	1	1	0	1	1	0

X2

0	0	1	1	0	0	0	1	1	1	1	1	1	0	1	1

Figure 3: Chromosome coding result

Figure 3 shows the binary code for the chromosomes X_1 and X_2 derived from the translation of data from the example of predictive assessment of the growth of investor financial resources in Smart City for the case of investment projects in areas related to energy (Smart Grid) and water supply. Calculation of the predictive assessment is based on the models [17, 18].

The developed GA should support the N chromosomal filaments forming a population. During each iteration, a selection will be made from the population of chromosomes best suited for further development. These chromosomes form pairs of parents. Then, according to the classical crossover operator, a new generation of descendants is reproduced. Accordingly, the descendants will inherit the best parental genes. Gene diversity will provide the mutation operator. Its application provides for exploring new areas in the search space for a combination of areas of investment in Smart City projects.

In the selection process, the copies of chromosomes that demonstrate the greatest fitness will survive. Chromosomes with lower fitness will be excluded from progeny reproduction procedures. The probability of selection can be defined as follows:

$$P_i^{sel} = \frac{F_i}{\sum_{j=1}^{N} F_i}, \qquad (1)$$

where $F -$ is the value of the fitness function when analyzing the $i-^{\text{th}}$ area of investment in Smart City projects; $N -$ is number of chromosomes.

The crossing point was determined randomly. After that, the contents of the corresponding bits located to the right or to the left of this point are exchanged with another split chromosome.

An example for parental chromosomes $N1, N2$ is shown in Figure 4. Crossing point is shown with a yellow fill.

N1

1	0	0	0	1	1	1	0	1	1	1	0	0	1	0	0	1	0	1	0	0	1	0	1	1	0	0	0	1	1	0	0

N2

0	1	1	1	0	0	1	0	1	0	1	0	0	0	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	1

Figure 4: Example for parental chromosomes $N1, N2$ with a crossing point

Journal of Theoretical and Applied Information Technology
15th February 2022. Vol.100. No 3

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Assuming that the bit exchange takes place to the right of the crossing point, we get the picture for the descendants shown in Figure 5.

Replaced fragments of chromosomes are shown by fountain fill. Accordingly, for the first descendant (*N1 ᵖ*), the fill is light green. For the second descendant (*N2 ᵖ*), the fill is blue.

N1 ᵖ

1	0	0	0	1	1	1	0	1	1	1	0	0	1	0	0	1	0	1	0	0	1	1	1	1	1	0	0	0	1	1	1

N2 ᵖ

0	1	1	1	0	0	1	0	1	0	1	0	0	0	1	1	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	0

Figure 5: Example of the formation of descendants

Next, a mutation is implemented, which is a random process that will modify the chromosome binary code by changing the value at a certain bit position. For example, if we assume that for chromosome *N1ᵖ* the mutation changes 9 bits from 1 to 0, respectively, the entire descendant chromosome will look like the chromosome shown in Fig. 6.

N1 ᵖ

1	0	0	0	1	1	1	0	0	1	1	0	0	1	0	0	1	0	1	0	0	1	1	1	1	1	0	0	0	1	1	1

Figure 6: View of the descendant chromosome N1 ᵖ after gene mutation

Once the operators for selection, crossing and mutation have been implemented, it is necessary to perform a directed search. Such a search is implemented on the basis of the rule that each of subsequent generation will inherit only the best patterns of previous generations. And this rule should be implemented based on the need to move towards the optimal choice for investors. Thus, as a result, a subset of points containing the solution of the problem will be formed. For these points, their deviation from the target function is minimal.

It should be noted that highly nonlinear problems can be solved using this combined approach to the problem of finding investment strategies with maximization of the benefit from the financial resource for investors. And it is important that we do not depend on the type of the target function. The solution found will be quasi-optimal and close to holistic one. The general scheme of implementation of the GA proposed in the study is shown in Figure 7.

The main stages of solving the problem of selection of rational strategies for investment in Smart City technology with the help of GA are discussed below.

1. Initialization. An initial population containing N chromosomes is generated. Chromosomes are represented in binary code. Input data for encoding are data obtained during the process of solving as a multistep quality game with multiple terminal surfaces [17].

