ISSN 2664-9969

UDC (004.89:519.22](043.3)
DOI: 10.15587/2706-5448.2024.313960

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APPLICATION OF PROBABILISTIC AND STOCHASTIC MODELS AND DATA MINING FOR FORECASTING THE CONTINGENT OF OLD AGE PENSION RECIPIENTS IN THE CONTEXT OF SYSTEMIC UNCERTAINTY

The object of the research is mathematical models for forecasting the contingent of pension recipients in conditions of uncertainty caused by both the reform of the pension system and the impact of armed aggression. Based on the study of statistical information on the structure and dynamics of the contingent of pension recipients, an approach to uncovering systemic uncertainty in the task of forecasting the contingent of pensioners is proposed. This work is part of a study of the application of data mining methods of intellectual data analysis and mathematical modeling in information technology intended for use in the pension system. The main focus of this work is on forecasting the dynamics of the contingent of pension recipients by age, in particular, forecasting the number of newly appointed pensions. The difficulty of forecasting the contingent of pension recipients, in particular by age, is connected with the fact that it is necessary to ensure the representativeness and variability of data sets. In addition, it should be taken into account that a significant number of factors must be included in the model in accordance with the requirements of regulatory documents. Another problematic issue is that the time series of the investigated indicators, such as data on the insurance experience of insured persons (based on the results of a sample survey), may contain significant (more than 40 %) gaps that can be filled only on the basis of primary (paper) documents. Therefore, the input data sets are formed with assumptions about the probability of the accumulation of insurance experience in various groups of insured persons. The paper proposes an analytical toolkit based on the use of probabilistic and statistical models in the form of Bayesian networks, intended for use in specialized decision-making support systems of the Ukrainian pension system. In the course of the study, a number of numerical experiments were carried out, in which the correctness of the proposed method was investigated. The proposals presented in the paper will improve the stability of the pension system of Ukraine, including through a more accurate definition of the dynamics of the contingent of pension recipients and, accordingly, the costs of pension payments. The proposed models and methods can be used as part of decision-making support systems of state and public administration bodies to analyze the results of reforming the pension system.

Keywords: *Bayesian network, uncertainty, pension reform, data mining, probability-statistical models, pension recipients.*

Received date: 13.09.2024
Accepted date: 23.10.2024
Published date: 25.10.2024

How to cite
Zarudnyi, O., Koval, R. (2024). Application of probabilistic and stochastic models and data mining for forecasting the contingent of old age pension recipients in the context of systemic uncertainty. Technology Audit and Production Reserves, 5 (2 (79)), 56–62. https://doi.org/10.15587/2706-5448.2024.313960

1. Introduction

A new stage of reforming the pension system of Ukraine, announced by the Ministry of Social Policy [1–3], will soon begin – a transition to a pension system that will combine three components: a solidarity system, an accumulation system, and a voluntary one [3–5]. Therefore, not only updating the system of actuarial calculations, but also the introduction of modern, adapted to domestic conditions, model tools, which would allow obtaining high-quality forecasts even in conditions of systemic uncertainty, becomes relevant. After all, for a long time, in the system of mandatory state pension insurance in Ukraine, the main attention was paid to the issue of actuarial calculations and actuarial forecasts [5–10], which provided acceptable results. However, the implementation of a three-level pension system involves the use of a methodological apparatus for modeling the state and dynamics of the pension system, which is actively used in many countries [4, 11–13]. An example of such models are models developed by the World Bank [11], which are used in more than 90 countries of the world. However, they are more acceptable for

countries with established economies, so foreign experience requires adaptation to domestic conditions, taking into account the influence of various groups of factors that affect the financial balance of the pension system. According to experts in [5, 10], these factors can be summarized into three groups: macroeconomic, demographic, and organizational and legal.

Given the expected changes in the pension system, military aggression, special attention should be paid to demographic factors, and, in particular, to forecasting the number of pension recipients. Traditionally, forecasting of the contingent of pension recipients is based on the use of mainly demographic approaches, the basis of which are methods of extrapolation, statistical modeling, etc. [11, 14, 15]. All of these methods require a significant amount of statistical information, the collection of which in full during the war is practically impossible, or is limited, for example, to certain regions or communities. We need new models and methods that will ensure obtaining demographic forecasts, actuarial calculations, forecasts of the contingent of pension recipients, in conditions of systemic uncertainty.

