International Journal of Technology 14(8) 1643-1652 (2023)
Received September 2023 / Revised November 2023 / Accepted December 2023

International Journal of Technology

http://ijtech.eng.ui.ac.id

Neural Simulation of Digital Twin of Top Management Motivation Mechanism in Regional Government Agencies

Sergei Yashin[1*], Nadezhda Yashina[2], Egor Koshelev[1], Alexey Ivanov[1], Svetlana Zakharova[1]

[1]*Department of Management and Public Administration, The Institute of Economics and Entrepreneurship, Lobachevsky University, 23 Gagarin Ave, 603950, Nizhni Novgorod, Russia*
[2]*Department of Finance and Credit, The Institute of Economics and Entrepreneurship, Lobachevsky University, 23 Gagarin Ave, 603950, Nizhni Novgorod, Russia*

Abstract. The aim of the research was the problem of neural simulation of the digital twin of non-financial and financial motivation of top management in government agencies, as well as the strategic potential of regions. Bayesian regularization is used as the network training algorithm because the quasi-time series developed for 83 regions in Russia for the period from 2010 to 2021 is highly noisy. The inner layer of the network has 15 neurons since in this case, the network is trained most optimally. In the verification stage of the trained network, the comparison of actual and forecast data showed that in 2021, the error of the trained network was to average the fluctuations of the quasi-time series. In other words, the network does not account for the overall downward trend in the data. This problem requires a separate in-depth study. For instance, in the case of the Nizhny Novgorod Region, it has been observed that in 2020 and 2021, top managers performed better than those in the leading region (Moscow) based on the parameter of the total area of residential premises per capita. Therefore, they should be financially rewarded for their performance. In terms of non-financial motivation, the top managers should be rewarded more in 2021 than in 2020. The strategic potential of the Nizhny Novgorod Region as a whole is more developed in 2021 than in 2020, which allows us to assess the region's development prospects positively.

Keywords: Bayesian regularization; Digital twin; Motivation of top managers; Neural simulation

1. Introduction

Advances in machine learning, the Internet of Things and big data have led to significant improvements in digital twin (DT) functions such as real-time monitoring and accurate forecasting (Sharma *et al.*, 2022).

A digital twin is a digital (virtual) model of objects, systems, processes, or people. It precisely replicates the form and actions of the original and remains synchronized with it. Thus, the paper by Sulitka *et al.* (2022) presents a strategy for implementing a process digital twin as an extension of the CNC machining process planning chain.

The paper by Blair and Henrys (2023) discusses the role of data science in the digital twins of the natural environment, focusing on how the resulting data models can work alongside the rich legacy of process models that exist in this domain.

*Corresponding author's email: jashinsn@yandex.ru, Tel.: +7-831-2451164; Fax.: +7-831-2403003
doi: 10.14716/ijtech.v14i8.6840

Digital twins are highly dependent on their individual use case, which leads to a plethora of DT configurations. Based on a thorough literature review and two series of interviews with experts from various electrical and mechanical engineering companies, this paper proposes a set of digital twin archetypes for individual use cases (Valk, Haße, and Möller, 2022).

However, digital twins are highly compatible with artificial intelligence (AI) as they can be mapped to all types of data and intelligence associated with a physical system (Elbouzidi *et al.*, 2023).

Given that artificial intelligence (AI) has predictive capabilities that enable it to anticipate the future state of a physical system, digital twins proactively take context-sensitive preventive steps. In contrast, traditional closed-loop feedback control is typically reactive (Gunasegaram *et al.*, 2021).

A transfer learning method is applied in the paper by Tan *et al.* (2022) to train the model. The type of transfer learning used is finetuning. A modified pre-trained ResNet18 network architecture is used to train the Malaysian vanity license plate recognition model.

In the paper by Amalia, Ushada, and Pamungkas (2023), the optimal ANN structure was determined by four input, four hidden, and two output neurons. The activation function was sigmoid for both layers.

In this paper, we perform a neural simulation of the digital twin of the motivation mechanism for top management in government agencies. By the digital twin of this mechanism, we mean a joint digital model of non-financial and financial motivation of top management in regional government agencies and a model of the strategic potential of regions. These types of motivation are the object of research.