Journal of Theoretical and Applied Information Technology
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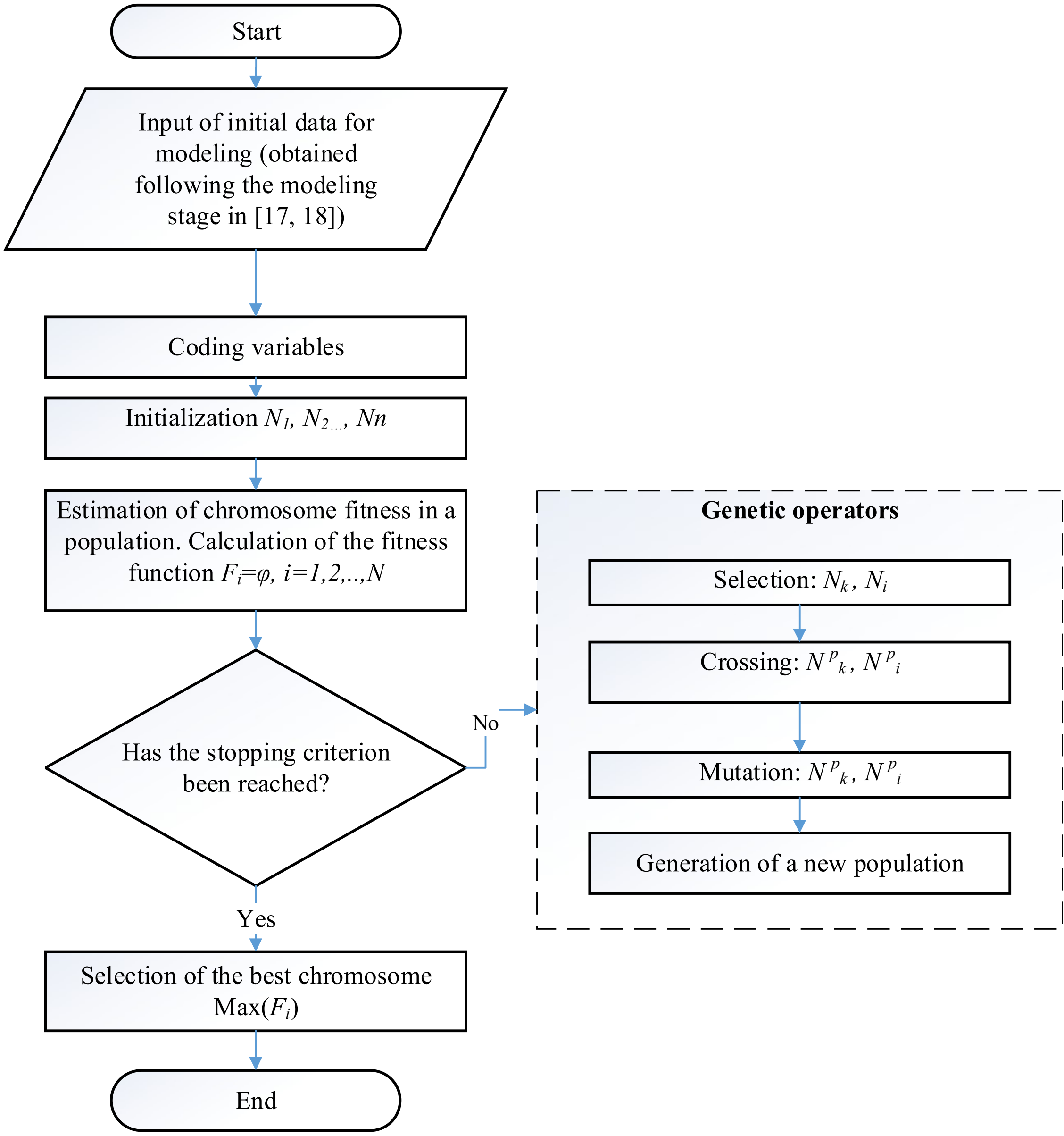

Figure 7: Block diagram of the genetic algorithm for solving the problem of the selection of a rational technology investment in Smart City technology

2. An assessment of chromosome adaptation in the population is performed. The fitness function (the target function in the general case) is calculated. As a target function, the predictive values of benefit from investment in certain areas of Smart City development are taken. The target function is determined for each chromosome.

3. Reproduction. The following steps 3.1–3.4 are performed. It shall be implemented until a new population consisting of N chromosomes is created.

3.1. Selection. We select two parental chromosomes from the population with a probability of P_i^{sel}.

3.2. Crossing. Let us determine whether there is a need to perform a crossing operation. If required, we will exchange bits at random positions. For either option (whether crossing is realized or not), the chromosomes will pass into the descendant category.

3.3. Mutation. For descendant chromosomes, we randomly replace the selected bit.

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3.4. Generation of a new population. A new population is being generated. Here, the principle of "elite" selection will be applied.

4. Replication. The process is reproduced according to point 2 until the conditions for the algorithm's termination are reached.

5. We select the "best" chromosome, which characterizes the priority areas of investment projects, from the investor's point of view. As well, for these areas the benefit from investment will be maximum.