The aim of research is to develop mathematical models and information technology intended for forecasting the number of pensioners by age in the task of budget planning of the Pension Fund of Ukraine under conditions of uncertainty. This will allow, in particular, to increase the efficiency of the budget process of the Pension Fund of Ukraine and contribute to the rational use of funds for financing pension payments, optimization of state budget expenditures on social protection and social security. What is extremely relevant in the conditions of the growth of the contingent of recipients of pensions and benefits for the reduction of the income part of the Pension Fund budget and the reduction of budget funding of the sphere of social protection and security.

2. Materials and Methods

The research presented in this paper is part of the work devoted to the development of information technology for analysis and forecasting of the state and dynamics of the national pension system, in particular the Pension Fund of Ukraine. The research was carried out on the materials of the State Statistics Service and materials of sample surveys. The pension system defined by the Law of Ukraine "On Mandatory State Pension Insurance" [16] has undergone significant transformations, and its reformation continues. And since the entry into force of this Law – on January 1, 2004, the system of collecting and accumulating information on the payment of mandatory state pension insurance contributions by all insured persons began to work. This created the prerequisites for the automation of processes related to the appointment and payment of pensions, as well as the improvement of the analytical functions of the Pension Fund of Ukraine [17]. According to the Ministry of Social Policy of Ukraine [18], in 2021, the share of the population aged 60 and older in the total structure of the population of Ukraine was 24.8 %, which is a powerful factor in increasing the demographic burden, increasing the need for medical services and social security. As of January 1, 2023, the largest share in the contingent of pension recipients is age pensioners – 74 % of the total number of pension recipients [15]. The average amount of monthly retirement pension as of January 1, 2023 is 4,522.98 UAH (123.68 USD) [19]. For pension payments made by the Pension Fund of Ukraine in 2023, 671.4 billion UAH (18.36 billion USD) [19, 20] will be allocated, which is 90 % of the Pension Fund's expenditures (in 2022, pension payments will amount to 97.3 %). In 2023, expenses financed from own funds were provided by the receipt of these funds by 101.9 %, which is 1.8 % more compared to 2022 [20]. Therefore, in order to predict a possible change in the volume and structure of expenses, planning the budget of the Pension Fund, it is important to have an effective forecasting toolkit, in particular, a methodology for predicting the number of newly assigned pensions during the calendar year.

This study considers the task of forecasting the number of newly assigned age pensions for population groups of a certain year of birth, when the main criterion for determining the right to grant an age pension, in addition to the onset of retirement age for the insured person, is the presence of the necessary insurance experience. The assumption in this problem is that people who have insurance experience after 2004 were just as likely to have had it in the period from 1990 to 2004, and by 1991, 98 % of people of working age were working. The most likely scenario will be the appointment of old-age pensions for persons who have the required insurance experience for a certain age category or category of insured persons who are entitled to the appointment of an old-age pension before reaching the age of 60 on preferential terms, early or by reducing the retirement age.

Therefore, this problem is characterized by the presence of systemic uncertainty, vague input information [21–24]. The sources of data are official statistical information, public information in the form of open data, expert opinions, unstructured data from various Internet sources, including information on the activities of executive authorities and other state bodies. Therefore, for the aim of this research, it is proposed to use the approach, basis which consists of probabilistic statistical methods [25, 26], tools for intelligent data analysis, methods of processing large volumes of data. These models and methods have proven themselves well in decision support information systems in the management of socio-economic systems [23, 24, 26–39], in particular, in the tasks of revealing systemic uncertainty.

Bayesian networks [26, 31–37] are a high-resource method of probabilistic modeling of processes of various nature, which allows working out statistical, structural, parametric uncertainties. Both discrete and continuous variables can be used as input data. The construction of models is possible in the presence of hidden peaks and incomplete observations, and the formation of a conclusion is possible using both approximate and exact methods.

Taking into account the peculiarities of the studied subject area, hybrid Bayesian networks were chosen as an analytical tool [26, 33, 36, 37]. Hybrid Bayesian networks are graphical models that contain nodes with discrete and continuous variables.

When using Bayesian networks containing nodes with continuous and discrete variables, there are a number of limitations:

– nodes with discrete variables cannot have parent nodes with continuous variables;

– nodes with continuous variables must have a normal distribution law conditional on the values of parent nodes;

– distribution of a continuous variable with discrete parent nodes and continuous parent nodes is a normal distribution [26]:

$$P\left(X|Y=y,Z=z\right)=N\left(\mu_x\left(\mu_y,\mu_z\right),\sqrt{\sigma_x\left(\sqrt{\sigma_y}\right)}\right), \quad (1)$$

ISSN 2664-9969

where μ_x, μ_y, μ_z – mathematical expectations, σ_x, σ_y – variances, $\sqrt{\sigma_x}, \sqrt{\sigma_y}$ – standard deviation; μ_x depends linearly on parent nodes with continuous variables, and σ_x does not depend on parent nodes with continuous variables at all. However, μ_x and σ_x depend on parent nodes with discrete variables. This limitation guarantees the possibility of forming an accurate conclusion.