An article by Fernandes, Santinha, and Forte (2022) assesses the motivational factors of choice for the public health sector, as well as the conceptual and methodological trends of this research stream. The Construction and Scale of Public Service Motivation (PSM) is often used as a major framework, but there is also a concern when assessing motivation based on psychological constructs that reflect a complex line of work and environment, such as presenteeism, stress, and perceived obstacles.

Motivation in work in public service (WMPS) was investigated in the article by Xu (2022) to solve the problem of work motivation of officials based on the theory of self-determination (SDT). Correlation analysis has shown that a favorable work climate, such as perceived autonomy and kinship, is positively associated with autonomous motivation and negatively associated with controlled motivation and amotivation.

It is noted that citizens are not ready to fully exercise public control. Abdullahi *et al.* (2022) analyze the role of professional officials in the context of good governance. The findings of this paper revealed the main problems of the bureaucratic institution, which include, among others, corruption, lack of a merit system, poor training, and favoritism, which undermine good governance and innovation in Nigeria.

2. Methods

We use Bayesian regularization of the neural network. While it may take longer for some noisy and small tasks, it provides a better solution. Let us describe its benefits in more detail.

Based on asymmetric Laplace distribution, the Bayesian regularized quantum regression approach performs better than the non-Bayesian approach in parameter estimation and prediction (Tang *et al.*, 2020).

In the study by Kiani *et al.* (2021), intelligent backpropagation networks based on AI-Bayesian regularization (IBNs-BR) were used to numerically process mathematical models representing environmental economic systems (EESs).

Mulgrave and Ghosal (2022) apply a plug-in variational Bayesian algorithm to learn a sparse precision matrix and compare the performance with a Gibbs posterior sampling scheme in a simulation study. The proposed methods have better performance as the dimensionality increases, and in particular, the variational Bayesian approach can potentially speed up the estimation in a Bayesian nonparanormal graphical model without assuming Gaussianity while preserving the graph information.

The paper by Olivier *et al.* (2023) presents an ensemble method with regularization of the function space that integrates a priori information about the function of interest, thereby improving generalization performance while allowing quantification of aleatory and epistemic uncertainties.

Fiorentini, Pellegrini, and Losa (2023) implemented a backpropagation Bayesian regularization (BR) algorithm to calibrate an artificial neural network (ANN) as an accident prediction model (APM) to be used on Italian four-lane divided roads. They selected BR-ANN due to its effective handling of small sample sizes and its ability to mitigate overfitting problems by introducing a regularization term into the target function, which is minimized during training.

A Bayesian regularization-backpropagation neural network (BRBPNN) model is employed to predict some aspects of the gecko spatula peeling. These aspects include, the variation of the maximum normal and tangential pull-off forces and the resultant force angle at detachment with the peeling angle. The BR-BPNN model, in combination with the *k*-fold method, has been shown to have significant potential for estimating the peeling behavior (Gouravaraju *et al.*, 2023).

In the paper by Yashin *et al.* (2020), the authors have already addressed a simpler problem related to financial and non-financial motivation in regional government agencies. To solve this problem, a multi-objective genetic algorithm was used to obtain a Pareto frontier for a two-objective function of natural population growth, all the solutions of which are equally optimal.

However, here we solve a larger-scale problem of simulating the non-financial and financial motivation of top management, as well as the strategic potential of regions, which allows us to assess the prospects of regional development. In addition, the digital twin of this motivation mechanism will be simulated using a neural network. All of this allows for more detailed simulation results, which is the purpose of the study.

Let us describe the objectives of the study. For the purpose of neural simulation of the digital twin of top management motivation in government agencies, the dependence of the coefficient of natural population growth per 1,000 people depending on three aggregated input data types is investigated: indicators characterizing non-financial and financial motivation of top management, as well as the strategic potential of the region. After such a model is developed and trained, the optimal values of all input parameters of the model are determined, and then tangible and intangible rewards are assigned to top managers depending on the extent to which the performance of their regions corresponds to the optimal values.