This algorithm was implemented as a software product (SP) in the algorithmic language C#.

5. DESCRIPTION OF THE SOFTWARE PRODUCT AND COMPUTATIONAL EXPERIMENTS

Figure 8 shows the general view of the SP interface in which the above described process of selecting a rational investment strategy in Smart City technology is implemented. GA testing was carried out on an *i*3 processor PC.

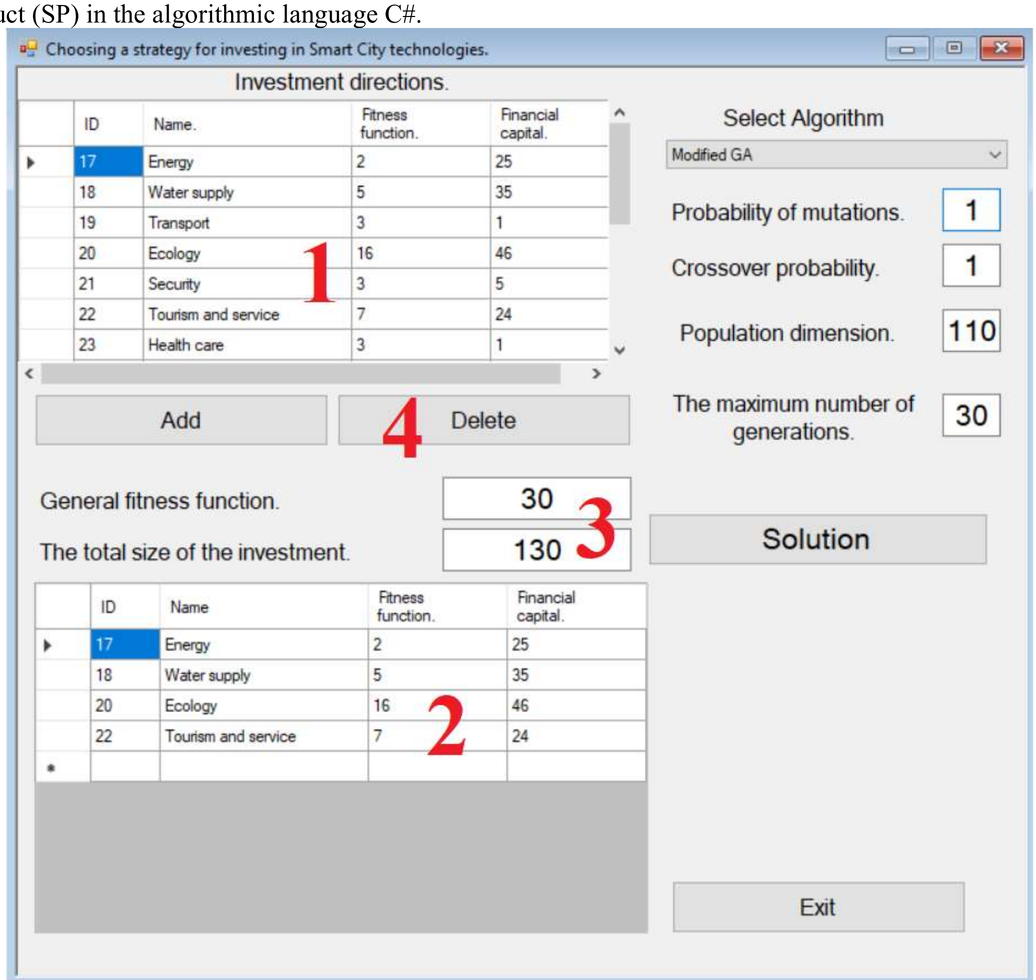

Figure 8: General view of the SP interface in which the process of selecting a rational investment strategy in Smart City technology is implemented

Figure 8 shows the following interface blocks with red numerals: 1 – List of investment areas in Smart City technology (the list is formed on the basis of preliminary calculations using the differential equation system for a bilinear dynamic quality game with multiple terminal surfaces [17, 18]); 2 – The selection response through the GA of investment areas that will make a rational investor strategy; 3 – Limitations for GA operation (population size, population crossingover and mutation probability, etc.); 4 – controls.

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6. DISCUSSION OF THE RESULTS OF COMPUTATIONAL EXPERIMENTS

In the course of computational experiments, the following game for choosing a rational strategy for investment in Smart City technology was considered. Two players (investors) consider the results of a predictive assessment of the attractiveness of investment strategies in Smart City projects. The winner is the player who has more positions corresponding to indicator 1, i.e. this investment area is more profitable according to data of the models [17, 18]. Figure 9 shows the time required for the selection of investment strategies based only on finding solutions using a system of differential equation system for a bilinear dynamic quality game with multiple terminal surfaces and for the combined approach. In the combined approach, at the first stage, statistics are collected for the variants of the solutions with the help of a system of differential equation system for a bilinear dynamic quality game with multiple terminal surfaces, and directly processing and finding the final rational investor strategy is performed with the help of GA.