The method of using Bayesian networks for forecasting the number of newly assigned pensions by age during one calendar year is presented in Fig. 1.

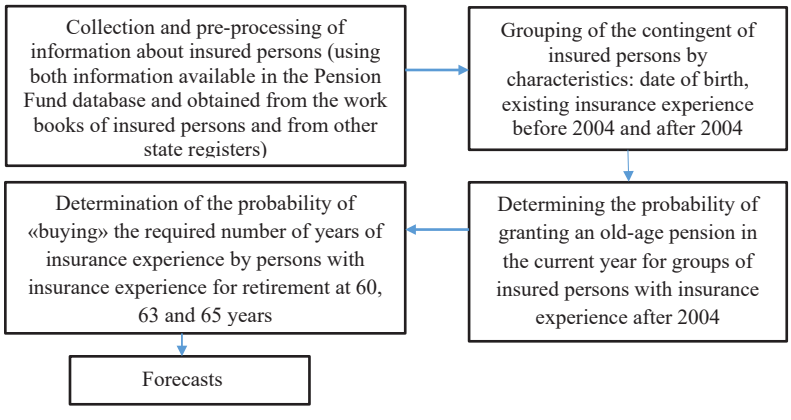

Fig. 1. Scheme of forecasting the number of newly appointed pensions by age using probabilistic modeling

The issue of collecting and pre-processing the input data set deserves special attention, as it contains complete information about the insurance experience of insured persons in the information system of the mandatory state pension insurance, starting from 2004. Information about the work experience of insured persons in the period before 2004 is stored mainly on paper media. Therefore, when building models, it is necessary to ensure representativeness and variability of data sets. Take into account the possibility of adding information about the insurance period, the influence of demographic factors, as well as the fact that the algorithms for calculating the insurance period and assigning pensions by age are regulated by the current legislation.

3. Results and Discussions

In the study, the number of newly assigned pensions by age in 2024 is modeled in accordance with the norms of the current pension legislation and taking into account the assumptions regarding the availability of insurance experience for insured persons. The input data sets were generated on the basis of available statistical information, analysis of information sources on the Internet, expert assessments, the assumption that 90–98 % of the working population worked in the period before 1990, and in the period from 2004 to 2024 can "buy more" no more than five years of service before the required age pension in 2024.

Fig. 2 presents the assumptions regarding the distribution of insurance experience of insured persons who will turn 60 in 2024 (year of birth – 1964).

The distribution of the values of insurance experience for the entire period of employment of the insured person is described by the following statistical characteristics: mathematical expectation $\mu = 34.81$, standard deviation *sigma* = 7.08.

The distribution of the values of insurance experience before 2004 for insured persons is described by statistical characteristics: mathematical expectation $\mu = 18.67$, standard deviation *sigma* = 4.09.

The distribution of insurance length of service values after 2004 is described by the following statistical characteristics: mathematical expectation $\mu = 15.66$, standard deviation *sigma* = 4.67.

In fact, from the point of view of frequency analysis, the value of the distribution of insurance experience for the entire period of employment of the insured person is a combination of the distribution of the value of insurance experience before and after 2004. Such values can be seen in Fig. 2–4, using the usual operation of adding the values of mathematical expectations and standard deviations of the given distributions.

The mathematical apparatus of hybrid Bayesian networks was used for modeling, namely, a network was built that contains both discrete and continuous vertices. The computer program Genie 2 [40] was used to construct the topology and calculate the probability values, SAS software was used to prepare the input data, Fig. 5 [41, 42].

The vertex "Probability of receiving a pension" is characterized by a random variable conditionally normal on the values of the parents (that is, on the values of the parents).

It should be noted that, in the general case, the distribution of probabilities for vertices similar to the vertex "Probability of receiving a pension" is not just a normal distribution, but a mixed normal distribution. That is, it represents a weighted mixture of distributions, for each of which a list of its parameters must be specified:

– mathematical expectations and variances for distributions describing the degree of influence of discrete parents;
– weighting factors that take into account the degree of influence on the mathematical expectation of continuous parents.

