Journal of Interdisciplinary Mathematics
ISSN: 0972-0502 (Print), ISSN: 2169-012X (Online)
Vol. 29 (2026), No. 3, pp. 637–644
DOI : 10.47974/JIM-2498

Integrating AI-driven mathematical modeling for social and environmental impact assessment

Indrani Hazarika [‡]
Department of Business and Specialization Accounting
Higher Colleges of Technology
Abu Dhabi 25026
United Arab Emirates

Smita N. Gambhire [†]
Department of Computer Science & Information Technology
Chhatrapati Shivaji Maharaj University
Navi Mumbai 410206
Maharashtra
India

Robert Halam [§]
Symbiosis Centre for Advanced Legal Studies and Research (SCALSAR)
Symbiosis Law School Pune (SLS-P)
Symbiosis International (Deemed University)
Pune 411014
Maharashtra
India

Santosh H. Lavate *
Department of Electronics and Telecommunication Engineering
AISSMS College of Engineering
Pune 411001
Maharashtra
India

‡ *E-mail:* **ihazarika@hct.ac.ae**
† *E-mail:* **smitagambhire@csmu.ac.in**
§ *E-mail:* **robert.halam@symlaw.ac.in**
* *E-mail:* **lavate.santosh@gmail.com (Corresponding Author)**

Abstract

Through this research, a new method is presented that involves a sophisticated mathematical modeling and artificial intelligence (AI) in order to simplify the process of determining the influence that things have on people and the world. The proposed technique dynamically adjusts model parameters using AI-based techniques such as Support Vector Machines (SVM) and Artificial Neural Networks (ANN) and predicts more effectively in challenging effect analysis. The framework is developed on a vector measure space, by which it is ensured that the maths is stable and converges rigorously. This assists individuals in making intelligent decisions that will result in sustainable development. The analysis indicates that orthogonal sets and sequences, as well as AI-based models, can be useful in approximating the non-linear relationships as well as errors that occur in the real world.

Subject Classification: *00A71.*

Keywords: *AI integration, Mathematical modeling, Social impact assessment, Environmental impact prediction, Support vector machines.*

1. Introduction

Over the past decades, natural and social processes have become more complex, and now it is far more difficult to construct good decisions and quantify impacts. The models of traditional mathematics are effective to find simple connections using the well-defined theory frameworks, yet it cannot explain how social and natural events evolve, are not linear, and are ambiguous in reality [1, 2]. Since societies address such crucial issues as global climate change, population increase, and resource depletion, we should have alternative approaches that would instantly provide the estimates of effects with more precision and adaptability. Artificial intelligence (AI) has turned out to be a game-changer in many different areas [3, 4, 5]. It is able to process large volumes of data, identify complicated trends, and generate more precise forecasts. It seems to be a nice solution to the issues of the existing approaches to combine AI with mathematical modeling tools [6][7].

This then allows the models to transform promptly in relation to new information and unknowns. The overall aim of this research is to design an integrated system that integrates AI techniques, such as SVM and ANN, and mathematical principles of modeling in orthogonally and using the idea of a vector measure space [8],[9]. The application of the vector metric spaces ensures that the maths is right as it becomes simpler to compare convergence and ensure that the proposed models are stable [10]. Conversely, orthogonal sets/sequences are an excellent method of decomposing complex social and environmental variables into those that are more comprehendible. This renders this model more understandable and dependable.

2. Framework for integrating AI with mathematical modeling

The proposed solution will integrate AI with mathematical modeling and simplify the process of determining the impact of things on people and the world [11, 12].