For this purpose, the neural simulation method is applied, which involves Bayesian regularization of neural network training.

The stages of development and implementation of such a model are presented in Figure 1. The advantage of our model consists in the fact that it makes it possible to solve the problem of neural simulation of the digital twin of non-financial and financial motivation of top management in government agencies, as well as the strategic potential of regions.

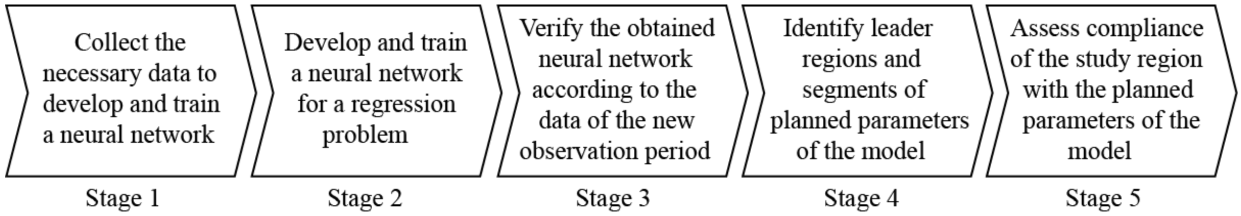


Figure 1 Stages of Neural Simulation of Digital Twin of Top Management Motivation in Regional Government Agencies

Stage 1 – Collect the necessary data to develop and train a neural network. For this purpose, data on the ranks of the constituent entities of the Russian Federation are collected according to the following criteria:

1) Gross regional product (GRP) per capita (x_1);
2) Capital investments per capita (x_2);
3) Per capita expenditure on innovation activities (x_3);
4) Average cash income per capita (per month) (x_4);
5) Total living space per capita (x_5);
6) Relative share of paved roads (x_6);
7) Per capita tax revenue (x_7);
8) Employment level (x_8);
9) Number of students per 10,000 population (x_9).

These are the input parameters of the model. At the same time, the first 3 factors determine the non-financial motivation of top management, the next 3 factors determine the financial motivation, and the last 3 factors determine the strategic potential of the regions.

Financial motivation of top managers refers to the amount of salary, and non-financial motivation refers to their career growth.

The natural population growth rate per 1,000 people is taken as the target function (y). Its value should be maximized.

We take all these input and output parameters of the model for 83 regions of the country for the period from 2010 to 2021. Thus, we obtain a quasi-time series with a duration of 996 periods. For it, we develop multiple regression using neural network training.

Stage 2 – Develop and train a neural network for a regression problem. We develop and train a neural network in the *Matlab* software program. In doing so, we apply Bayesian regularization as the training algorithm because the developed quasi-time series is highly noisy. On the inner layer of the network, we set 15 neurons because, in this case, the network is trained most optimally.

We train the neural network on 913 observation periods from 2010 to 2020. We allocate 70% of the data for the training sample, 15% for validation, and 15% of the data for the test sample. We leave the remaining 83 observation periods in 2021 for verification of the already trained neural network.

Stage 3 – Verify the obtained neural network according to the data of the new observation period. At this stage, we substitute the latest 2021 data into the already trained neural network to evaluate how well the network predicts the values of the target function (y).

Stage 4 – Identify leader regions and segments of planned parameters of the model. Here, we initially identify leader regions by considering cases where the value of the target function (y) is positive for both actual and predicted values obtained from the model. In doing so, we exclude those cases where the deviation of forecast values from actual values for the coefficient of natural population growth (y) is greater than 1. Then, we find those regions for which the above criteria are fulfilled simultaneously more times. These will be the regions we are looking for – leaders by which we will be guided in the future.

After that, the segments of the planned model parameters (x_1, x_2, ..., x_9) are determined for the found leader regions according to the actual values of the ranks of the constituent entities of the Russian Federation in 2010-2020.

