YE.A. SAVCHENKO-SYNYAKOVA, PhD (Eng.), Senior Research Associate,
International Research and Training Centre for Information Technologies and Systems
of the NAS and MES, Kyiv, Ukraine, Glushkov Ave., 40, Kyiv, 03187, Ukraine,
savchenko_e@meta.ua

O.V. TUTOVA, PhD (Econ.), Senior Research Associate, International Research
and Training Centre for Information Technologies and Systems of the NAS and MES,
Kyiv, Ukraine, Glushkov Ave., 40, Kyiv, 03187, Ukraine,
olenatutova@gmail.com

H.A. PIDNEBESNA, junior research scientist, Department for Information Technologies
of Inductive Modelling International Research and Training Centre for Information Technologies
and Systems of the NAS and MES, Kyiv, Ukraine, Glushkov Ave., 40, Kyiv, 03187, Ukraine,
pidnebesna@ukr.net

APPLICATION OF THE CORAL GMDH ALGORITHM FOR MODELING AND FORECASTING THE NATIONAL INCOME OF UKRAINE

CORAL GMDH is a method of the inductive approach. In this article it is used for modeling and forecasting socio—economic processes. Here the CORAL GMDH algorithm is applied to solve three problems: recovery of missing data, modeling of macroeconomic indicators, and forecasting the gross national income (GNI). Also the CORAL GMDH algorithm is used to build models in the problem of modeling the dependence of GNI on socio-demographic indicators and develop recommendations on how the state can influence the level of human capital development in the country by influencing certain socio-demographic indices. All three tasks have been solved for Ukraine, Belarus, and Poland.

Keywords: *recovery of missing data, modeling, forecasting, gross national income per capita, CORAL GMDH, domestic health spending, socio-demographic indicators.*

Introduction

According to a study of economic growth factors conducted by the World Bank (WB) in 192 countries, 64% of countries achieve economic growth thanks to human capital, and only 16% of countries — due to the use of productive potential, and 20% — owing to natural resources. Therefore, the structure of national wealth of many developed countries is dominated by human capital, which constitutes from 2/3 to 3/4 of the total national wealth [1].

The Government of Ukraine considers an increase in the position of the Human Development Index, reducing mortality and poverty as the main indicators of the effectiveness of work in this direction [2].

Education, health care and their connection with the creation of general economic well-being of the people or the state can be considered as the main levers of influence on the development of human capital [1].

The state of human capital development in Ukraine in the field of education, science and

innovation should be analyzed in comparison with the parameters of other countries. According to the ranking of countries based on the value of the Human Capital Index of the WB in 2018, Ukraine ranked 50th among 157 countries. The top three in the ranking were: Singapore, Japan, and South Korea.

According to the United Nations (UN) HDI, Ukraine belongs to the group of countries with a high level of human development, ranking 88th out of 189 countries in 2017. The top three in the ranking are: Norway, Switzerland, and Australia.

In the World Economic Forum Global Human Capital Report, which calculates the Global Human Capital Index (GHCI) and provides a comprehensive assessment of the country's human capital — both current and expected, Ukraine in 2017 took 24th place among 130 countries. The top three in the ranking were: Norway, Finland and Switzerland.

Regarding the rating places of Ukraine according to separate sub-indices of GHCI, their analysis shows high rating places of the country in terms of quantitative indicators of education (general level of education, coverage of children with different levels of education correspond to the 5th rating place), but in terms of quality indicators already significantly worse (quality of primary education — 47th place, quality of the education system — 51st place). According to the indicators of the employment market and skills of employees, the ranking places are even lower: 88 — by the level of employment in the age category 25—54 years, 89 — by investments in staff training, 57 — by the variety of graduates' skills, 40 — by economic complexity.

The above positioning of Ukraine in international rankings shows that the availability of educated able-bodied human resources remains a competitive advantage of the national economy, and the state of its use and balanced development is a determining factor in strengthening its innovation capacity. However, Ukraine is inefficiently using its innovation and scientific potential for economic growth and competitiveness at the regional (sub regional) and global levels. In addition, the long-standing mismatch between human capital development and gross domestic product levels encourages the outflow of young people and highly skilled professionals, including scientists and inventors.

In conditions of intensive changes in economic and social life it is extremely important to have a scientifically substantiated direction of the country's development, first of all — the development of productive forces as a system of personal (human, human potential, human capital, intellectual capital) and material (reproductive and natural capital) elements. After all, it is in the process of combining human and natural capital that production is carried out, the economy is built and developed [3].

Creating the necessary basic conditions for a comfortable and safe life, opportunities to realize the potential of citizens is one of the most important functions of the state. It is the qualitative development of human capital that is the basis for the growth of the national economy and the strengthening of Ukraine's competitive position in the world [4—15].

The main indicators of the effectiveness of work in this direction, the Government of Ukraine considers an increase in the position of the HDI, reducing mortality and poverty [2].

Ukraine's participation in international rankings and indices that assess the state of human capital development, serving as a tool for international comparison of countries, allows us to see the weak points that should be focused on in shaping public policy in relevant areas.

To achieve the priority goal, that is sustainable development of human capital in Ukraine; a number of transformations in key social fields are needed: ensuring equal access of citizens to quality medical services by creating a new health care system based on health insurance, reforming and improving health care; transformation of Ukrainian education into an innovative environment; pension reform; improving the effectiveness of social support.

Thus, the main levers of influence on the development of human capital can be considered education, health care and their connection with the creation of general economic welfare of the people or the state [1].