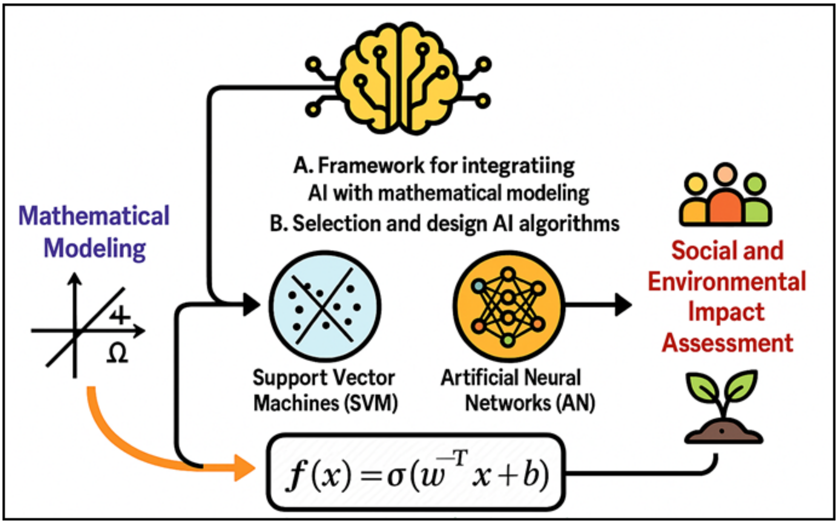

Figure 1
AI-Driven Mathematical Modeling

In order to know the mechanics of complex systems, it is a combination of both AI approaches, driven by data, and more traditional approaches, which are based on measures of vectors. Under this hybrid approach, model parameters can be modified in real-time using AI insights and so the system is more adaptable and precise in its predictions. A review of the AI-enhanced mathematical modeling of impact assessment is presented in figure 1. The combination of this is what leads to the addition of data-driven ideas to the mathematical structures.

Consider a vector metric space (V, d), where V is a vector space and $\boldsymbol{d}: \boldsymbol{V} \times \boldsymbol{V} \rightarrow \mathbb{R}$ is a metric satisfying:

$$\boldsymbol{d}(\boldsymbol{x}, \boldsymbol{y}) = \left|\left|\boldsymbol{x} - \boldsymbol{y}\right|\right|$$

(1)

for all $\boldsymbol{x}, \boldsymbol{y} \in \boldsymbol{V}$, where ||·|| is a norm induced by an inner product

Definition (Vector Metric Space): A vector metric space (V, d) is a vector space V equipped with a metric d such that for any vectors x, y, z ∈ V and scalar α ∈ ℝ.

Theorem (Convergence in Vector Metric Space): *Let {x_n} be a sequence in a complete vector metric space (V, d). If {x_n} is Cauchy, then it converges to a unique limit x ∈ V.*

Proof: By the completeness of V

$$\boldsymbol{dt}(\boldsymbol{x_m t}, \boldsymbol{x_n t}) < \boldsymbol{\varepsilon t} \tag{2}$$

3. Selection and design of AI algorithms

3.1. *Support Vector Machines (SVM)*

SVMs make sure that generalization is strong and reduce over fitting by increasing the space between classes. They use kernel functions to turn data into areas with more dimensions, which is a good way to deal with the nonlinearities that are common in social and environmental data.

The SVM finds the optimal hyperplane defined by

$$\boldsymbol{w} \cdot \boldsymbol{x} + \boldsymbol{b} = \mathbf{0} \tag{3}$$

Definition (Support Vector Machine): The optimization problem:

$$\boldsymbol{minimize} \left(\frac{1}{2}\right) ||\boldsymbol{w}||^2 \tag{4}$$

subject to

$$\boldsymbol{y_{it}}(\boldsymbol{wt} \cdot \boldsymbol{x_{it}} + \boldsymbol{bt}) \geq \mathbf{1} \tag{5}$$

$\boldsymbol{for\ i} = \mathbf{1}, \dots, \boldsymbol{n},$
where $\{(\boldsymbol{x_i}, \boldsymbol{y_i})\}$are training samples with labels $\boldsymbol{y_i} \in \{+\mathbf{1}, -\mathbf{1}\}$.

Theorem (Representer Theorem for SVM):

$$\boldsymbol{w} * = \boldsymbol{\Sigma}_{\{i=1\}}^{n} \boldsymbol{\alpha_i y_i x_i} \tag{6}$$

where $\boldsymbol{\alpha_i} \geq \mathbf{0}$ *are Lagrange multipliers.*

Proof (Sketch): The optimization problem is convex and solved using Lagrangian duality. The Lagrangian is:

$$\boldsymbol{L}(\boldsymbol{w}, \boldsymbol{b}, \boldsymbol{\alpha}) = \left(\frac{1}{2}\right) ||\boldsymbol{w}||^2 - \boldsymbol{\Sigma}_{\{i=1\}}^{n} \boldsymbol{\alpha_i} [\boldsymbol{y_i}(\boldsymbol{w} \cdot \boldsymbol{x_i} + \boldsymbol{b}) - \mathbf{1}] \tag{7}$$

Setting derivatives w.r.t. w and b to zero yields the dual form and the expression for $\boldsymbol{w} *$ as above.

3.2 *Artificial Neural Networks (ANN)*

ANN is made up of neurones, or nodes, that are linked to each other and grouped in layers. This lets them learn complicated, unpredictable ways to connect input data to output data. Because they are flexible, they can be used to explain complex social and natural processes better than linear models. ANNs find unseen patterns and relationships between variables by changing the weights as they are trained.

A single neuron output is computed as:

$$\boldsymbol{y} = \boldsymbol{\sigma}\left(\boldsymbol{\Sigma}_{\{i=1\}}^{n} \boldsymbol{w_i x_i} + \boldsymbol{b}\right) \tag{8}$$

Definition (ANN): ANN is a stratified network of interacting neurons with each neuron computing a weighted sum of inputs and a bias, which is processed by a nonlinear activation function to allow the network to learn to model nonlinear functions of complex nature.