The settings of the vertices of the built hybrid Bayesian network are as follows:

– the vertex "Insurance experience for all time" is described by the value 34.81 ± 7.08;
– the vertex "Insurance experience before 2004" is described by the value 18.67 ± 4.09;
– the vertex "Insurance experience after 2004" is described by the value of 15.66 ± 4.67;
– the vertex "Probability of buying 1–5 years of insurance experience" is described by the value of 12.52 ± 2.1;
– the vertex "Age of a person" is a discrete vertex that accepts discrete values of the number of years;
– the vertex "Preferential service (harmful conditions)" is described by the following marginal table of conditional probabilities: "yes" – preferential service of 6.5 years or more – probability – 2 %, "no" – less than 6.5 years – 98 %;
– the vertex "Sign of the right to early retirement or with a reduction of the retirement age" is described by the following marginal table of conditional probabilities: the value of the conditional probability of the vertex – "yes" – probability 2.5 %, the value of the conditional probability of the vertex – "no" – probability 97.5 %;
– the vertex "Probability of receiving a pension" is a resulting vertex, which, based on the parameters of the parent vertices, gives the probability of receiving a pension.

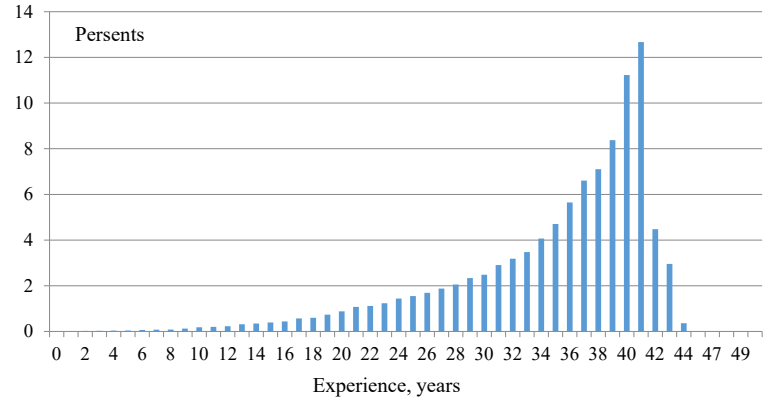

Fig. 2. Distribution of insurance experience of insured persons born in 1964 for the entire period of their employment

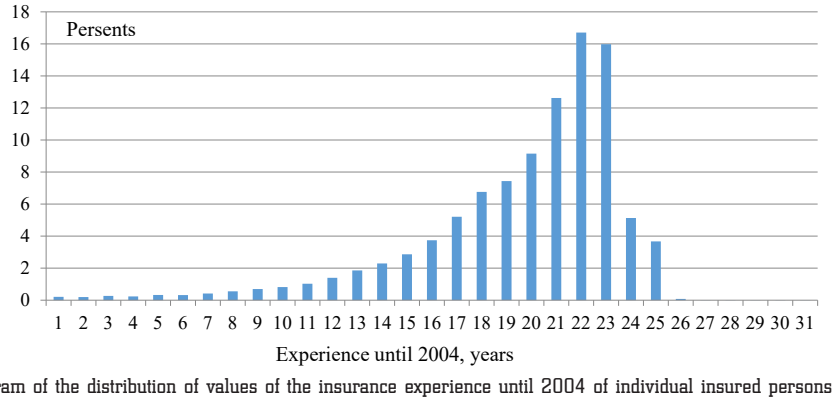

Fig. 3. Histogram of the distribution of values of the insurance experience until 2004 of individual insured persons born in 1964

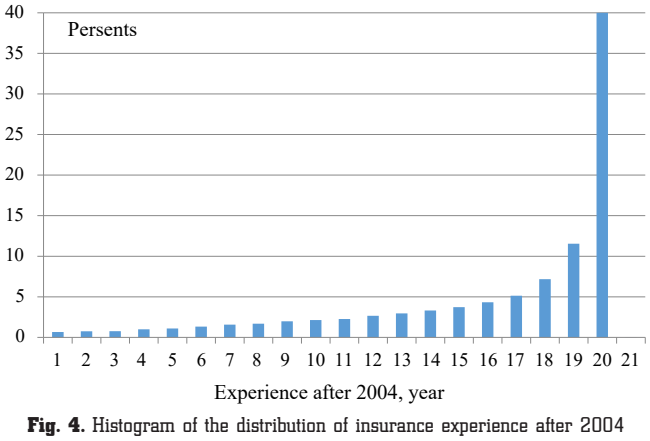

Fig. 4. Histogram of the distribution of insurance experience after 2004 for persons born in 1964

As a result of the calculations, the following results were obtained (Table 1).

