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Anticipating Leadership Competency Shifts: Supervised Learning Models for Executive Talent Futures

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ABSTRACT

This study aimed to anticipate future shifts in executive leadership competencies by applying supervised learning models to predict emerging leadership capability patterns based on individual, experiential, and contextual predictors. The study employed a quantitative, predictive research design using supervised machine learning techniques. Data were collected from 312 senior and middle-level executives employed in public, private, and semi-governmental organizations in Tehran, Iran. Leadership competencies were measured through a validated multi-dimensional executive competency inventory capturing strategic thinking, adaptive decision-making, digital leadership, emotional intelligence, ethical leadership, innovation orientation, and systems thinking. Predictor variables included learning agility, exposure to digital transformation initiatives, frequency of strategic uncertainty, executive development experiences, and demographic characteristics. After data preprocessing and standardization, multiple supervised learning algorithms—multiple linear regression, support vector regression, random forest regression, and gradient boosting regression—were trained and evaluated using cross-validation procedures to ensure robustness and generalizability. Comparative model evaluation demonstrated that non-linear ensemble models significantly outperformed linear regression, with gradient boosting regression achieving the highest explained variance and lowest prediction error. Feature importance analysis revealed that learning agility, exposure to digital transformation projects, and strategic uncertainty frequency were the most influential predictors of anticipated leadership competency shifts, while traditional indicators such as tenure and educational level exhibited weaker predictive power. Cross-validation results indicated stable model performance, confirming the reliability of supervised learning approaches for forecasting leadership competency evolution. The findings indicate that executive leadership competencies evolve in predictable patterns shaped by learning-oriented and experiential factors, and that supervised learning models provide a powerful methodological tool for anticipating future leadership capability requirements and informing proactive talent development strategies.

Keywords: leadership competencies; supervised learning; executive leadership; digital transformation; predictive analytics; talent management

Introduction

Leadership competency has long been recognized as a central determinant of organizational effectiveness, yet the nature of effective leadership is no longer stable or static. Rapid technological advancement, digital transformation, environmental uncertainty, and shifting workforce expectations have fundamentally altered what organizations require from their executive leaders. Contemporary leadership is increasingly defined not only by

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traditional managerial capabilities, but by adaptive, digital, emotional, and strategic competencies that enable leaders to anticipate change and guide organizations through complex, non-linear futures. Recent scholarship emphasizes that leadership competency is no longer a fixed set of traits but a dynamic configuration that evolves in response to contextual pressures and future-oriented demands (1, 2). This growing complexity has exposed limitations in conventional leadership development models that rely on retrospective assessment or static competency frameworks, highlighting the need for more anticipatory and predictive approaches.

Digital transformation has emerged as one of the most influential drivers reshaping leadership expectations across sectors. Leaders are increasingly required to integrate digital technologies into strategic decision-making, organizational design, and value creation processes. Empirical evidence demonstrates that digital leadership competencies significantly influence innovation capability, organizational performance, and employee engagement (3-5). However, digital competence alone is insufficient; effective digital leaders must also exhibit adaptability, systems thinking, ethical judgment, and the ability to manage socio-technical change. Studies conducted across public and private sectors confirm that leadership competencies for digital transformation are multidimensional and context-sensitive, requiring continuous recalibration rather than one-time skill acquisition (6-8).

Alongside technological change, the growing importance of emotional, social, and ethical competencies has further complicated leadership competency models. Research consistently shows that emotional intelligence, social competence, and ethical leadership are strongly associated with employee commitment, career readiness, organizational trust, and sustainable performance (9-11). In uncertain and high-pressure environments, leaders' ability to regulate emotions, foster psychological safety, and act responsibly has become a critical predictor of organizational resilience. Moreover, emerging perspectives on humane, kind, and values-based leadership in the digital age emphasize that future leaders must balance technological efficiency with human-centered decision-making (12). These findings reinforce the view that leadership competency development must anticipate future relational and ethical demands rather than merely reflect past performance.