Stage 5 – Assess compliance of the study region with the planned parameters of the model. This stage determines whether the actual ranks of the constituent entities of the Russian Federation in 2020 and 2021 correspond to the segments of the planned parameters of the model. This assessment is performed for each parameter x_1, x_2, ..., x_9. If such correspondence is revealed for x_1, x_2, x_3, it means that top managers of government agencies of the region under study should be encouraged non-financially. If correspondence is observed for x_4, x_5, and x_6, it suggests that they should be financially rewarded. If the correspondence is for x_7, x_8, and x_9, it indicates the strategic potential of the region's development in the near future, which will subsequently affect the parameters of non-financial or financial motivation, which will entail the need to encourage them accordingly.

In the future, the trained neural network can be further trained on new actual data so that it predicts the forecast of the natural population growth rate (y) even more accurately.

3. Results and Discussion

Let us illustrate the process of neural simulation of the digital twin of top management motivation in regional government agencies using the data of 2010-2021. **Stage 1.** Using data from the website of the Federal State Statistics Service (*www.gks.ru*), let us to collect all the necessary data in Table 1. As a result, we obtain a data matrix of the 996×10 dimension.

Stage 2. Using the Bayesian regularization algorithm and 15 neurons on the inner layer of the network, we develop and train a neural network in the *Matlab* software program. The results are shown in Figures 2 and 3.

As Figure 2 shows, for this problem, the correspondence of the output data to the target values is sufficiently good for all data sets with correlation coefficient R values of 0.93 or higher in each case.

The error histogram in Figure 3 (a) shows that there is a training point with error -7. However, this is not critical for this neural network.

Stage 3. Comparing the actual and forecast data in Figure 3 (b), it is easy to see that in 2021, the error of the trained network consists in averaging the fluctuations of the quasi-time series. In other words, the network does not take into account the general downward trend of the data. This problem requires a separate in-depth study.

Stage 4. Table 2 presents the leader region for which the positive value of the target function (y) is observed simultaneously for its actual and forecast values in 2010-2020 and for which this is fulfilled more times, i.e., 9. This excludes cases when the deviation of forecast values from actual values for y is greater than 1.

Table 1 Input Data for Neural Simulation of the Digital Twin

Region	Russian constituent entity's rank									Coeffi-cient of natural popu-lation growth per 1,000 people
	Non-financial motivation			Financial motivation			Strategic potential			
	GRP per capita	Capital invest-ments per capita	Per capita expen-diture on innova-tion activi-ties	Ave-rage cash in-come per capita (per month)	Total living space per capita	Rela-tive share of paved roads	Per capita tax reve-nue	Em-ploy-ment level	Num-ber of stu-dents per 10,000 popu-lation	
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	y
2010										
Belgo-rod Region	17	25	28	24	13	28	34	47	16	-3.5
Bryansk Region	69	63	55	60	20	26	74	59	35	-6.3
Vladi-mir Region	47	60	33	69	22	3	46	34	56	-7.2
...	...	...	...	...	...	...	...	...	...	...

Source: Federal State Statistics Service (*www.gks.ru*)

Table 2 Ranges of Ranks of the Leader Region in 2010-2020

Region	Segments of Russian constituent entity's rank									Frequency
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	
Moscow	[4;6]	[10;27]	[3;12]	[1;4]	[76;82]	[1;3]	[5;6]	[3;6]	[1;2]	9 times

Stage 5. In Table 3, as an example, we will assess to what extent the performance of the top management of the Nizhny Novgorod Region government agencies in 2020 and 2021 corresponds to the planned parameters for the leader region from Table 2.

Table 3 Performance Results of the Nizhny Novgorod Region in 2020 and 2021

Year	Russian constituent entity's rank									Coefficient
	Non-financial motivation			Financial motivation			Strategic potential			
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	y
2021	38 [4;6]	31 [10;27]	**<u>6</u>** [3;12]	21 [1;4]	**34** [76;82]	50 [1;3]	23 [5;6]	16 [3;6]	27 [1;2]	-6.7
2020	36 [4;6]	**<u>25</u>** [10;27]	**2** [3;12]	21 [1;4]	**32** [76;82]	50 [1;3]	30 [5;6]	13 [3;6]	29 [1;2]	-8.6

According to the data of Table 3, the following conclusions can be drawn:

1. In both years, the top managers worked better than in the leader region by the parameter of the total area of residential premises per capita (x_5 better). Therefore, they should be rewarded financially for this. (Financial motivation of top managers refers to the amount of salary, and non-financial motivation refers to their career growth).