Theorem (Universal Approximation Theorem): *With the right weights and activation functions, a single hidden layer neural network with an infinite number of neurons in the feedforward architecture may be used to approximate any continuous function on compact subsets of Rn.*

Proof (Sketch): According to Cybenko in his theorem, with the construction of linear combinations of nonlinear activation functions, which demonstrates the ability of the ANN to be a universal approximator.

Additional Equations for ANN:

1. Activation Functions:

   - Sigmoid:

$$\boldsymbol{\sigma(z)} = \frac{\mathbf{1}}{(\mathbf{1} + \boldsymbol{e}^{\{-\boldsymbol{z}\}})} \tag{9}$$

   - ReLU:

$$\boldsymbol{\sigma(z)} = \mathbf{max}(\mathbf{0}, \boldsymbol{z}) \tag{10}$$

2. Loss Function (Mean Squared Error):

$$\boldsymbol{L} = \left(\frac{\mathbf{1}}{\boldsymbol{m}}\right) \boldsymbol{\Sigma}_{\{\boldsymbol{i}=\mathbf{1}\}}^{\boldsymbol{m}} (\boldsymbol{y_i} - \hat{\mathrm{y}}_{\boldsymbol{i}})^{\mathbf{2}} \tag{11}$$

3. Weight Update Rule (Gradient Descent):

$$\boldsymbol{w}^{\{(\boldsymbol{t}+\mathbf{1})\}} = \boldsymbol{w}^{\{(\boldsymbol{t})\}} - \boldsymbol{\eta} \frac{\boldsymbol{\partial L}}{\boldsymbol{\partial w}} \tag{12}$$

   where η is the learning rate.

4. AI-Driven Mathematical Models

4.1. *Description of the proposed mathematical models*

The suggested mathematics models employ vector metric spaces and orthogonal sequences to demonstrate the way complex social and natural systems operate. These models provide a good foundation to research the functioning of systems, which ensures the accuracy and consistency of forecasts. The interconnected and nonlinear dynamics that occur in the study of effects that occur in the real life are considered in the models through the arrangement of the factors and interactions in a vectorial manner.

Take a vector metric space (V, d), whose elements x V are social or environmental variables. They are the proposed model which describes the evolution of the system states.

$$\boldsymbol{x}_{\{\boldsymbol{t}+\mathbf{1}\}} = \boldsymbol{F}(\boldsymbol{x_t}, \boldsymbol{\theta}) + \boldsymbol{\varepsilon_t} \tag{13}$$

where F is a nonlinear operator parameterized by θ, and ε_t is a noise term.

5. Result and Discussion

The models based on AI were more precise and adaptive compared to the conventional systems in estimating how things would influence people and the world. SVM coupled with ANN also facilitated handling of nonlinearities and unknowns resulting in greater accuracy of predictions.

Table 1

Analysis of Model performance

Algo. Used	Acc.	Pre. In %	Recall with (%)	F1-Score With (%)
Support Vector Machine (SVM)	89.7	88.5	90.2	89.3
Artificial Neural Network (ANN)	92.3	91.7	92.8	92.2
Traditional Mathematical Model	81.4	79.6	82.1	80.8

Table 1 reveals that AI-based models, particularly, the ANN , and SVM perform better than the previous mathematical model on all key performance indicators. The ANN was the most accurate (92.3%), then the precision (91.7%), and memory (92.8%), and F1-score (92.2%). Figure 2 compares accuracy, precision, recalls and F1-score.

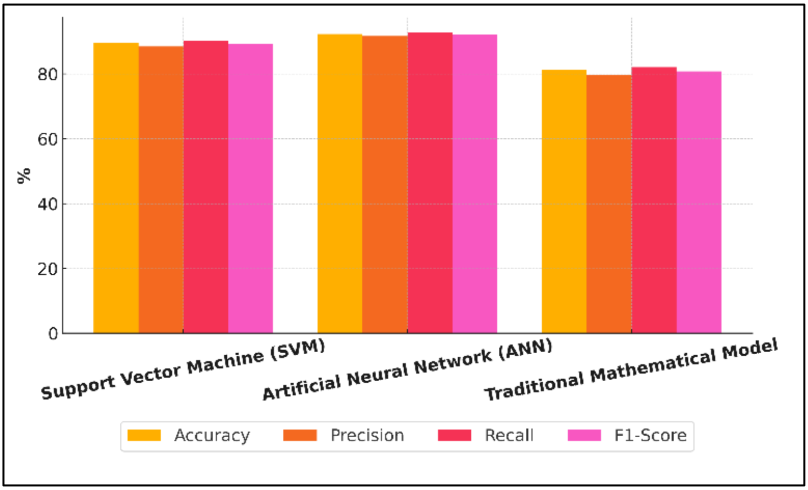

Figure 2

Comparison of Model Performance Metrics

This demonstrates that it had an excellent ability to determine and categorize the factors of the effects. It also was good and SVM performed significantly better than the standard model. The conventional model, however, lagged behind since it was not well able to capture the intricate, dynamic exchanges that are present in social and environmental data.