If a person planning to retire does not have 5 or less years of experience before the required experience for the appointment of an old-age pension, it can enter into an agreement with the Pension Fund of Ukraine on voluntary participation in the pension insurance system – to "buy up" the experience. The probability of such an event, if to "buy back": 1 year – 91.98 %, 2 years – 90.59 %, 3 years – 55.19 %, 4 years – 23.35 %, 5 years – 12.85 %.

The most likely scenario for the number of newly appointed old-age pensions for 2024 is as follows. Persons born in 1964 will buy the right to an old-age pension when they reach the age of 60 and have 31 years of insurance experience. There are 374,046 (77.7 %) of such persons.

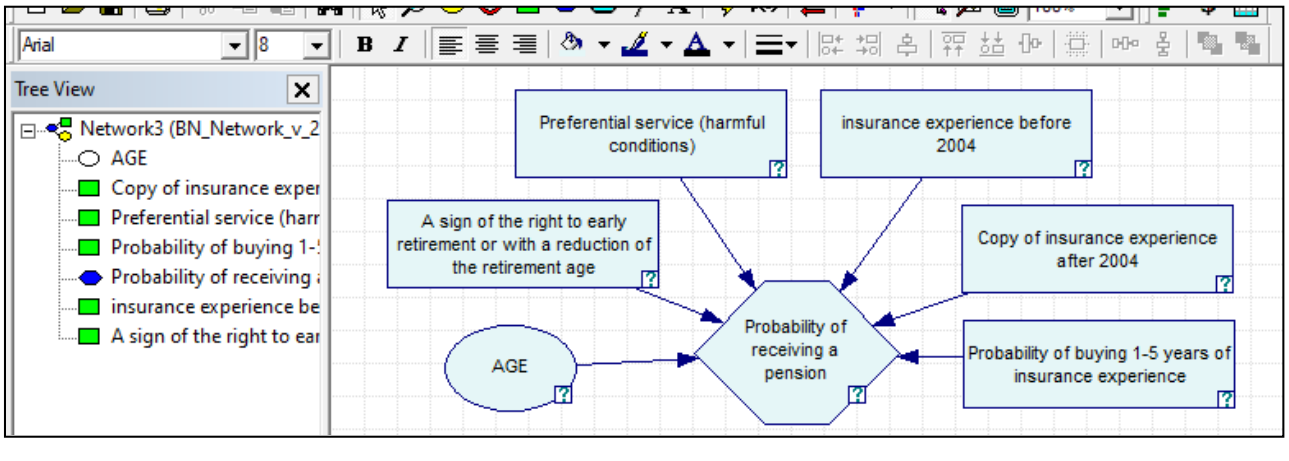

Fig. 5. Topology of the constructed Bayesian network in the Genie 2 system

ISSN 2664-9969

Table 1

The results of modeling the number of people born in 1964–1968 who will retire by age with different insurance experience, it is possible to take into account that the experience that is not enough (but not more than 5 years) can be bought up

Year of birth	Number of insured persons (available information on insurance experience)	From the total number of insured persons, %			
		The old-age pension will be assigned upon reaching the retirement age	The pension will be assigned upon reaching the retirement age, subject to the buying of experience	Pension will be assigned later (at age 63)	Pension will be assigned later (age 65)
1964	480964	77.77	10.44	6.41	3.21
1965	462280	75.67	11	6.75	3.95
1966	485298	72.01	12.26	7.78	4.7
1967	489583	68.79	13.48	8.63	5.25
1968	500903	65.06	15.44	9.42	5.87

In addition, another 50,213 (10.44 %) will be able to receive a pension at the age of 60, if they can (will have the desire) to "buy up" insurance experience, i. e., a total of 424,258 (88.21 %) people will buy the right to a pension at the age of 60 years. At the age of 63, with 21 to 31 years of insurance experience, 30,829 (6.41 %) people born in 1964 will be entitled to a pension. 15,438 (3.21 %) people will be entitled to a pension at the age of 65, having insurance experience of 15 years or more.

