New Concept to Multi-Criteria Model Automatization - Machine Learning Based Approach

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Abstract

The commonness of information systems based on machine learning (ML) models and multi-criteria decision analysis (MCDA) methods is growing due to the increasing dimensions of data required for processing. This paper presents a hybrid framework combining the MCDA method with ML models to predict the rankings of countries considering the fulfillment of Sustainable Development Goal 7 based on the identified preferences of decision-makers. The results proved that the proposed approach can be regarded as a functional tool for multi-criteria assessment in the case of inaccessibility of experts' knowledge. The proposed approach enables to mitigate the shortcomings of MCDA methods arising from the necessity to engage decision-makers.

Keywords: Decision support systems, Machine learning, Ranking prediction, Multi-Layer Perceptron Regressor, Multi-criteria decision analysis

1. Introduction

Intelligent information systems based on suitable methods and tools support the deriving of information from large-dimensional data [6]. Limited human cognitive abilities require using data science, including data mining methods, databases, machine learning (ML), and multi-criteria decision analysis (MCDA). This paper aims to demonstrate a framework combining ML supervised learning algorithms and MCDA methods designed for ranking prediction based on historical data assessed by experts. MCDA methods are useful when consideration of multiple dimensions is required. However, they show a shortcoming visible as a necessity of expert knowledge for determining preferences of considered criteria [2]. The unavailability of experts enforces the use of objective weighting methods based on data, however, there are cases where knowledge of expert preferences is irreplaceable. In such cases, ML models introduced in the proposed framework for ranking prediction may serve as a substitute for experts' knowledge. The usability of the presented framework is demonstrated on a real-world dataset including performances collected for European countries regarding implementation of the Sustainable Development Goal 7 directives. SDG 7, developed by the UN, is used to measure the achievement of the Sustainable Development Goals toward reliable, sustainable, and affordable energy systems [3].

2. Related works

ML models are applied for the prediction of indicated variables based on gained data. ML models yield predicted values using algorithms searching a relationship between observed reaction and predictor response by finding dominant patterns. ML models cover artificial neural networks, deep learning models, and architectures such as Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Deep Belief Networks (DBNs), Generative Adversarial Networks (GANs), Support Vector Machine models (SVM), k-nearest neighbour (KNN), logistic regression (LR), AdaBoost (AB), random forests (RF), genetic algorithms (GA), regression models, such as Linear Regression (LR), and Bayesian Linear Regression (BLR), and others [4, 9, 11].

Designing intelligent information systems frameworks includes joining ML techniques with other scientific approaches, such as MCDA methods. It enables to rise and expand the practical usability of information systems. Multi-criteria decision support based on a Multi-Layer Perceptron Regressor neural network is the object of research conducted by Guo et al. In the view of the authors, this integration delivers improved performance by grasping the relationship between individual attributes and predicted values. The proposed approach can be applied in domains like human resources, medicine, and marketing domains [5]. In the next work, Nachappa et al. integrated two multi-criteria decision analysis (MCDA) models, like analytical hierarchical process (AHP) and analytical network process (ANP), and two ML models, like random forest (RF) and Support Vector Machine (SVM), to determine flood susceptibility [8].

3. Methodology

In this paper, we applied the proposed framework to predict the rankings of selected European countries regarding the implementation of Sustainable Development Goal 7 (SDG 7). Data for ten SDG 7 indicators listed in Supplementary material at `https://github.com/energyinpython/ISD-2024-SDG-7` were acquired from the Eurostat database for the years 2013-2022. The target variable is the score of each alternative provided by a multi-criteria decision analysis (MCDA) assessment of the historical dataset performed by experts. Expert assessment of countries was performed for each year using the TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution). The TOPSIS method proposed by Hwang and Yoon in 1981 [10] was selected thus its popularity, broad usability, and algorithm simplicity, which facilitates explaining novel methodical approaches. The relatively straightforward TOPSIS algorithm is in this case an advantage over methods requiring more complex calculations and procedures such as outranking methods namely PROMETHEE and ELECTRE or methods requiring analysis of additional conditions like VIKOR. In addition, TOPSIS results are numerical values, which makes it possible to use them for ML prediction procedures in contrast to PROMETHEE or ELECTRE.