In 2015, the 193 member states of the UN adopted the 2030 Agenda for Sustainable Development.

The agenda identified 17 Sustainable Development Goals (SDGs). Of the 17 goals, many address health indirectly, while SDG3 focuses directly on health, with the objective being to "ensure healthy lives and promote well-being for all at all ages" [16].

The aim of this study is to assess the impact of socio-demographic gross national income (GNI) as a key indicator describing the level of economic development. These indicators characterize the state of the health care system, causes of death, and the level of overall health care coverage.

Thus, the aim of this article is to apply the CORAL GMDH algorithm to build models in Introduction.

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Review of the Application of Intelligent Modeling Methods for Solving Economic Problems

The methods of intelligent modeling are widely applied for scientific, research, educational, and commercial use.

There are many companies in the commercial field nowadays that proclaim that they develop intelligent models. They state that their mission is to create tools and methods that enable cost-effective application-oriented innovations about humans and their environments and blend together converging multi-disciplinary discoveries into actionable knowledge. They use tools and expertise to help their customers shorten the innovation cycle, develop offerings of high practical importance, and bring better products to the market faster. They use advanced technologies, mathematics, and concepts to create powerful informational models. [17] overviews the way how the methods of intelligent modelling are applied for commercial use.

Different highly inter-disciplinary research groups focus on the development of models and techniques for real-world and multifaceted problems in data analysis. They include researchers from a variety of backgrounds including computer science, the biomedical sciences, operational research, mathematics, statistics and complexity science.

They use a range of techniques for end-to-end data modelling and analysis including:
- Artificial Intelligence-based Data Mining;
- Bio-Inspired Algorithms;
- Computational Modelling;

- Discrete and Agent-Based Simulation;
- Fuzzy Methodologies;
- Multi-Sensor Data Fusion;
- Qualitative Methods including Structured Interviews.

The methods of intelligent modelling are used in projects in various fields including digital economy and sustainable development [18—21]. The main research objectives of these projects are:

— Modelling and representation of challenging problems, with particular emphasis on biomedical and digital economy application domains;

— Creating cutting-edge analysis methodologies, both for general purposes and specifically tailored to the main application domains;

— Focusing on difficult, challenging and important real-world problems, with particular emphasis on large and noisy data sets.

Target Setting for the Problem of Assessing of Social and Demographic Indicators' Impact on the Economical Growth

The primary task for solving the problem of assessing the impact of factors describing the state of the health care system and the socio-demographic situation on economic development in Ukraine is the selection of relevant socio-demographic indicators. [22—26] presents the results of studies conducted as part of a comprehensive regional and/or global medical statistical study, combined under the name Global Burden of Disease 2019 (GBD). GBD is a group of indicators that characterize mortality and disability from major diseases, injuries and their risk factors. At present, GBD is the result of collaboration between researchers from 152 countries.

GBD allows to show clearly how the difference in the organization of health care, financing of medical care, its availability, levels of economic development are transformed into morbidity, disability, mortality and their consequences [27].

This approach gives a possibility to substantiate the feasibility of allocating funding for a particular region to solve a particular problem and investing in medical products and medicines. Also it gives an opportunity to define global priorities and fore-cast their trends in the global perspective. The root cause of many phenomena and events is the state of health of population.

GBD is a systematic scientific work aimed at studying how health initiatives can save years of life, including a healthy and wholesome period of life. The global level of research reveals both bottle-necks in the organization of health care system and gaps in statistics. Today, the research covers 195 countries and territories, hundreds of nosological forms, and it continues to expand as new data become available [28].

Loss of health is measured in years of disability-adjusted life-years (DALY), which combine the years lost due to disability, illness and premature death. It is calculated as the number of years lived with disability, i.e. the number of years of life lost. Loss of health (measured in DALY) is also called disease burden.

The results of a comprehensive global study examining 286 causes of death, 369 diseases and injuries and 87 risk factors in 204 countries and regions showed that it was not early death but disability that became increasingly common in the global disease burden: in 1990 it accounted for about one-fifth (21%) of the total burden, and in 2019 exceeded one-third (34%). In some countries, more than half of all cases of loss of health (measured in [DALY] [23]) are currently related to disability caused by noncommunicable diseases and injuries.

According to [22] coronary heart disease, cerebrovascular disease, self-harm, cirrhosis and other chronic liver diseases, road injuries, low back pain, cardiomyopathy and myocarditis, neonatal disorders, alcohol-related disorders, falls from a height are the 10 main causes of death and disability in Ukraine.

The studies [22—28] were used to determine the factors that describe the socio-economic and demographic situation, the state of the health care system of Ukraine, the level of general coverage of health care services.

In [27] domestic health spending is estimated. It is disaggregated by source (government, out-of-pocket, and prepaid private) from 1995 to 2017 for 195 countries and territories. The sum of spending

from these three domestic sources, plus development assistance for health, equate to total spending on health, meaning these four sources are mutually exclusive and collectively exhaustive. Government health spending is an aggregate of social health insurance and government public health programs. Out-of-pocket health spending captures health-care spending by an individual patient or their household, excluding insurance premiums paid before needing care. Prepaid private-health spending includes non-governmental agency spending on health and private insurance.

Therefore, the government health spending and out-of-pocket health spending were selected as socio-demographic indicators for this research because the share of prepaid private-health spending and development assistance for health always has been very low in Ukraine since 1995.