Persons born in 1965 will buy the right to a pension at the age of 60 if they have 32 years of insurance experience at the time of retirement age. There may be 349,807 (75.67 %) of such persons, subject to the conclusion of an agreement with the Pension Fund of Ukraine on voluntary participation in the pension insurance system, an additional 50,851 (11 %) persons will be able to receive the right to a pension at the age of 60, i. e. a total of 400,658 (86.67 %) persons. At the age of 63, having an insurance experience of 22 to 32 years at the time of retirement age, 31,203 (6.75 %) persons from the number of persons born in 1965 will buy the right to a pension. 18,260 (3.95 %) persons can become recipients of a pension at the age of 65 if they have at least 15 years of insurance experience at the time of retirement age.

Persons born in 1966 will be entitled to an old-age pension if they have 33 years of insurance experience by the time, they turn 60. There may be 349,463 (72.01 %) of such potential pensioners, and 59,498 (12.26 %) may potentially "buy up" insurance experience. That is, a total of 408,961 (84.27 %) people will have the right to receive a pension at the age of 60. At the age of 63, 37,756 (7.78 %) people with insurance experience of 23 to 33 years can become pensioners. 22,809 (4.7 %) persons will buy the right to receive a pension at the age of 65, having an insurance record of at least 15 years.

Persons born in 1967 will be entitled to a pension at the age of 60 if they have 34 years of insurance experience at the time of retirement age. There may be 336,784 (68.79 %) of such insured persons. If 65,996 (13.48 %) people decide to "buy up" the seniority, then a total of 402,780 (82.87 %) people will receive old-age pensions. At the age of 63, with 24 to 34 years of insurance experience at the time of retirement age, 42,251 (8.63 %) persons will be entitled to an old-age pension. Old-age pensions can be received from the age of 65 by persons who at that moment have at least 15 years of insurance experience. Potentially, there may be 25,703 (5.25 %) of such persons.

Persons born in 1968 will buy the right to receive a pension at the age of 60 if, at the time of reaching 60, they will have 35 years of insurance experience (this is 325,887 (65.06 %) persons). Persons who do not have the required length of service (35 years) at the time of reaching retirement age, but will be able to (have the desire to) "buy up" length of service, will be able to join the pension recipients. This is another 77,339 (15.44 %) potential recipients of old-age pensions. That is, a total of 403,227 (80.5 %) persons will buy the right to receive a pension at the age of 60 in 2028. At the age of 63, with insurance experience from 25 to 35 years, 47,185 (9.42 %) will receive the right to receive a pension. At the age of 65, with 15 to 25 years of insurance experience at the time of buying the right to a pension, 29,403 (5.87 %) people will be able to receive a pension.

In the future, the method should be improved by using ensembles of models, which will include regression models, cognitive models, scenario analysis, etc., in addition to Bayesian networks. In addition, additional regressors will be added to the studied data sets, which will allow taking into account more criteria that determine the right to the appointment of old-age pensions.

Expanding the range of applied mathematical models will allow the proposed method to be used in the social security system to determine the number of people who will need social assistance.

The proposed system can be adapted for use in the new pension system. In particular, it can be used to perform predictive calculations, develop scenarios and foresights for the development of the pension system. This will make it possible to increase its financial stability on the basis of the implementation of scientifically based approaches to decision-making in the conditions of systemic uncertainty during the war and post-war reconstruction.

The limitations of the research are the lack of complete information about the length of service of persons insured in the system of national pension insurance, death or stay abroad, and there is also no complete information about the number of missing persons.

The conditions of martial law greatly complicated the conduct of this research, since it is practically impossible to obtain reliable statistical data on the number, composition and structure of the population both in the occupied territories and those who are abroad. Therefore, the error in predictive calculations is greater than under normal conditions.

4. Conclusions

The proposed method of forecasting the number of pension recipients using probabilistic statistical models can be used during the formation of the budget of the Pension Fund of Ukraine. However, it needs to be tested on real data of personalized accounting. To verify the correctness of the obtained results, a comparison was made between the results of forecasting the number of pensioners by age according to the proposed model and the increase in the number of pensions by age assigned in 2021–2023. The deviation of the simulated values from those calculated on the basis of statistical data does not exceed 15 %, which indicates an acceptable the quality of the proposed methodology.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

