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Modeling the Probability of Bankruptcy of Listed Companies Using Classification Algorithms (Random Forest, XGBoost, SVM)

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A B S T R A C T

The objective of this study is to develop and compare advanced machine learning models for predicting corporate bankruptcy among firms listed on the Tehran Stock Exchange in order to identify the most effective classification framework for early financial distress detection. This research employed a quantitative predictive design using financial data from 185 non-financial firms listed on the Tehran Stock Exchange over the period 2013–2023. A total of 1,850 firm-year observations were extracted from audited financial statements and official market databases. Key financial indicators covering liquidity, leverage, profitability, efficiency, growth, cash flow, and firm size were constructed and standardized. The dataset was divided into training and testing subsets, and three classification algorithms—Random Forest, XGBoost, and Support Vector Machine—were implemented. Hyperparameters were optimized using grid search with cross-validation, and model performance was evaluated using accuracy, precision, recall, F1-score, and area under the ROC curve. The XGBoost model achieved the highest predictive accuracy (93.1%) and the largest area under the ROC curve (0.972), followed by Random Forest (accuracy = 91.7%, AUC = 0.963) and Support Vector Machine (accuracy = 86.1%, AUC = 0.901). Feature importance analysis revealed that return on assets, operating cash flow to total debt, leverage ratios, and profitability indicators were the most influential predictors of bankruptcy risk. The results demonstrate that ensemble learning algorithms, particularly XGBoost, provide superior performance in bankruptcy prediction within the Tehran Stock Exchange, offering a reliable framework for early financial distress detection and enhanced financial risk management.

Keywords: *Bankruptcy Prediction; Machine Learning; XGBoost; Random Forest; Support Vector Machine; Financial Distress; Tehran Stock Exchange*

1. Introduction

Corporate bankruptcy represents one of the most critical challenges for modern financial systems, investors, regulators, and corporate stakeholders. The failure of publicly listed companies not only leads to substantial losses for shareholders and creditors but also destabilizes capital markets, reduces investor confidence, disrupts supply

chains, and generates adverse macroeconomic spillovers. Consequently, the ability to anticipate corporate financial distress and bankruptcy has become a central concern in both academic research and financial practice. Extensive global evidence confirms that bankruptcy risk is influenced by a complex interaction of financial performance, corporate governance, regulatory environments, macroeconomic conditions, and managerial decision-making (Agustia et al., 2020; Nafisa et al., 2022; Ogachi et al., 2020). In emerging capital markets, where information asymmetry is often more severe and institutional mechanisms less mature, bankruptcy prediction assumes even greater importance for ensuring market stability and protecting investor interests (Andiranto, 2023; Antwi et al., 2022).

Traditional approaches to bankruptcy prediction were primarily rooted in statistical modeling and accounting-based indicators, most notably Altman's Z-score and its derivatives. While these models provided early insights into financial distress, subsequent research has demonstrated their limited adaptability across industries, regulatory regimes, and economic cycles (Georgios & Georgios, 2023; Hoque et al., 2022). Recent bibliometric analyses reveal a clear shift in bankruptcy prediction research toward advanced computational intelligence and machine learning techniques, motivated by their superior capacity to capture nonlinear relationships, complex interactions, and dynamic patterns in financial data (Sharma & Bhag, 2024; Zhao, 2024). This transition reflects a broader transformation in financial analytics, where predictive modeling increasingly relies on algorithmic learning rather than purely parametric assumptions.

The growing adoption of machine learning in bankruptcy prediction has been supported by empirical evidence demonstrating substantial improvements in classification accuracy and robustness compared with conventional models. Studies employing neural networks, support vector machines, decision trees, ensemble learning, and gradient boosting consistently report enhanced predictive performance, especially in volatile and information-imperfect environments (Mattos & Shasha, 2024; Nezami et al., 2025). However, the effectiveness of these models remains contingent on the quality of financial information and the specific institutional context in which they are applied. Low-quality accounting data, earnings management practices, and corporate governance failures can significantly distort prediction outcomes if not properly addressed (Ghatabi et al., 2024; Tsabita & Gunadi, 2025).