In [27], health spending is defined similarly to the System of Health Accounts 2011 and the World Health Organization Global Health Expenditure Database as spending on basic infrastructure, services, and supplies to deliver health care. This health spending is exclusive of informal care spending and major capital investments, such as building hospitals.

In 2017, total domestic health care spending in Ukraine was $ 219 per capita. These included $ 116 of public health expenditures, $ 96 from the pockets of patients or their families, $ 5 of prepaid private health insurance expenditures, and $ 2 received as health development assistance (from international donors). Therefore, public expenditures on health care and expenditures on medical goods and services paid by the patient out of pocket were selected as the socio-demographic indicators for this study because the share of prepaid private insurance expenditures on health care and assistance from international donors for the development of the health care system has always been very low in Ukraine. Since 1995 it has not had much influence on the health care system. All countries may need more resources to achieve SDG 3. Other challenges of health care systems, such as inefficient allocation of resources between different medical programs and groups of population, misconduct in governance, lack of human re-

sources and shortages of medicines, will also need to be addressed.

Health spending is an important impact factor for the economic development [28]. That is why government health spending and out-of-pocket health spending are chosen as variables for this research.

Road injuries, self harm and interpersonal violence (falls, drowning, poisonings, fire, heat and hot substances, drowning, etc) are among the leading causes of death in Ukraine. Moreover, these injures become a cause for death much more often in Ukraine than in other countries. Therefore, it is important to examine the possible negative impact of these indicators on the economic growth in our country.

For example, road traffic injuries are ranked 9th in the world and 10th in our neighbouring countries. Road injuries rank 5th among the leading causes of death in Ukraine. Self-harm and interpersonal violence ranked 3rd by the level of morta-lity in Ukraine in 2019, though they rank only 14th in our region and 16th in the world. As mortality from injuries is much higher in Ukraine than in neighbouring countries, it is important to study the possible negative impact of these indicators on economic growth in our country.

Injuries can be unintentional, such as those caused by road traffic injuries, poisonings, falls, burns or scalds, drowning or submersion, or intentional. Intentional injuries can be self-directed (suicide or self-harm), interpersonal, collective (war), or perpetrated through legal intervention. In this research only self harm and interpersonal violence are considered [29].

Unintentional injuries are on the 10th place among the causes of death in Ukraine, and on the 13th place in our region.

Young people (aged 15—49) are more likely to lose their health and ability to work as a result of injury than to die, as are older people. Compared to all other causes, injuries is the leading cause of death among people aged 5—49. Injuries cause half of all deaths in young people aged 15—29, a third in children aged 5—14 and a quarter in adults aged 30—49 in Europe [29].

Worldwide, 3 million deaths occur each year from alcohol abuse, accounting for 5,3% of all deaths. Alcohol consumption is a causal factor in more than 200 disease and injury conditions. Alcohol consumption is associated with a risk of developing health problems such as mental and behavioural disorders, including alcohol dependence, major non-communicable diseases such as liver cirrhosis, certain cancers and cardiovascular diseases, and injuries resulting from violence and road collisions and conflicts. Alcohol consumption causes death and disability relatively early in life. In the 20−39 age groups, approximately 13,5% of all deaths are caused by alcohol. Causal links have recently been established between harmful alcohol consumption and the incidence of infectious diseases such as tuberculosis and the severe course of HIV/AIDS.

Beyond health consequences, the harmful use of alcohol brings significant social and economic losses to individuals and society at large [30].

Disorders caused by alcohol consumption are on the 9th place among the causes of death in Ukraine, and only on the 28th position in our region. Cirrhosis of the liver is associated with alcohol abuse, and it ranks 4th among the causes of death in Ukraine and only 23rd among the causes of death in our region. This means that in our country this problem affects much more people than the average in our region. That is why this indicator was chosen for our study.

Prematurity, respiratory dysfunction, birth trauma, birth defects, neonatal infections and hemolytic disorders of the newborn are some examples of common neonatal disorders. Infant mortality, i.e. mortality in the first four weeks of life (neonatal period), today accounts for 41% of all deaths in children under five. Almost 3 million of all babies who die each year can be saved through low-tech, inexpensive but effective measures [31]. Thus, how the health care system copes with neonatal disorders describes the state of the entire health care system in the country. Disorders in newborns rank 8th among the causes of death in Ukraine and 11th in our region.

The way in which the health care system prevents and treats HIV/AIDS and tuberculosis also demonstrates the sustainability of the health care system [26]. Moreover, these diseases often affect quite young people. It can also negatively affect economic development. That is why these two indicators were chosen for our study.

Electricity consumption characterizes the degree of infrastructure development for the efficient use of ICT and overall economic development.

In order to solve the problem of assessing the impact of factors describing the state of the health care system and the socio-demographic situation on economic development in Ukraine, the following socio-demographic indicators were selected:

$x1$ — government domestic health spending;

$x2$ — out-of-pocket domestic health spending;

$x3$ — road injuries;

$x4$ — self harm and interpersonal violance;

$x5$ — alcohol use disorder;

$x6$ — neonatal disorder;

$x7$ — unintentional injuries (falls, drowning, etc);

$x8$ — HIV/AIDS;

$x9$ — tuberculosis;

$x10$ — electric power consumption (kWh per capita).

GNI is chosen as an output value y because it describes economic development.

The CORAL GMDH algorithm is chosen as a method for this research because it gives a possibility to select the most informative indicators.