References

1. Zelenko, V. (2023). *Reformuvannia pensiinoi systemy Ukrainy u svitli yevropeiskykh standartiv*. Lviv: LNU im. Ivana Franka, 202.
2. *Ministerka sotsialnoi polityky Maryna Lazebna: pro pensiinu reformu i zaprovadzhennia nakopychuvalnoi systemy* (2021). Available at: https://www.msp.gov.ua/news/20328.html
3. *U Minsotspolityky spodivaiutsia zapustyty reformu solidarnoi pensiinoi systemy u lypni 2025 roku* (2024). Available at: https://www.ukrinform.ua/rubric-society/3910430-u-minsocpolitiki-spodivautsa-zapustiti-reformu-solidarnoi-pensijnoi-sistemi-u-lipni-2025-roku.html
4. *Korporatyvnyi nederzhavnyi pensiinyi fond Natsionalnoho banku Ukrainy*. Available at: https://knpf.bank.gov.ua
5. Lypko, N. (2023). Analysis of the current state of the pension system in Ukraine and the search for the ways to reform IT. *Economy and Society, 51*. https://doi.org/10.32782/2524-0072/2023-51-44
6. *Maibutnie pensiinoi systemy Ukrainy: adekvatnist, okhoplennia ta stiikist* (2019). Budapesht: Mizhnarodna orhanizatsiia pratsi, 90. Available at: https://www.ilo.org/uk/publications/maybutnye-pensiynoyi-systemy-ukrayiny-adekvatnist-okhoplennya-ta-stiykist
7. *Metodyka provedennia aktuarnykh rozrakhunkiv u systemi zahalnooboviazkovoho derzhavnoho pensiinoho strakhuvannia* (2004). Postanova Kabinetu Ministriv Ukrainy No. 1677. 16.12.2004. Available at: https://www.kmu.gov.ua/npas/10301286
8. *Pro zatverdzhennia Poriadku provedennia aktuarnykh rozrakhunkiv u systemi zahalnooboviazkovoho derzhavnoho pensiinoho strakhuvannia* (2005). Postanova pravlinnia Pensiinoho Fondu Ukrainy No. 12-1. 18.07.2005. Available at: https://zakon.rada.gov.ua/laws/show/z0840-05#Text
9. Telichko, N. A. (2013). Actuarial methods to ensure of the pension systems financial sustainability. *Visnyk Skhidnoukrainskoho nats. un-tu imeni Volodymyra Dalia, 3 (192)*, 164–171.
10. Romanchuk, N. N. (2017). Tax-benefit model: methodological aspects of implementation. *Ekonomika i suspilstvo, 11,* 588–592.
11. *Modeling Pension Reform: The World Bank's Pension Reform Options Simulation Toolkit* (2010). World Bank Pension Reform Primer Series, World Bank PROST Model. Available at: http://hdl.handle.net/10986/11074
12. *Pensions at a Glance 2021: OECD and G20 Indicators* (2020). Paris: OECD Publishing, 224. https://doi.org/10.1787/ca401ebd-en
13. *Pensions Schemes and Projection Models in EU-25 Member States* (2007). Occasional Papers, 35, 377. Available at: https://ec.europa.eu/economy_finance/publications/pages/publication10173_en.pdf
14. Sze, M. (1993). The Process of Pension Forecasting. *Journal of actuarial practice, 1 (1)*, 31–50. Available at: https://core.ac.uk/download/pdf/127444889.pdf
15. Trukhan, S. V., Bidiuk, P. I. (2015). Methods of building mathematical models ofactuarial processes. *Eastern-European Journal of Enterprise Technologies, 1 (4 (73))*, 27–35. https://doi.org/10.15587/1729-4061.2015.36486
16. *Pro zahalnooboviazkove derzhavne pensiine strakhuvannia* (2003). Zakon Ukrainy No. 1058-IV. 09.07.2003. Available at: https://zakon.rada.gov.ua/laws/show/1058-15#Text
17. *Ofitsinyi sait Pensiinoho fondu Ukrainy*. Available at: https://www.pfu.gov.ua/statystyka/
18. *Stratehiia demohrafichnoho rozvytku Ukrainy na period do 2040 roku*. Available at: https://www.msp.gov.ua/projects/870/
19. *Derzhavna sluzhba statystyky Ukrainy*. Available at: http://www.ukrstat.gov.ua/
20. *Zvit pro robotu ta vykonannia biudzhetu Pensiinoho fondu Ukrainy u 2023 rotsi*. Available at: https://www.kmu.gov.ua/storage/app/sites/1/17-civik-2018/zvit2023/zvit_PFU_2023_.pdf
21. Zghurovskyi, M. Z., Pankratova, N. D. (2007). *Osnovy systemnoho analizu*. Kyiv: Vydavnycha hrupa BHV, 544.
22. Zgurovsky, M. Z., Zaychenko, Y. P. (2016). *The Fundamentals of Computational Intelligence: System Approach*. Springer International Publishing, 375. https://doi.org/10.1007/978-3-319-35162-9
23. Andreica, M., Popescu, M. E., Micu, D., Albu, E. (2016). Adaptive management procedural model for support of economic organizations. *Proc of 10th International Management Conference "Challenges of Modern Management"*, 295–301.
24. Dobrescu, E. (2017). Modelling an Emergent Economy and Parameter Instability Problem. *Journal for Economic Forecasting of Institute for Economic Forecasting, 2*, 5–28. Available at: https://ideas.repec.org/a/rjr/romjef/vy2017i2p5-28.html
25. Bidyuk, P., Tymoshchuk, O., Kovalenko, A., Korshevnyuk, L. (2022). *Systems and Methods for Decision Support*. Kyiv: Polytechnika Publisher at the National Technical University of Ukraine "Igor Sikorsky KPI", 610.
26. Zgurovsky, M. Z., Bidyuk, P. I., Terentiev, O. M., Prosyankina-Zharova, T. I. (2015). *Bayesian Networks in Decision Support Systems*. Kyiv: Edelweiss, 300.
27. Holsapple, C. W., Winston, A. B. (1996). *Decision Support Systems*. Saint Paul: West Publishing Company, 850.
28. Turban, E., Aronson, J. E. (2001). *Decision Support Systems*. New Jersey: Prentice Hall, 865.
29. Borra, S., Dey, N., Bhattacharyya, S., Bouhlel, M. S. (2019). *Intelligent decision support systems, Intelligent Decision Support Systems: Applications in Signal Processing*. Berlin, Boston: De Gruyter, 183. https://doi.org/10.1515/9783110621105
30. Alasiri, M. M., Salameh, A. A. (2020). The impact of business intelligence (BI) and decision support systems (DSS): exploratory study. *International Journal of Management, 11 (5)*, 1001–1016.
31. Friedman, N., Linial, M., Nachman, I., Pe'er, D. (2000). Using Bayesian Networks to Analyze Expression Data. *Journal of Computational Biology, 7 (3-4)*, 601–620. https://doi.org/10.1089/106652700750050961
32. Heckerman, D. (1997). Bayesian Networks for Data Mining. *Data Mining and Knowledge Discovery, 1,* 79–119. https://doi.org/10.1023/a:1009730122752
33. Trofimchuk, O., Bidyuk, P., Kozshukhivska, O., Kozshukhivskyy, A. (2015). Probabilistic and statistical uncertainty Decision Support Systems. *Visnyk of Lviv Polytechnic National University, 826*, 237–248.
34. Gelman, A., Carlin, J. B., Stern, H. S., Rubin, D. B. (2000). *Bayesian Data Analysis*. New York: Chapman and Hall, CRC Press, 670.