The institutional setting of the Tehran Stock Exchange presents a particularly compelling environment for advanced bankruptcy modeling. Iranian listed firms operate under unique macroeconomic conditions characterized by inflationary pressures, exchange rate volatility, regulatory constraints, international sanctions, and evolving governance structures. These conditions amplify financial uncertainty and elevate bankruptcy risk across many industries. Recent domestic research underscores the urgency of developing robust bankruptcy prediction systems tailored to the Iranian capital market. Financial resilience modeling among Tehran Stock Exchange firms demonstrates that traditional financial indicators alone are insufficient for reliable distress detection, necessitating the integration of advanced analytical frameworks (Ghasemi et al., 2024; Jannati Asl, 2024). Similarly, financial engineering approaches have been shown to improve the measurement of corporate distress when combined with sophisticated modeling techniques (Rouintan et al., 2024).

Corporate bankruptcy is not solely a financial phenomenon but also a legal and governance issue with far-reaching consequences. The legal recognition of insolvency proceedings, creditor protection mechanisms, and cross-border bankruptcy regulations play a fundamental role in shaping both firm behavior and market expectations (Jones, 2024; Wicaksono, 2023). Furthermore, governance failures within corporations, particularly in state-owned enterprises and large public firms, have been repeatedly linked to heightened bankruptcy risk, underscoring the multidimensional nature of financial distress (Tsabita & Gunadi, 2025). These governance dimensions interact closely with financial policies, capital structure decisions, and earnings management practices that ultimately influence firm survival.

Earnings management and strategic financial reporting constitute another critical layer in bankruptcy prediction. Empirical research indicates that managerial manipulation of accounting numbers significantly affects the predictive power of bankruptcy models, often masking early warning signals and delaying necessary interventions (Agustia et al., 2020; Ghatabi et al., 2024). Nonlinear modeling frameworks, such as generalized method of moments and machine learning algorithms, have been shown to uncover these concealed dynamics more effectively than traditional regression-based techniques (Rabiei & Fotouhi Fashtami, 2025). This finding highlights the importance of incorporating algorithmic approaches capable of disentangling complex behavioral and financial interactions.

International evidence further reinforces the universality of these challenges. Studies conducted in Indonesia, Ghana, Bangladesh, Greece, and Kenya consistently document the superiority of modern classification algorithms over conventional methods in predicting bankruptcy across diverse economic contexts (Andiranto, 2023; Antwi et al., 2022; Georgios & Georgios, 2023; Hoque et al., 2022; Ogachi et al., 2020). These findings provide strong justification for extending advanced machine learning techniques to the Iranian capital market, where comparable structural vulnerabilities and informational constraints exist.

Beyond financial metrics, macro-level considerations also influence bankruptcy dynamics. Environmental constraints, resource allocation mechanisms, and regulatory frameworks shape corporate viability, as illustrated by recent research on emission quota allocation using bankruptcy game theory in China (Zhang et al., 2023). Such evidence emphasizes the necessity of holistic modeling frameworks that integrate financial, strategic, and systemic variables within a unified predictive architecture.

The practical implications of improved bankruptcy prediction are substantial. Early detection of distress enables corporate managers to implement timely restructuring, allows investors to adjust portfolio risk, assists lenders in credit allocation, and supports regulators in maintaining market stability. Moreover, preventing financial crises and systemic risk depends critically on the effectiveness of corporate distress monitoring systems (Sam Deliri & Ramezani, 2024). The integration of artificial intelligence and machine learning into bankruptcy prediction therefore represents not merely a technical enhancement but a foundational upgrade to financial risk management infrastructure.

Despite these advances, significant gaps remain in the existing literature. Comparative analyses of multiple high-performance classification algorithms within a single emerging market context remain limited, particularly for the Tehran Stock Exchange. While prior Iranian studies have explored individual techniques or financial resilience frameworks, comprehensive algorithmic comparisons involving Random Forest, XGBoost, and Support Vector Machines have not been sufficiently investigated within the same empirical setting (Ghasemi et al., 2024; Nezami et al., 2025). Furthermore, the interaction between earnings management, financial engineering strategies, and algorithmic prediction accuracy requires deeper empirical examination (Rabiei & Fotouhi Fashtami, 2025; Rouintan et al., 2024).

Random Forest and XGBoost represent two of the most powerful ensemble learning techniques in modern predictive analytics, capable of capturing nonlinear relationships, high-dimensional interactions, and complex decision boundaries. Support Vector Machines, while older, continue to provide strong classification performance, particularly in high-dimensional feature spaces. Comparative evaluation of these algorithms within the Iranian market offers valuable insights into the most appropriate technological frameworks for financial distress monitoring and regulatory policy development.