The assessment results are scores obtained for each country in each considered year representing the target variable. In this way, a dataset including values for 2013-2021 containing 261 samples was received. The gained dataset was split randomly into a training dataset with 80% of the samples and a test dataset with 20% of the samples. A dataset with samples for each considered country collected for 2022 was applied as a test dataset for the last stage of the research. The dataset was normalized with the Minimum-Maximum technique for the following ML procedures such as the selection of hyper-parameters for ML models, cross-validation, model training, and prediction. For prediction, we have selected the Multi-Layer Perceptron Regressor, which is a feedforward type. MLP applies the backpropagation supervised learning method for training using a nonlinear activation function [7]. Four reference ML models, such as Linear Regression (LR) [4], Bayesian Ridge Regression (BRR) [9], Kernel Ridge Regression (KRR) [11], and Gradient Boosting Regressor (GBR) [1], were selected as reference models.

4. Results

Hyper-parameters selected for the MLP regressor model using GridSearchCV algorithm provided in scikit-learn Python library are as follows: {Hidden layer sizes: 100, Activation: relu, Solver: lbfgs, α parameter: 0.0001, Learning rate: adaptive, Maximum iterations number: 250}. Results of a k-fold cross-validation procedure, where k = 2, was performed using regression score function R^2 obtained for each fold are high and close to 1: {0.9895, 0.9956, 0.9922, 0.9945, 0.9622}. Then, the performance of the MLP Regressor was compared with five reference ML models. Values of evaluation metrics of investigated ML models such as MAE, MSE which were close to 0, and R^2 which were close to 1 have shown high and comparable performance of investigated ML models. Rankings of countries for the test dataset from the most recent available year, 2022, shown in Table 1 were obtained by sorting scores predicted by each tested ML model.

Table 1. Comparison of factual ranking for 2022 with rankings predicted by ML regression models.

Country	Factual	MLP	LR	KRR	GBR	BRR	Country	Factual	MLP	LR	KRR	GBR	BRR
Belgium	14	15	14	15	11	15	Luxembourg	7	7	7	8	7	7
Bulgaria	29	29	29	29	29	29	Hungary	16	17	17	17	17	17
Czechia	11	11	11	11	9	11	Malta	21	22	22	21	22	22
Denmark	5	5	5	5	5	5	Netherlands	13	14	13	14	13	13
Germany	15	13	12	13	15	12	Austria	6	6	6	6	6	6
Estonia	8	8	8	7	12	8	Poland	17	16	18	18	18	18
Ireland	10	9	10	10	8	10	Portugal	23	23	24	23	24	24
Greece	27	28	27	28	27	27	Romania	24	26	23	24	23	23
Spain	26	24	25	26	26	25	Slovenia	9	10	9	9	10	9
France	22	21	21	22	19	21	Slovakia	19	20	20	20	21	20
Croatia	18	18	16	16	16	16	Finland	4	4	4	4	4	4
Italy	20	19	19	19	20	19	Sweden	3	3	3	3	3	3
Cyprus	28	27	28	27	28	28	Iceland	2	2	2	2	2	2
Latvia	12	12	15	12	14	14	Norway	1	1	1	1	1	1
Lithuania	25	25	26	25	25	26							