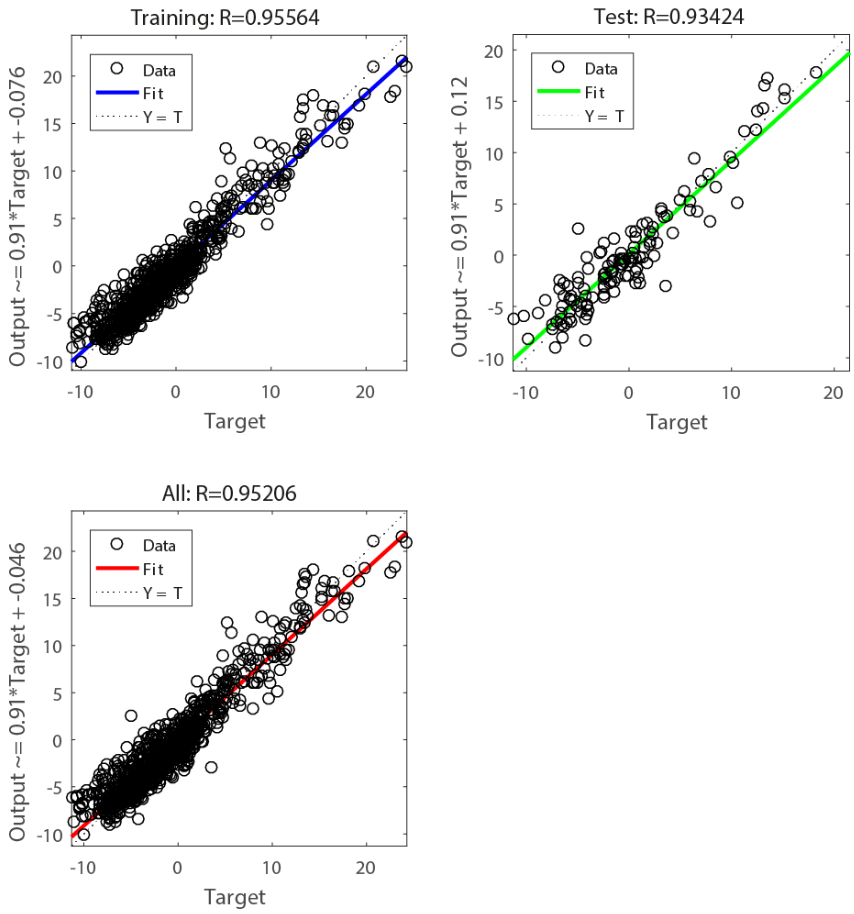
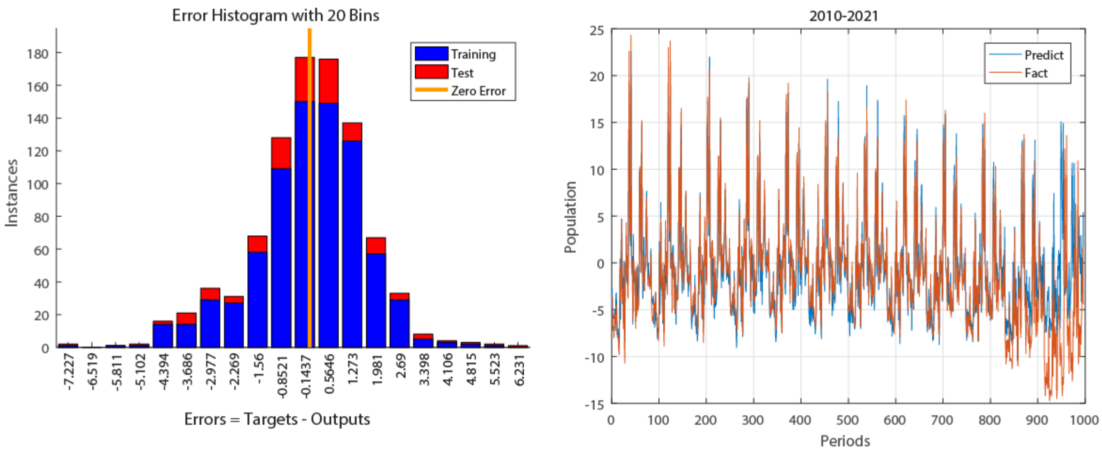