Correlation-rating Algorithm GMDH CORAL GMDH

The tools were developed for data analysis, modeling and forecasting of socio-economic data based on GMDH in [17]. This toolkit is based on the combinatorial algorithm of GMDH. This algorithm belongs to the sorting-out algorithms of GMDH. There are many different algorithms among sorting-out algorithms. This tool was used to solve applied economic problems in [32−34]. The tasks of searching for informative arguments, constructing dependencies between variables have been solved here in order to analyze the influence of indicators, forecast indicators, and recover the missed variables.
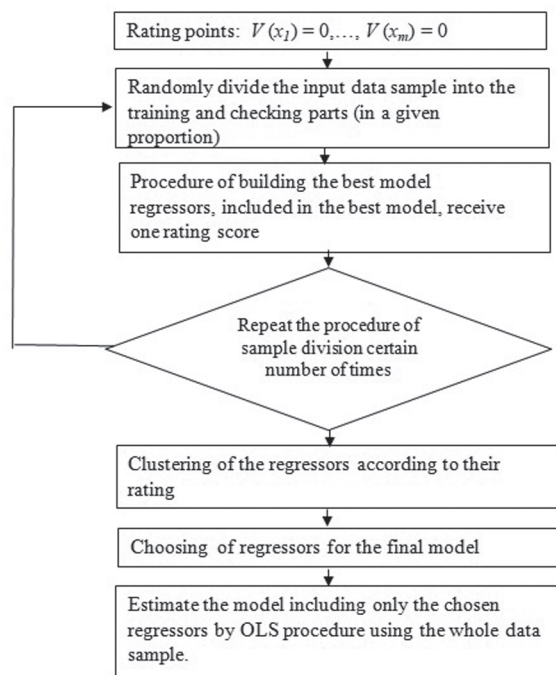
Fig. 1. The main idea of CORAL GMDH

There are many different algorithms among sorting-out algorithms. In [35], a new correlation-rating algorithm of GMDH is proposed. The advantage of the CORAL GMDH algorithm is in selecting the informative arguments which influence on the output value the most during the check of the models.

Existing GMDH algorithms are used to build models of complex objects. These models can be used for data recovery, modeling and forecasting.

There is a real example of how the correlation-rating algorithm CORAL GMDH is applied to solve the listed above problems of modeling. The proposed method of selection of informative arguments by means of correlation analysis belongs to the class of algorithms of GMDH with incomplete (directional) selection of models [36].

When modelling by GMDH algorithms, the obtained result often significantly depends on the division of the training data sample into training and testing ones.

The main idea of the CORAL algorithm (Fig. 1) is to determine the arguments that are more often included in the best models for different options

of dividing the training data sample (they have the highest rating). We use the division randomly into two equal parts a given number of times. A set of candidate models is built on each division.

Models are built by sequentially adding one argument. The correlation with the original variable for this argument has the biggest value; provided that it is not a random variable (i.e. the p-Val is calculated). Among the candidate models, the best model for the current division is selected. It should have the lowest value of the external criterion (we use the criterion of regularity). Those arguments that are included in the best model receive rating points.

When the simulation is performed on a given number of divisions of the data sample, we obtain a rating of arguments (variables). It shows how often each variable was included in the best models.

For the final model, the variables with the highest rating are selected using the clustering procedure. The coefficients of the final model are calculated on the entire data sample by the least squares method.

The proposed algorithm belongs to the class of GMDH algorithms with incomplete (directed) search of models and is a development of this field. The optimal model is chosen from the set of candidate models. The choice is based on the minimum value of the external criterion. The division of the input data sample changes. The procedure is repeated a specified number of times. Regressors' rating is calculated. Variables with a higher rating are selected for the final model.

Studies of the correlation-rating algorithm have shown that it has high sensitivity index values, does not include redundant variables in the model and allows obtaining a stable result due to multiple division of the sample during modeling.

Application of CORAL GMDH for Modeling and Forecasting of Indicators of Different Countries

We will conduct research for a group of countries close to Ukraine in the space of all measured parameters. To do this, we calculate the value of the Euclidean distance for all countries and select the

closest ones to Ukraine (see Table 1). The Table 1 shows the value of the Euclidean distance for 8 countries closest to Ukraine. Belarus, Poland, Hungary, Bulgaria, Moldova, Kazakhstan, and Romania were chosen for our research as the neighbouring states of Ukraine. Also all these countries belong to the region of Eastern Europe and the former Soviet Union, they have many economical, political, and social connections with Ukraine.

The closest to Ukraine in the space of all indicators was Belarus, then Poland and others. On the example of these three countries we will show the solution of the three mentioned problems of modeling and forecasting for Ukraine, Belarus, and Poland.

Application of the Coral GMDH for Modelling Indicators of Ukraine

The description of the input data was given above. For Ukraine, their values in 1990—2019 are given in the Table. 2. The Table 2 contains fragment of the input data for recovery of gaps in data and modelling. They include the values of 10 socio-demographic indicators measured over 30 years (lines).

Because the data in different numerical ranges will be used to analyze relationships, they are scalable, meaning that the value of each column is divided by the maximum value of that column.

The three previously described above problems will be considered in more detail.

Recovery of data gaps. Let's consider application of CORAL GMDH to restore missed values on the example of recovery of the indicators x_1 — government domestic health spending and x_2 — out-of-pocket domestic health spending for Ukraine.