6. Conclusion

The framework presented in this research is strong, involving the utilization of AI and mathematical models to enhance measurement of social and environmental effects. The approach manages to contend with complexity, nonlinearities, and skepticism that emerge in real-life systems through fusion of

Support Vector Machines, Artificial Neural Networks and models that take place in the space of vectors measures. The mixed model is more flexible in predictions and accurate when the parameters are continually optimized using AI insights. Also, the orthogonal sequences enhance the interpretability by subdividing complex factors into small segments that is easier to observe how they influence the results. The results indicate that the framework can assist the lawmakers and other stakeholders to make decisions grounded on facts and information and contribute to long-term development.

References

[1] D. Javeed, U. M. Badamasi, T. Iqbal, A. Umar, and C. O. Ndubuisi, "Threat detection using machine/deep learning in IoT environments," *International Journal of Computer Networks and Communications Security,* vol. 8, pp. 59–65 (2020).

[2] K. H. Le, M. H. Nguyen, T. D. Tran, and N. D. Tran, "IMIDS: An intelligent intrusion detection system against cyber threats in IoT," *Electronics*, vol. 11, pp. 524 (2022).

[3] F. M. Alrowais, S. Althahabi, S. S. Alotaibi, A. Mohamed, M. A. Hamza, and R. Marzouk, "Automated Machine Learning Enabled Cybersecurity Threat Detection in Internet of Things Environment," *Computer Systems Science and Engineering*, vol. 45, pp. 687–700 (2023).

[4] P. E. Bhakve, A. N. Jambhale, and V. S. Kumbhar, "Online Payment Fraud Detection using Machine Learning," *International Journal of Advanced Electronics and Communication Engineering* (IJAECE), vol. 14, no. 1, pp. 1–7 (Apr. 2025).

[5] M. R. Labu and M. F. Ahammed, "Next-Generation Cyber Threat Detection and Mitigation Strategies: A Focus on Artificial Intelligence and Machine Learning," *Journal of Computer Science and Technology Studies*, vol. 6, pp. 179–188 (2024).

[6] P. K. Shukla, S. V. Pandit, C. Gandhi, M. Alrizq, A. Alghamdi, P. K. Shukla, and A. Rizwan, "Effective privacy preserving model based on adversarial CNN with IBOA in the social IoT systems for CEC," *International Journal of Communication Systems*, vol. 2024, pp. e5669 (2024).

[7] R. Chataut, A. Phoummalayvane, and R. Akl, "Unleashing the Power of IoT: A Comprehensive Review of IoT Applications and Future Prospects in Healthcare, Agriculture, Smart Homes, Smart Cities, and Industry 4.0," Sensors, vol. 23, pp. 7194 (2023).

[8] L. Tawalbeh, F. Muheidat, M. Tawalbeh, and M. Quwaider, "IoT Privacy and Security: Challenges and Solutions," *Applied Sciences*, vol. 10, pp. 4102 (2020).

[9] S.-H. Lee, Y.-L. Shiue, C.-H. Cheng, Y.-H. Li, and Y.-F. Huang, "Detection and Prevention of DDoS Attacks on the IoT," *Applied Sciences,* vol. 12, pp. 12407 (2022).

[10] Q. Wang, P. Geng, H. Qiu, J. Zhang, and R. Zhao, "Development of intelligent automatic water intake system for open-pit mine," *Journal of Physics: Conference Series*, vol. 2591, pp. 012057 (2023).

[11] A. Balaji, N. N. V. Gopi Chand, P. H. V. Hasmitha, and M. Viswa Prakash, "Power quality enhancement in renewable energy-based distributed generation using DPFC," *International Journal for Interdisciplinary Sciences and Engineering Applications* (IJISEA), vol. 6, no. 2, pp. 46–51 (2025).

[12] P. Sahane, M. Gulhane, N. Rakesh, S. M. M. Naidu, M. Grover, and V. Mahajan, "Evaluating lightweight encryption schemes for resource-constrained devices in wireless sensor networks," *Journal of Discrete Mathematical Sciences and Cryptography*, vol. 28, no. 5-A, pp. 1803–1812 (2025), doi: 10.47974/JDMSC-2180.

Received April, 2025