ISSN 2664-9969

35. Jensen, F. V., Nielsen, Th. D. (2007). *Bayesian Networks and Decision Graphs*. New York: Springer, 457. https://doi.org/10.1007/978-0-387-68282-2
36. Jilani, T., Najamuddin, M. (2014). A Review Adaptive Bayesian modeling for time series forecasting. *Journal of Applied Environmental and Biological Sciences, 4 (7S)*, 99–106.
37. Mani, S., McDermott, S., Valtorta, M. (1997). MENTOR: A bayesian model for prediction of mental retardation in newborns. *Research in Developmental Disabilities, 18 (5)*, 303–318. https://doi.org/10.1016/s0891-4222(97)00012-7
38. Gembarski, P. C., Plappert, S., Lachmayer, R. (2021). Making design decisions under uncertainties: probabilistic reasoning and robust product design. *Journal of Intelligent Information Systems, 57 (3)*, 563–581. https://doi.org/10.1007/s10844-021-00665-6
39. Bidyuk, P., Prosyankina-Zharova, T., Terentiev, O.; Hu, Z., Petoukhov, S., Dychka, I., He, M. (Eds.) (2019). Modelling Nonlinear Nonstationary Processes in Macroeconomy and Finances. Advances in Computer Science for Engineering and Education. *ICCSEEA 2018. Advances in Intelligent Systems and Computing*. Cham: Springer, 754, 735–745. Available at: http://doi.org/10.1007/978-3-319-91008-6_72
40. *GeNIe 2.0*. Available at: https://genie.updatestar.com/en#google_vignette
41. Brocklebank, J. C., Dickey, D. A. (2003). *SAS System for Forecasting Time Series*. Cary N C. SAS Institute Inc., 418.
42. *SAS Visual Analytics*. SAS Institute. Available at: https://www.sas.com/ru_ua/software/visual-analytics.html

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