In the sample of the Table 2 the values of variables x_1 and x_2 omitted from 1990 to 1999. The easiest way to recover missed data based on GMDH is to build a single model to recover a number of gaps when the values of the only one variable are missed.

Let's try to restore them according to the GMDH algorithm, as shown in [37]. x_1 data can be recovered using the following model:

$$\hat{x}_{1i} = 0,07 + 0,82x_{2i} - 1,75x_{3i} - 0,175x_{5i} + 2,12x_{9i}.$$

Table 1. **The Euclidean distance for the countries**

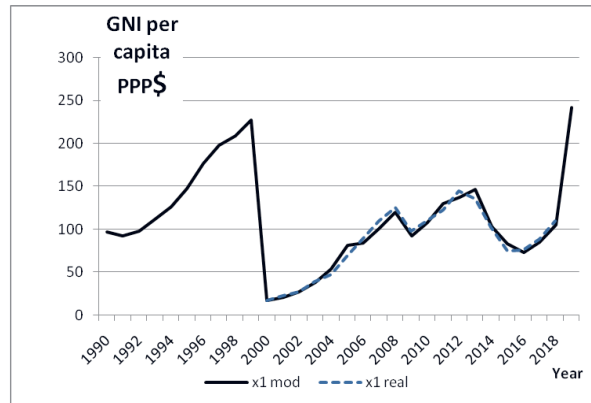| №	Country Name	Euclidean distance
1	Ukraine	0,00
2	Belarus	0,59
3	Poland	3,91
4	Hungary	4,28
5	Bulgaria	9,04
6	Moldova	10,02
7	Kazakhstan	10,24
8	Romania	12,74

Fig. 2. Real and recovered by the model values of the variable x_2

The value of the criteria: $AR = 0,013$; $MAPE = 0,0018$; $R^2 = 0,973$, where AR — regularity criterion in GMDH algorithms, $MAPE$ — statistical criterion of absolute error; R^2 – determination criterion.

Similarly, a model for x_2 is built and the value of this variable is restored.

$$\hat{x}_{2i} = 0,818 + 0,939x_{1i} - 0,42x_{3i} - 0,696x_{5i} - 0,864x_{6i} + 0,75x_{7i} - 0,189x_{8i}.$$

The value of the criteria: $AR = 0,0018$; $MAPE = 0,0006$; $R^2 = 0,990$.

A graph of the initial and model-calculated values of the variable x_1 is shown on the Fig. 2. Restored values x_1 and x_2 are shown with a hatch on the Fig. 2 and in italics in the Table 2.

The obtained models give a possibility recovering data gaps rather quickly and preparing them for a further analysis.
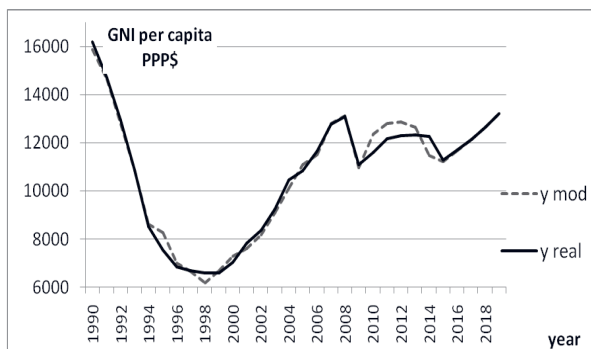
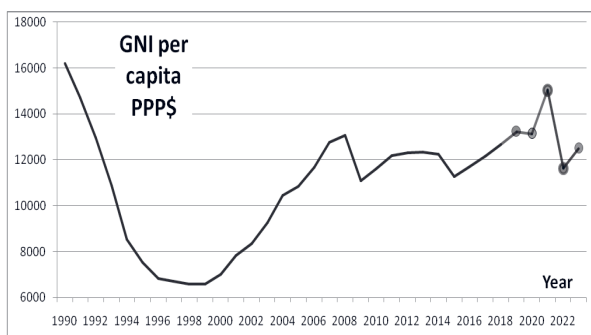*Fig. 3.* Real values of GNI and those received by the model for Ukraine

Fig. 4. Forecasting of GNI of Ukraine in 2020−2023 years

Modelling of dependence of GNI of Ukraine on socio-demographic indices. The second task is to analyze the relationships in the data.

Let us construct a model of the dependence of the output variable y on the variables $x_1−x_{10}$ using the CORAL GMDH algorithm.

The recovered in the previous task data are used for this purpose. They are shown in italics in the Table 2.

The following optimal model is obtained:
$$y = -0,8756x_5 - 0,058x_8 + 0,9644x_9 + 0,866x_{10}.$$
The value of the criteria: $AR = 0,463$; $MAPE = =0,024$; $R^2 = 0,984$.

This model gives a possibility to analyze which of the following socio-demographic indicators affect GNI.

The model-obtained results are given on the Fig. 3.

Analysis of the obtained model shows that the best model includes only four variables. It shows that the best model included only four variables: x_5,

x_8, x_9 and x_{10}. These variables have the greatest impact on the original variable.

Forecasting of GNI. The variables $x_1−x_{10}$. are taken as input data in order to build a model for forecasting GNI from 2020 to 2022. GNI is the output variable. A model is built for each forecast.

For example, such a model is obtained for the forecast for 2021:
$$y_{k+3} = -0,3611x_1 - 0,4311x_4 - 1,3419x_5 - 0,1849x_6 - -0,0515x_8 + 1,592x_9.$$

The value of the criteria: $AR = 1,732$; $MAPE = =0,038$; $R^2 = 0,934$.