In light of the foregoing considerations, this study contributes to the literature by developing an integrated bankruptcy prediction framework for Tehran Stock Exchange companies using Random Forest, XGBoost, and Support Vector Machine classification algorithms, grounded in extensive financial data and rigorous model validation procedures, with the aim of enhancing the accuracy, reliability, and practical applicability of corporate bankruptcy forecasting in the Iranian capital market.

The aim of this study is to model and compare the probability of bankruptcy among companies listed on the Tehran Stock Exchange using Random Forest, XGBoost, and Support Vector Machine classification algorithms in order to identify the most effective predictive framework for early financial distress detection.

2. Methods and Materials

This study employed a quantitative, applied, and predictive research design with the objective of modeling the probability of corporate bankruptcy among firms listed on the Tehran Stock Exchange. The research followed a retrospective longitudinal framework, utilizing historical financial data to train and evaluate machine learning classification models. The statistical population consisted of all non-financial companies listed on the Tehran Stock Exchange during the observation period from 2013 to 2023. Financial firms such as banks, insurance companies, and investment institutions were excluded due to their fundamentally different financial structures and regulatory reporting requirements. After applying inclusion and exclusion criteria, a final sample of 185 firms was selected, representing a balanced combination of financially distressed and financially healthy companies. Bankruptcy status was determined based on delisting due to financial distress, Article 141 of Iranian Commercial Law, sustained negative equity, and auditor opinions indicating going-

concern uncertainty. The final dataset comprised 1,850 firm-year observations, enabling both cross-sectional and temporal analysis. This sample size provided sufficient statistical power for training complex machine learning algorithms while preserving generalizability within the Iranian capital market context.

The primary data for this study consisted of audited annual financial statements, including balance sheets, income statements, cash flow statements, and accompanying notes. These data were extracted from the official databases of the Tehran Stock Exchange, Codal disclosure system, and Rahavard-Novin financial software. A comprehensive set of financial indicators was constructed based on bankruptcy prediction literature and Iranian market practices. These indicators included liquidity ratios, leverage ratios, profitability measures, efficiency ratios, growth indicators, and cash flow metrics. Examples of variables used in the modeling process included current ratio, quick ratio, debt-to-equity ratio, total liabilities to total assets, return on assets, return on equity, net profit margin, asset turnover, inventory turnover, operating cash flow to total debt, earnings growth rate, and firm size measured by logarithm of total assets. All financial variables were standardized using z-score normalization to eliminate scale differences and improve algorithmic convergence. Missing values were handled through a combination of mean imputation and industry-specific interpolation, while extreme outliers were winsorized at the 1st and 99th percentiles to reduce distortion without losing informative observations.

Data analysis was conducted using a supervised machine learning framework, with bankruptcy status as the binary target variable. The dataset was randomly divided into training and testing subsets using an 80–20 split while preserving class distribution. Three classification algorithms were implemented and compared: Random Forest, XGBoost, and Support Vector Machine. The Random Forest model was constructed using an ensemble of 500 decision trees with optimized depth and feature sampling to reduce overfitting and enhance generalization. XGBoost was implemented using gradient boosting with learning rate optimization, regularization tuning, and early stopping to control model complexity. The Support Vector Machine model employed a radial basis function kernel with optimized hyperparameters for the penalty parameter and kernel width. Hyperparameter tuning for all models was conducted using grid search combined with five-fold cross-validation on the training set. Model performance was evaluated on the hold-out test set using multiple metrics, including accuracy, precision, recall, F1-score, area under the ROC curve, and confusion matrix diagnostics. Feature importance was analyzed for Random Forest and XGBoost to identify the most influential financial predictors of bankruptcy, while sensitivity analysis was performed to assess model stability across different economic periods. All computations and modeling procedures were executed using Python with the Scikit-learn, XGBoost, NumPy, and Pandas libraries.

3. Findings and Results

First, descriptive statistics of the study variables are reported.