Figure 2 Output Data Regarding Targets for Training and Testing Sets and Whole Set



a) b)

Figure 3 Error Histogram (a) and Correspondence Between Actual and Forecast Data (b)

2. In terms of non-financial motivation, the top managers should be rewarded more in 2020 than in 2021.

3. The strategic potential of the Nizhny Novgorod Region as a whole is more developed in 2021 than in 2020 (x_7 and x_9), which allows us to assess the region's development prospects positively. This may further have a positive impact on financial and non-financial motivation of the top managers. Let us compare the results obtained with those of other authors.

In the paper by Popadinets *et al.* (2021), using the method of linear multiple regression, a system of equations was developed to describe the economic-mathematical model of management motivation at oil and gas enterprises, which, after repeated experiments provided diagnostics of indicators before, during and after the implementation of the management motivation model.

A study by Zubair, Khan, and Mukaram (2021) developed a structural model to test the different scenarios predicted in the hypotheses for public service motivation (PSM). Analysis revealed that PSM, political support and altruism have a positive relationship with organizational performance whereas PSM relationship with political support could not be established. An analysis showed that PSM, political support (PS), and altruism (ALT) intermediate effects had a positive relationship with organizational performance (OP), while the relationship of PSM with PS could not be established.

The paper by Fernandes, Santinha, and Forte (2022) assessed motivational factors for public sector choice in health care. This study used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. It has been found that it is important to assess motivation based on psychological constructs that reflect the complex lineage of work and environment, such as presenteeism, stress, and perception of obstacles.

The paper by Xu (2022) investigated work motivation in public service (WMPS) based on self-determination theory (SDT). Using mixed methods, the WMPS scale was developed in the Chinese context. A correlation analysis showed that a favorable work climate, such as perceived autonomy and relatedness, was positively associated with autonomous motivation and negatively associated with controlled motivation and amotivation.

The advantage of our model consists in the fact that it makes it possible to solve the problem of neural simulation of the digital twin of non-financial and financial motivation of top management in government agencies, as well as the strategic potential of regions.

4. Conclusions

In conclusion, we will present the main findings of the study:

1. The paper solves the problem of simulating the non-financial and financial motivation of top management and the strategic potential of regions, which allows us to assess the prospects of regional development as well. In addition, the digital twin of this motivation mechanism is simulated using a neural network. All of this allows for more detailed simulation results.

2. Bayesian regularization has been applied as the training algorithm because the developed quasi-time series is highly noisy. The inner layer of the network comprises 15 neurons, as this configuration is optimal for training in this particular case.

3. In 2020 and 2021, the top managers In the Nizhny Novgorod Region worked better than in the leader region (Moscow) by the parameter of the total area of residential premises per capita. Therefore, they should be rewarded financially for this. In terms of non-financial motivation, the top managers should be rewarded more in 2021 than in 2020.

4. The strategic potential of the Nizhny Novgorod Region as a whole is more developed in 2021 than in 2020, which allows us to assess the region's development prospects positively. This may further have a positive impact on financial and non-financial motivation of the top managers.

In the verification stage of the trained network, the comparison of actual and forecast data showed that in 2021, the error of the trained network was to average the fluctuations of the quasi-time series. In other words, the network does not take into account the general downward trend of the data. This problem requires a separate future study.

Acknowledgments

The study was carried out within the framework of the realization of the Strategic Academic Leadership Program "Priority 2030", project H-426-99_2022-2023 "Socio-economic models and technologies for the creative human capital development in the innovative society".

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