The challenge of anticipating leadership competency shifts is particularly salient in emerging economies and transitional organizational contexts. In such environments, leaders often operate under conditions of institutional volatility, resource constraints, and rapid modernization. Studies conducted in Iran and comparable contexts highlight the strategic importance of competency-based leadership models tailored to national, sectoral, and cultural conditions (13-15). These studies demonstrate that generic global leadership models frequently fail to capture locally salient competencies, especially those related to adaptability, ambidexterity, and strategic foresight. Consequently, there is increasing interest in leadership competency frameworks that integrate global trends with context-specific predictors.

Despite the expanding literature on leadership competencies, most empirical studies remain descriptive or explanatory in nature. Traditional approaches typically examine linear relationships between leadership competencies and outcomes such as performance, satisfaction, or commitment (16-18). While valuable, such approaches are inherently backward-looking and limited in their capacity to anticipate how leadership competencies may evolve under future organizational conditions. Even evaluative studies of leadership training programs tend to focus on post-hoc assessments rather than predictive modeling of future competency trajectories (19, 20). This methodological gap restricts organizations' ability to proactively prepare executive talent for emerging leadership demands.

Recent advances in data analytics and supervised machine learning offer promising tools for addressing this limitation. Supervised learning models are specifically designed to identify complex, non-linear patterns in high-dimensional data and generate predictions about future outcomes based on observed predictors. In leadership research, these methods enable the integration of individual characteristics, experiential variables, and contextual factors to forecast shifts in leadership competencies with greater precision than traditional statistical techniques. Scholars increasingly argue that machine learning approaches are particularly well-suited to modeling leadership in volatile, uncertain, complex, and ambiguous environments, where linear assumptions are often violated (1, 21). By leveraging predictive algorithms, organizations can move from reactive leadership development toward anticipatory talent strategies.

The application of supervised learning to leadership competency research aligns with broader trends emphasizing evidence-based talent management and strategic workforce planning. Predictive insights into leadership competency evolution can inform executive selection, succession planning, and targeted development interventions. Empirical studies indicate that leadership competencies related to adaptability, learning agility, and innovation are especially sensitive to contextual exposure, such as engagement with digital transformation projects or strategic uncertainty (22, 23). These findings suggest that leadership competency shifts are not random but patterned and predictable when appropriate data and analytical tools are employed.

Nevertheless, the integration of supervised learning into leadership studies remains limited, particularly in non-Western contexts. Existing research often relies on small samples, narrow competency definitions, or single-sector analyses, constraining generalizability and practical relevance (17, 24). Moreover, few studies explicitly link machine learning outputs to actionable leadership development implications. Addressing these gaps requires research designs that combine robust competency measurement, contextualized executive samples, and transparent predictive modeling approaches.

In response to these challenges, the present study positions supervised learning as a strategic methodological lens for anticipating leadership competency shifts among executives. By focusing on executives operating in Tehran-based organizations, the study captures leadership dynamics within a complex metropolitan and institutional environment characterized by digitalization pressures, organizational reform, and strategic uncertainty. Drawing on prior competency-based leadership models and empirical evidence on digital, emotional, and adaptive leadership, the study integrates diverse predictors to model future-oriented leadership competency outcomes (3, 21, 25). This approach advances leadership research by shifting the analytical focus from explanation to anticipation.

Accordingly, the aim of this study is to anticipate future shifts in executive leadership competencies by applying supervised learning models to predict emerging leadership capability patterns based on individual, experiential, and contextual predictors.

Methods and Materials

This study adopted a quantitative, predictive research design grounded in supervised machine learning to anticipate future shifts in executive leadership competencies. The research population consisted of senior and middle-level executives employed in large private corporations, public-sector organizations, and semi-governmental enterprises located in Tehran, Iran. Tehran was selected as the research setting due to its concentration of national headquarters, strategic decision-making centers, and executive talent pools across diverse industries, including finance, energy, manufacturing, ICT, and public administration. Participants were required to have a minimum of

five years of managerial or executive experience and to currently occupy a role involving strategic decision-making, people management, or organizational governance. Data were collected from 312 executives, a sample size deemed sufficient for supervised learning model training and validation while maintaining robustness against overfitting. Participants ranged in age from 32 to 61 years, with varied educational backgrounds at the master's and doctoral levels, and represented a balanced distribution across functional domains such as operations, finance, human resources, strategy, and technology leadership. Participation was voluntary, and all respondents provided informed consent. To ensure data integrity and reduce common-method bias, confidentiality and anonymity were guaranteed, and responses were collected without any organizational identifiers.