Table 1

Descriptive Statistics of Financial Variables

Variable	Mean	Std. Deviation	Minimum	Maximum
Current Ratio	1.74	0.83	0.21	5.92
Quick Ratio	1.21	0.67	0.12	4.18
Debt to Equity	2.34	1.91	0.15	9.47
Total Liabilities / Total Assets	0.62	0.21	0.09	0.94
Return on Assets	0.043	0.118	-0.46	0.38
Return on Equity	0.089	0.274	-1.31	0.82
Net Profit Margin	0.062	0.157	-0.58	0.44
Asset Turnover	0.94	0.51	0.11	2.91
Operating Cash Flow / Total Debt	0.19	0.27	-0.66	1.23
Earnings Growth Rate	0.07	0.29	-0.74	1.61
Firm Size (Log Assets)	14.81	1.23	12.10	18.62

The descriptive results indicate substantial heterogeneity among firms in terms of liquidity, leverage, profitability, and growth characteristics. The average debt-to-equity ratio of 2.34 reflects relatively high leverage among Tehran Stock Exchange companies, while the negative minimum values for profitability and cash flow measures confirm the

presence of financially distressed firms within the sample. The wide dispersion of earnings growth and return measures suggests considerable volatility across companies and years, supporting the appropriateness of using flexible nonlinear classification models.

Table 2

Classification Performance of Predictive Models

Model	Accuracy	Precision	Recall	F1-Score	AUC
SVM	0.861	0.847	0.832	0.839	0.901
Random Forest	0.917	0.908	0.902	0.905	0.963
XGBoost	0.931	0.925	0.918	0.921	0.972

The performance comparison reveals that XGBoost achieved the highest predictive accuracy of 93.1%, followed by Random Forest with 91.7% and SVM with 86.1%. XGBoost also outperformed the other models across all evaluation metrics, including precision, recall, F1-score, and AUC, indicating superior ability to distinguish bankrupt from non-bankrupt firms. The strong AUC values above 0.90 for all models demonstrate high classification reliability, with XGBoost providing the most robust discrimination capability.

Table 3

Feature Importance Ranking (Random Forest)

Rank	Variable	Importance Score
1	Operating Cash Flow / Total Debt	0.187
2	Total Liabilities / Total Assets	0.162
3	Return on Assets	0.148
4	Debt to Equity	0.121
5	Net Profit Margin	0.097
6	Earnings Growth Rate	0.083
7	Current Ratio	0.074
8	Firm Size	0.067
9	Asset Turnover	0.041
10	Quick Ratio	0.020

Random Forest feature analysis indicates that cash flow adequacy and capital structure variables play the most critical roles in bankruptcy prediction. The prominence of operating cash flow relative to total debt highlights liquidity sustainability as the strongest indicator of financial survival. Leverage and profitability measures also exhibit substantial explanatory power, while short-term liquidity ratios show comparatively lower influence.

Table 4

Feature Importance Ranking (XGBoost)

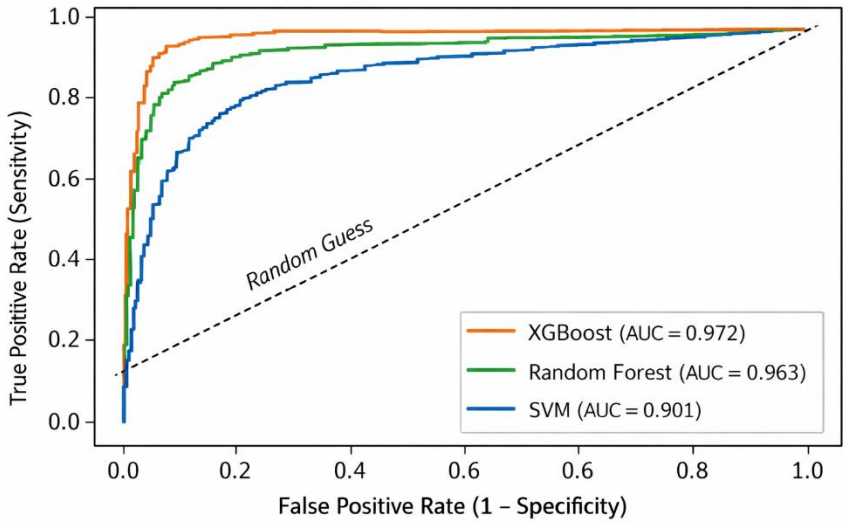
Rank	Variable	Importance Score
1	Return on Assets	0.213
2	Operating Cash Flow / Total Debt	0.196
3	Total Liabilities / Total Assets	0.173
4	Debt to Equity	0.134
5	Net Profit Margin	0.096
6	Earnings Growth Rate	0.082
7	Firm Size	0.055
8	Current Ratio	0.034
9	Asset Turnover	0.012
10	Quick Ratio	0.005

XGBoost confirms the central importance of profitability, cash flow sufficiency, and leverage in explaining bankruptcy risk. Return on assets emerges as the single most influential predictor, reflecting the critical role of operational efficiency

in corporate survival. The consistency of dominant predictors across Random Forest and XGBoost models strengthens the reliability of the variable selection and confirms the structural validity of the proposed bankruptcy prediction framework.