Similarly the models for the values for 2022 and 2023 were obtained.

The GNI values for 2020−2023 calculated by the model are given on the Fig. 4.

The calculated values show that at first GNI increases in 2020, then a downward trend in GNI in 2021−2022 with a slight growth in 2023.

Application of the Coral GMDH for Modelling of Indicators of Belarus

Similarly to the solved above three problems for Ukraine, we will solve the same problems for Belarus.

The Table 3 shows fragment of the input data characterizing the indicators of the socio-demographic sphere in Belarus in 1990-2019.

Similarly we will solve the three stated above problems.

Recovery of data gaps. CORAL GMDH is applied to restore the omitted values x_1 and x_2 for Belarus the same way how it was done for Ukraine.

In the sample shown in the Table 3 the values of variables x_1 and x_2 are missed from 1990 till 1999.

Such a model was obtained for the values x_1:
$$\hat{x}_{1i} = -0,035 + 0,24x_{2i} - 0,13x_{5i} - 0,83x_{7i} - - 0,82x_{8i} + 0,75x_{9i} + 2,756\,x_{10i}.$$
The value of the criteria: *AR = 0,002; MAPE = =0,0043; R^2 = 0,98*.

The Fig. 5 shows real data for the variable x_1 and x_2 those recovered by the model in italics.

Similarly such a model was received for x_2:
$$\hat{x}_{2i} = -3,56 + 0,76x_{1i} + 2,67x_{4i} + 1,81x_{5i} + 3,54x_{6i} - - 2,98x_{7i} + 1,38x_{9i}$$

Table 2. **The fragment of the input data sample for the Ukraine**

№	Year	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	y
1	1990	*71,8*	*72,1*	23,3	31,0	14,2	9,4	42,8	2,8	5,7	4787,5	16182
2	1991	*60,2*	*59,5*	24,3	34,2	16,1	8,9	47,1	3,0	6,0	4643,3	14707
3	1992	*50,1*	*48,5*	24,7	39,1	18,0	8,1	51,1	3,5	6,6	4313,5	12939
4	1993	*43,7*	*39,7*	24,3	42,7	19,8	7,5	54,3	4,2	7,2	3953,3	10862
5	1994	*28,6*	*25,9*	24,4	48,4	21,5	7,2	59,4	4,9	8,0	3475,1	8532
6	1995	*4,9*	*7,8*	25,0	55,1	23,6	6,8	66,2	6,3	9,4	3348,9	7538
7	1996	*15,2*	*11,6*	22,8	55,3	24,3	6,4	65,2	7,3	9,7	3060,3	6841
...	...	...	...	...	...	...	...	...	...	...	...	...
30	2019	*92,1*	*103,7*	15,8	43,7	17,5	3,0	39,1	15,1	9,2	3805,9	13216

Table 3. **The fragment of the input data sample for the Belarus**

№	Year	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	y
1	1990	*243,85*	*100,30*	23,94	29,75	13,35	8,15	43,63	0,94	3,61	8891	243,85
2	1991	*230,37*	*98,40*	25,23	31,50	14,73	7,80	46,38	0,97	3,70	8780	230,37
3	1992	*199,87*	*77,88*	25,70	35,60	16,53	7,23	49,72	0,95	3,90	7920	199,87
4	1993	*168,87*	*56,77*	26,39	41,70	18,80	6,47	55,19	1,09	4,49	7301	168,87
5	1994	*125,21*	*24,52*	25,57	44,08	20,27	6,12	57,88	1,37	4,73	6431	125,21
6	1995	*105,23*	*6,91*	26,02	48,58	21,79	5,62	61,57	1,42	5,31	5784	105,23
7	1996	*114,68*	*4,86*	25,13	48,14	22,79	5,05	61,46	1,39	5,45	5976	114,68
...	...	...	...	...	...	...	...	...	...	...	...	...
30	2019	*359,62*	*153,51*	11,04	32,13	31,29	1,69	42,77	3,09	3,14	18546	359,62

The value of the criteria: $AR = 2,9$; $MAPE = 0,12$; $R^2 = 0,85$.

The recovered values of x_1 and x_2 are given in italics in the Table 4.

Modeling of dependence of Belarusian GNI on socio-demographic indices. The second task is to analyze interrelationships in data by modeling dependences among the factors.

Let us build a model of dependency of the output variable y on the input variables $x_1 - x_{10}$ with help of the algorithm CORAL GMDH.

Such the best model was obtained:

$$y = 0,97 - 0,11x_6 - 1,09x_7 + 0,75x_8 + 0,3x_9.$$

The value of the criteria: $AR = 0,463$; $MAPE = 0,024$; $R^2 = 0,984$.

Analysis of the obtained model shows that the best model includes only four variables x_5, x_8, x_9 and x_{10}. They make the greatest impact on the output variable.

Forecasting of GNI. The variables $x_1 - x_{10}$ were taken as input data in order to build a model for forecasting the GNI of Belarus in 2020−2022. GNI is an output variable. The Table 3 shows a fragment of the data sample for forecasting.

Similar to how it was carried out for Ukraine the results of forecasting the GNI of Belarus were received according to the generated data sample with help of the algorithm CORAL GMDH. These results are given on the Fig. 6. The calculated data show at first a decline of the GNI values in 2019−2021 but then a small growth in 2022−2023.