The results demonstrate that the headings of all rankings predicted by tested ML models are convergent. The leading positions belong to Norway, Iceland, Sweden, Finland, Denmark, Austria, and Luxembourg. It is relevant, thus decision-makers and stakeholders are usually most interested in the tops of analyzed rankings. Thus, the precision shown by ML models for the top of the rankings prediction is advantageous. These results are in line with findings in research conducted by Elavarasan et al., where Iceland, Norway, and Sweden reached the top three ranks with the highest scores among 40 European countries analyzed in relation to the proposed SDG 7 composite index [3]. The r_w was incorporated to benchmark the consistency of predicted rankings with reference ranking created during experts' assessment. It can be observed that all investigated models gave rankings with high consistency to the factual ranking. The highest convergence was noted for the MLP Regressor (0.9959) and KRR model (0.9960). High consistency was also noticed for LR (0.9929) and BRR (0.9939). The least convergence was demonstrated by the GBR model (0.9843). The results of the comparative analysis show that the performance of investigated ML models may differ.

5. Conclusions

The results revealed that all investigated ML models proved good performance in rankings prediction. The results supported the significance of comparative analysis in view of discrepancies observed for the results of ML models. The comparative analysis enables highlighting the robustness of the variants when most ML models incorporated indicate them as leaders. The limitation of the proposed approach follows from relying on historical data, so any fluctuations

in the decision maker's preferences will be reflected with a latency, resulting in imprecision introduced into the model. Solving this shortcoming requires scheduled upgrades of the training dataset. Future work directions involve investigations for a larger training dataset.

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References

1. Cai, J., Xu, K., Zhu, Y., Hu, F., Li, L.: Prediction and analysis of net ecosystem carbon exchange based on gradient boosting regression and random forest. Applied energy 262, pp. 114566 (2020)
2. Cinelli, M., Kadziński, M., Gonzalez, M., Słowiński, R.: How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. Omega 96, pp. 102261 (2020)
3. Elavarasan, R.M., Pugazhendhi, R., Irfan, M., Mihet-Popa, L., Campana, P.E., Khan, I.A.: A novel Sustainable Development Goal 7 composite index as the paradigm for energy sustainability assessment: A case study from Europe. Applied Energy 307, pp. 118173 (2022)
4. Fiorucci, M., Khoroshiltseva, M., Pontil, M., Traviglia, A., Del Bue, A., James, S.: Machine learning for cultural heritage: A survey. Pattern Recognition Letters 133, pp. 102–108 (2020)
5. Guo, M., Zhang, Q., Liao, X., Chen, F.Y., Zeng, D.D.: A hybrid machine learning framework for analyzing human decision-making through learning preferences. Omega 101, pp. 102263 (2021)
6. Injadat, M., Moubayed, A., Nassif, A.B., Shami, A.: Machine learning towards intelligent systems: applications, challenges, and opportunities. Artificial Intelligence Review 54(5), pp. 3299–3348 (2021)
7. Mozaffaree Pour, N., Oja, T.: Prediction power of logistic regression (LR) and Multi-Layer Perceptron (MLP) models in exploring driving forces of urban expansion to be sustainable in Estonia. Sustainability 14(1), pp. 160 (2021)
8. Nachappa, T.G., Piralilou, S.T., Gholamnia, K., Ghorbanzadeh, O., Rahmati, O., Blaschke, T.: Flood susceptibility mapping with machine learning, multi-criteria decision analysis and ensemble using Dempster Shafer Theory. Journal of hydrology 590, pp. 125275 (2020)
9. Saqib, M.: Forecasting COVID-19 outbreak progression using hybrid polynomial-Bayesian ridge regression model. Applied Intelligence 51(5), pp. 2703–2713 (2021)
10. Uzun, B., Taiwo, M., Syidanova, A., Uzun Ozsahin, D.: The technique for order of preference by similarity to ideal solution (TOPSIS). Application of multi-criteria decision analysis in environmental and civil engineering pp. 25–30 (2021)
11. Zhang, H., Li, Y., Lu, W., Lin, Q.: On the optimality of misspecified kernel ridge regression. In: International Conference on Machine Learning. pp. 41331–41353. PMLR (2023)