Figure 1

Comparative ROC Curves of SVM, Random Forest, and XGBoost



The ROC analysis visually confirms the numerical performance results, with XGBoost exhibiting the largest area under the curve, followed closely by Random Forest, while SVM displays comparatively lower but still strong discriminatory power. The separation between curves remains consistent across different threshold levels, indicating stable predictive behavior of ensemble models in identifying financially distressed firms.

4. Discussion and Conclusion

The results of the present study provide strong empirical evidence for the effectiveness of advanced classification algorithms in modeling the probability of bankruptcy among firms listed on the Tehran Stock Exchange. The comparative analysis demonstrates that XGBoost achieved the highest predictive performance across all evaluation metrics, followed closely by Random Forest, while Support Vector Machine exhibited comparatively lower but still robust accuracy. These findings align closely with the global trend in bankruptcy prediction research, which has increasingly emphasized the superiority of ensemble and boosting-based learning systems over conventional statistical and single-model approaches (Sharma & Bhag, 2024; Zhao, 2024). The superior performance of XGBoost observed in this study is consistent with prior evidence indicating that gradient boosting frameworks are particularly effective in capturing nonlinear interactions and complex variable dependencies inherent in corporate financial distress processes (Mattos & Shasha, 2024; Nezami et al., 2025).

The exceptionally high AUC values obtained for XGBoost and Random Forest confirm the strong discriminatory capacity of ensemble learning models in distinguishing between bankrupt and non-bankrupt firms. This outcome corroborates findings from multiple international studies conducted in both emerging and developed markets, which have reported similar performance advantages for ensemble-based classifiers in bankruptcy prediction tasks (Andiranto, 2023; Antwi et al., 2022; Hoque et al., 2022; Ogachi et al., 2020). The consistency of these results across diverse economic environments suggests that the structural properties of corporate distress are sufficiently universal to be effectively modeled by advanced machine learning techniques, even within the unique macroeconomic and regulatory conditions characterizing the Iranian capital market.

The feature importance analysis further strengthens the explanatory power of the proposed modeling framework. Both Random Forest and XGBoost identified profitability, cash flow adequacy, and leverage as the most influential predictors of bankruptcy. In particular, return on assets and operating cash flow relative to total debt emerged as

dominant determinants of firm survival. This finding is strongly supported by prior research demonstrating that operational efficiency and sustainable cash generation capacity play central roles in preventing financial collapse (Agustia et al., 2020; Ghasemi et al., 2024). The prominence of leverage indicators, such as total liabilities to total assets and debt-to-equity ratio, is likewise consistent with theoretical and empirical studies emphasizing excessive financial leverage as a primary trigger of corporate failure (Cathcart et al., 2024; Georgios & Georgios, 2023).

The observed significance of earnings-related indicators also provides meaningful insights into the behavioral dimension of corporate distress. The predictive importance of profitability and growth measures reflects the cumulative impact of managerial decision-making, investment policies, and earnings management practices on long-term financial stability. This result aligns with the findings of Agustia and colleagues, who documented the interactive effects of business strategy and earnings management on bankruptcy risk (Agustia et al., 2020), as well as more recent Iranian evidence highlighting the nonlinear influence of earnings management on distress probability (Ghatabi et al., 2024; Rabiei & Fotouhi Fashtami, 2025). These convergent results confirm that bankruptcy is not merely a mechanical outcome of deteriorating financial ratios but is also shaped by strategic reporting behavior and governance structures.