Application of the Coral GMDH for Modelling of Indicators of Poland

Similarly to the solved above problems for Ukraine and Belarus the same tasks will be carried out for Poland.

Table 4. **Fragment of the input data sample for Poland**

| №	Year	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	y
1	1991	*37,416*	*7,459*	23,195	23,322	7,939	10,600	32,625	0,039	5,391	10124	37,416
2	1992	*100,226*	*18,429*	22,252	23,239	8,336	9,619	31,421	0,048	5,001	10239	100,226
3	1993	*97,419*	*17,934*	20,983	22,254	8,319	8,551	29,784	0,047	4,629	10667	97,419
4	1994	*129,993*	*23,166*	21,191	22,866	8,525	9,302	29,941	0,042	4,409	11567	129,993
5	1995	*193,754*	*34,180*	21,428	23,481	8,928	7,722	29,934	0,049	4,341	12276	193,754
6	1996	*178,384*	*32,670*	20,720	22,967	8,831	6,777	28,902	0,071	4,333	13108	178,384
7	1997	*179,689*	*34,977*	20,805	23,541	8,839	5,430	28,800	0,114	3,908	13942	179,689
...	...	...	...	...	...	...	...	...	...	...	...	...
29	2019	*583,916*	*114,376*	10,024	18,730		1,419	24,877	0,349	1,454	31623	583,916
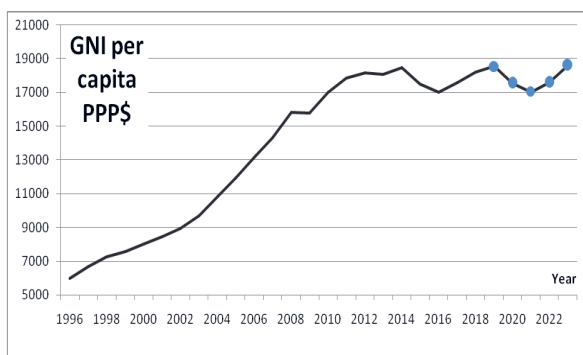
Fig. 6. Forecasting of the GNI of Belarus in 2020–2023 years

The Table 4 contains fragment of the input data characterizing the indicators of the social and demographic field in Belarus in 1991—2019.

The recovered data are given in italics in the Table 4 similarly to the described above. They are shown for the variable x_1 on the Fig. 7.

In the same way as it was stated above the values of the GNI of Poland will be calculated until 2023.

Thus the obtained results show that the constant upward trend of Polish GNI ended in 2020 with inconsiderable fall but then the GNI of Poland increases slowly in next years.

The technique of data gaps recovery, modelling and forecasting was applied in this research in order to build dependencies of GNI of Ukraine, Belarus and Poland on the social and demographic indicators of these countries. The use of the algorithm CORAL GMDH gives a possibility recovering the values of government domestic health spending and out-of-pocket domestic health spending for Ukraine, Belarus, and Poland in the 1990s. Also it was applied in order to analyze interrelationships in data by modeling dependences among the economic, social and demographic factors. The forecasts of the GNI of theses three countries were built with help of it too. All three forecasts show the same trend for all these states.

Scope of Use of the Developed Toolkit

This toolkit is designed for use in economic problems to build relationships between indicators, analyze them, and develop recommendations for impact on those indicators that can be adjusted in order to improve them.

The study gives a possibility to formulate proposals and recommendations for improving the quality of the decision-making process in the field of social investment, which will further contribute to sustainable development in the field of formation, reproduction and provision of human potential.

The practical significance of the research results is that the use of the proposed integrated innovation and institutional approach will allow policy makers in the socio-economic field to develop recommendations for possible adjustment of certain aspects of human development, which would improve the decision-making process in this field.

Conclusions

Thus, the results of using CORAL GMDH for solving three problems of data recovery, modeling and forecasting are obtained.

The use of CORAL GMDH makes it possible to determine the most informative factors in the model and, therefore, to identify those socio-demographic indicators that restrain the growth of GNI in Ukraine. It helps to develop recommendations how to promote decision-making process in the field of human capital.

Thus, the state must increase spending on health care, ensure equal access of citizens to quality health services by creating a new organization of health care based on principles of health insurance, reforming and improving health care, and reduce in the first place the negative impact of those factors that hinder the growth of GNI in order to achieve the priority goal — sustainable development of human capital in Ukraine and promote economic growth.

Public policy should be aimed at reducing the level of self-harm and interpersonal violence, include measures to prevent suicide, domestic violence, conflicts with weapons, and so on.

Another important task of the state should be to increase the efficiency of rescue services and monitor compliance with safety rules in enterprises, transport and recreation in order to reduce the level of unintentional injuries.

The state and civil society should also promote measures aimed at preventing alcohol consumption, especially among young people, and encourage citizens to lead a healthy lifestyle.

Thus, to promote economic growth, the state must increase spending on the health care system, promote the spread of health insurance services, and reduce in the first place the negative impact of those factors that hinder the growth of GNI.