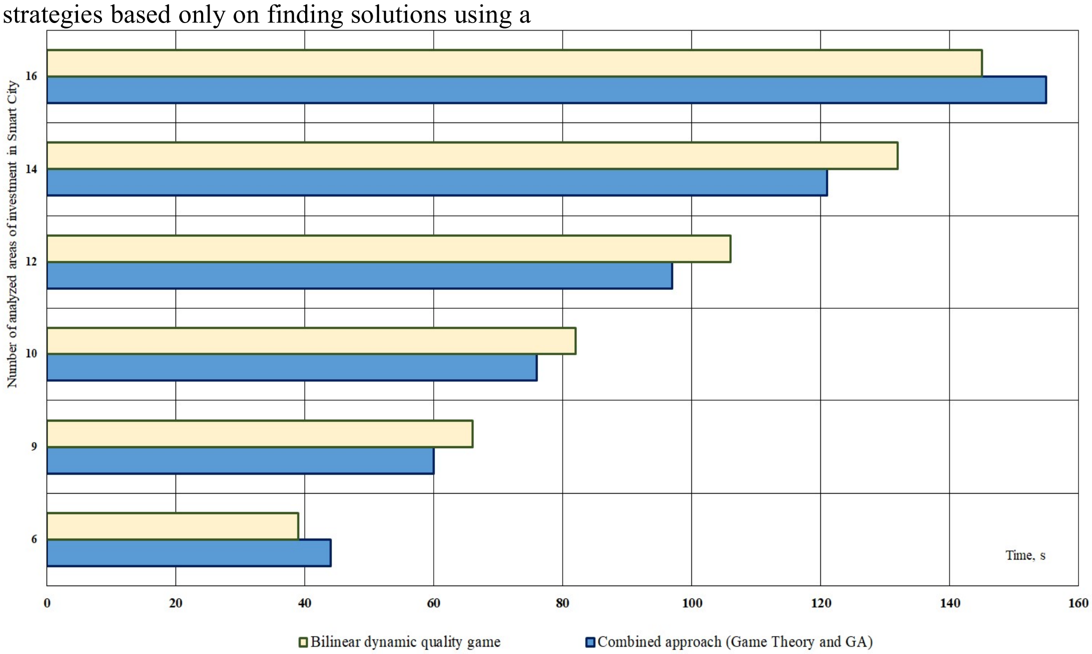

Figure 9: Time spent on the selection of investment strategies

The combined approach shows a shorter time for finding solutions. It is by about 15–17%. It can be explained by the following circumstance.

The points make it possible to determine the set of preferences of the first investor in the IB. It happens as follows. If we use only the apparatus of bilinear dynamic quality games, then each point corresponding to the investor's strategy will represent sets of certain components. These components correspond to the financial resources of investors. The sets of points that will be located on the terminal surface of each investor will characterize the selection of specific investment programs. For example, it can be programs of energy-saving technologies, water security, etc. I.e. the solutions themselves on the basis of application of the differential equation system for a bilinear dynamic quality game with multiple terminal surfaces give quite a large scatter of variants of points on the terminal surfaces of investors. Additional time is required to analyze these points and search for the area of preference of the investor. At this stage, the use of GA simplifies and minimizes significantly the search time for such points, and hence the rational strategy of the investor as a whole [21–23].

This GA is used to implement the fifth stage of the combined computational procedure as an additional tool for reducing the uncertainty of the set of stable generalized ε–equilibria of the game (1). The structure and features of this GA are considered in [6–8].

Thus, the GA presented in the paper can be used to reduce the time during the solution of the problem of finding rational (optimal) strategies

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of investors based on game models, in particular in conditions of conflict and uncertainty concerning information about financial resources of investors, etc.

7. CONCLUSIONS

In the paper, the following main results were obtained.

A genetic algorithm was proposed for the task of obtaining a predictive assessment of benefit from different areas of investment in Smart City projects. This allows potential investors at the stage of assessing the attractiveness of individual projects related to the development of Smart City, to obtain predictive assessment of the prospects for the selected investment strategies by identifying significant growth factors of benefit from investment in Smart City, as well as tracking points of growth and structural changes. Application software has been developed based on the GA described in the paper, and a series of computational experiments have been conducted to select rational strategies for investors in Smart City projects. Based on the data of computational experiments, a conclusion about the operability of the proposed GA in the task of forecasting the attractiveness of investment strategies in Smart City development projects was made.

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