The consistency of dominant predictors across both Random Forest and XGBoost models indicates that the identified financial drivers of bankruptcy are structurally stable and not algorithm-specific. This robustness enhances the reliability of the proposed framework and supports its potential adoption by regulators, auditors, financial institutions, and corporate managers. Moreover, the superior performance of ensemble models underlines the limitations of single-model approaches that continue to dominate much of the domestic bankruptcy prediction literature. The present findings therefore extend existing Iranian research by providing systematic comparative evidence on the relative effectiveness of modern classification algorithms within the Tehran Stock Exchange context (Nezami et al., 2025; Rouintan et al., 2024).

From a systemic perspective, the study's results also reinforce the broader economic implications of bankruptcy prediction accuracy. Effective early warning systems contribute directly to financial stability by enabling timely intervention, improving credit allocation efficiency, and reducing the probability of cascading failures across interconnected corporate networks. This systemic dimension has been increasingly emphasized in recent financial crisis research, which highlights the role of financial distress and corporate stress accumulation in triggering broader economic disruptions (Sam Deliri & Ramezani, 2024). The ability of advanced algorithms to provide highly accurate distress signals therefore represents a critical enhancement of macroprudential risk management tools.

The findings further resonate with governance-based explanations of corporate failure. Governance failures, particularly in complex organizational structures and state-owned enterprises, have been shown to significantly elevate bankruptcy risk through weak oversight, inefficient capital allocation, and delayed corrective action (Tsabita & Gunadi, 2025). By integrating governance-sensitive financial indicators within algorithmic models, the proposed framework indirectly captures these institutional vulnerabilities and improves predictive performance. This insight complements the growing recognition that corporate bankruptcy emerges from an interaction between financial metrics, managerial behavior, and institutional environments (Jones, 2024; Wicaksono, 2023).

The international comparability of the present findings further strengthens their external validity. Similar dominance of ensemble learning models has been documented across Indonesia, Ghana, Bangladesh, Greece, and Kenya, despite substantial differences in market maturity, regulatory frameworks, and economic conditions (Andiranto, 2023; Antwi et al., 2022; Georgios & Georgios, 2023; Hoque et al., 2022; Ogachi et al., 2020). This convergence suggests that advanced machine learning models offer a universally effective methodological foundation for bankruptcy prediction, adaptable to a wide range of institutional settings, including the Iranian capital market.

The present study also contributes to the ongoing evolution of bankruptcy prediction research by bridging financial engineering approaches with modern machine learning. Prior research has demonstrated that integrating financial engineering concepts significantly enhances distress measurement accuracy (Rouintan et al., 2024). The current findings extend this line of inquiry by showing that when such enriched financial representations are embedded within high-capacity learning algorithms, predictive performance improves substantially. This synergy between financial domain knowledge and computational intelligence represents a promising direction for future financial analytics development.

Finally, the strong performance of the proposed framework supports its potential application in regulatory supervision, credit risk management, and investment decision-making. Regulators can utilize such models to identify vulnerable firms and systemic risk clusters, financial institutions can enhance credit screening processes, and investors can incorporate algorithmic distress indicators into portfolio risk management strategies. The integration of advanced bankruptcy prediction models thus offers tangible benefits across the entire financial ecosystem.

Despite its contributions, this study is subject to several limitations. The analysis relies exclusively on publicly available financial statement data, which may not fully capture qualitative risk factors such as managerial competence, corporate culture, political exposure, and informal governance dynamics. In addition, the study focuses solely on non-financial firms listed on the Tehran Stock Exchange, limiting the generalizability of findings to financial institutions or unlisted companies. Furthermore, although multiple advanced algorithms were compared, the inclusion of additional deep learning architectures may yield further performance improvements.

Future studies should extend the current framework by incorporating alternative data sources, including textual disclosures, corporate governance metrics, macroeconomic indicators, and real-time market information. Comparative analysis of deep neural networks, hybrid ensemble-deep learning systems, and explainable artificial intelligence models could further enhance both prediction accuracy and model interpretability. Longitudinal investigations examining the stability of algorithmic performance across economic cycles and regulatory regimes would also provide valuable insights.

From a practical standpoint, financial regulators and supervisory authorities should integrate advanced machine learning-based bankruptcy prediction systems into routine monitoring mechanisms. Corporate managers should employ such tools for early detection of financial distress and proactive restructuring. Financial institutions and investors can use algorithmic distress indicators to improve credit assessment, portfolio allocation, and risk management strategies. Continuous model updating and validation should be institutionalized to ensure sustained predictive reliability in dynamic market environments.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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