Public policy measures should be equally aimed not only at the formation of human capital, but also at providing conditions for its self-realization, disclosure, preservation, and prevention of devaluation. It is impossible to solve the problems of national human capital development exclusively within one field (education, health, science, social security or economic development). Coordi-
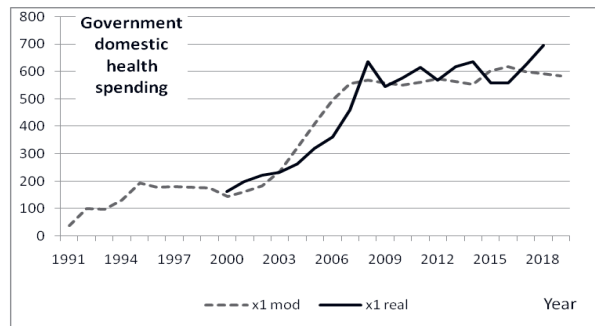

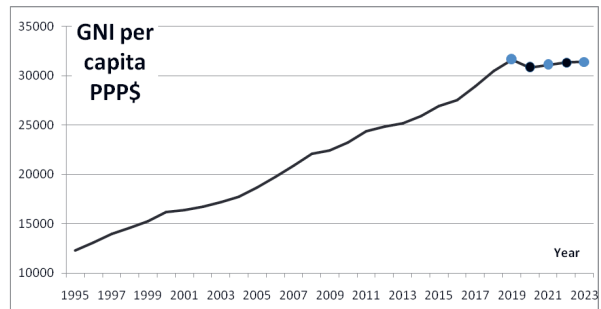*Fig. 7.* Результаты восстановления переменной x_1

Fig. 8. The results of forecasting the GNI of Poland in 2019—2023

nated efforts of the entire government and local governments are required. A joint mandate to systematically address existing problems is necessary. Another task of the state policy of Ukraine should be not only to direct significant amounts of financial resources to the fields where human capital is developing, but also to use them effectively to provide quality public services that require management capacity at all levels of government.

Ukraine's participation in international rankings and indices that assess the state of human capital development, serving as an instrument of international comparison of different countries, gives an opportunity to see the "bottlenecks" that should be focused on in shaping public policy in relevant fields.

Ukraine's international commitments in the field of human capital development, the source of which are international agreements, projects, declarations, are guidelines for further development, national adaptation of leading world experience and prioritization of economic growth strategies, but should not be seen as a constraint on public policy instruments.

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Є.А. Савченко-Синякова, кандидат технічних наук, старший науковий співробітник, Міжнародний

науково-навчальний центр інформаційних технологій та систем НАН та МОН України,

03187, м. Київ, просп. Академіка Глушкова, 40, Україна,

savchenko_e@meta.ua

О.В. Тутова, кандидат економічних наук, старший науковий співробітник, Міжнародний

науково-навчальний центр інформаційних технологій та систем НАН та МОН України,

03187, м. Київ, просп. Академіка Глушкова, 40, Україна,

olenatutova@gmail.com,

Г.А. Піднебесна, молодший науковий співробітник, Міжнародний науково-навчальний

центр інформаційних технологій та систем НАН та МОН України,

03187, м. Київ, просп. Академіка Глушкова, 40, Україна,

pidnebesna@ukr.net

ЗАСТОСУВАННЯ ІНДУКТИВНОГО АЛГОРИТМУ CORAL МГУА ДЛЯ МОДЕЛЮВАННЯ ТА ПРОГНОЗУВАННЯ НАЦІОНАЛЬНОГО ДОХОДУ УКРАЇНИ

Вступ. Аналіз цілей стійкого розвитку людства, сформульованих фахівцями ООН у 2015 р. на наступні 15 років показує, що досягнення цих цілей і пов'язаних із ними завдань є основою для формування, відтворення та забезпечення людського капіталу. Основними важелями впливу на розвиток людського капіталу можна вважати: освіту, охорону здоров'я та їхній зв'язок зі створенням загальноекономічного добробуту народу або держави.

Дослідження призначено для оцінки впливу соціально-демографічних показників, які характеризують стан системи охорони здоров'я, причини смертності, рівень загального охоплення послугами охорони здоров'я, на валовий національний дохід як на основний показник, що характеризує рівень економічного розвитку держави. За допомогою індуктивного підходу розв'язано три задачі, що виникли в процесі дослідження.

Метою статті є застосування індуктивного алгоритму *CORAL* МГУА для моделювання та прогнозування національного доходу України за соціально-демографічними показниками та розробка рекомендацій щодо того, як держава може вплинути на рівень розвитку людського капіталу в країні, впливаючи на окремі соціально-демографічні показники.

Методи. При проведенні дослідження для відбору показників використовується кореляційно-регресійний аналіз, побудова моделей для аналізу даних та прогнозування відбувається за допомогою індуктивного підходу, а саме алгоритму *CORAL* МГУА.

Результати. За допомогою алгоритму *CORAL* МГУА розв'язано три задачі: відновлення пропусків в даних, моделювання залежності валового національного доходу від соціально-демографічних показників з метою їх аналізу та прогнозування валового національного доходу.

Висновки. Отримані результати демонструють можливості індуктивного підходу, а саме перебірного алгоритму *CORAL* МГУА. За його використання розв'язано задачі відновлення пропущених даних, моделювання та прогнозування. Проаналізувавши розроблені моделі, можна зробити такі рекомендації: для сприяння економічному зростанню держава повинна збільшувати витрати на систему охорони здоров'я, сприяти поширенню послуг страхової медицини, та в першу чергу зменшувати негативний вплив тих чинників, які перешкоджають зростанню валового національного доходу. Перевагою цього алгоритму є те, що він дозволяє отримувати стійкий результат за рахунок багатократного поділу вибірки при побудові моделі.

Ключові слова: *відновлення пропусків у даних, моделювання, прогнозування, валовий національний дохід на душу населення, алгоримт CORAL МГУА, соціально-демографічні показники.*