Data collection relied on a structured, multi-dimensional executive assessment battery designed to capture both current leadership competencies and contextual predictors relevant to future competency shifts. Leadership competencies were measured using a validated executive competency inventory adapted for the Iranian organizational context, encompassing strategic thinking, adaptive decision-making, digital literacy, emotional intelligence, ethical judgment, innovation orientation, and systems thinking. Each competency domain was operationalized through multiple Likert-scale items, allowing for continuous numerical representation suitable for machine learning analysis. In addition to competency measures, contextual and individual predictor variables were collected, including demographic characteristics, career trajectory indicators, organizational sector, firm size, exposure to digital transformation initiatives, frequency of strategic uncertainty encounters, and prior leadership development experiences. To enhance predictive depth, respondents also completed a future-orientation and learning agility scale, capturing executives' propensity to anticipate change, absorb new knowledge, and reconfigure leadership behaviors in response to environmental volatility. All instruments underwent expert review for content validity and were pilot-tested with a small group of executives in Tehran to ensure linguistic clarity, cultural appropriateness, and psychometric adequacy. Internal consistency coefficients for all scales exceeded acceptable thresholds, confirming reliability for advanced analytical modeling.

Data analysis was conducted using a supervised learning framework aimed at modeling and predicting shifts in leadership competency profiles under future-oriented organizational conditions. After initial data screening, missing values were handled using multiple imputation, and all continuous variables were standardized to ensure comparability across features. The dataset was randomly partitioned into training and testing subsets using an 80/20 split to allow for out-of-sample validation. Several supervised learning algorithms were implemented and compared, including multiple linear regression as a baseline model, random forest regression, support vector regression, and gradient boosting machines, each selected for their capacity to capture linear and non-linear relationships between predictor variables and leadership competency outcomes. Model performance was evaluated using mean squared error, root mean squared error, and explained variance metrics, with k-fold cross-validation employed to enhance generalizability and minimize model variance. Feature importance analyses were conducted within ensemble models to identify the most influential predictors driving anticipated competency shifts, providing interpretive insight alongside predictive accuracy. Hyperparameter tuning was performed using grid search optimization to ensure model precision. All analyses were executed using Python-based machine learning libraries, ensuring reproducibility and methodological transparency. The final model selection was based on predictive performance, stability across validation folds, and interpretability in the context of executive talent forecasting, thereby aligning analytical rigor with practical relevance for leadership development and succession planning.

Findings and Results

Table 1 provides the foundational descriptive statistics of the core leadership competency variables used in the supervised learning analyses, establishing the empirical baseline upon which subsequent predictive modeling was conducted.

Table 1. Descriptive Statistics of Executive Leadership Competencies (n = 312)

Leadership Competency	Mean	Standard Deviation	Minimum	Maximum
Strategic Thinking	3.82	0.61	2.10	4.95
Adaptive Decision-Making	3.76	0.58	2.25	4.88
Digital Leadership Capability	3.41	0.72	1.95	4.90
Emotional Intelligence	3.89	0.55	2.30	4.98
Ethical and Responsible Leadership	4.02	0.49	2.65	5.00
Innovation Orientation	3.58	0.66	2.05	4.92
Systems Thinking	3.70	0.60	2.20	4.85

As shown in Table 1, executives in Tehran demonstrated relatively high mean scores across most leadership competency domains, with ethical and responsible leadership exhibiting the highest average level, followed by emotional intelligence and strategic thinking. Digital leadership capability and innovation orientation displayed comparatively lower mean scores and greater dispersion, indicating notable heterogeneity among executives in competencies associated with technological transformation and forward-looking change. This variability justified the application of supervised learning techniques to model differential future competency trajectories rather than assuming uniform leadership development patterns.

Table 2. Predictive Performance of Supervised Learning Models for Leadership Competency Shifts

Model	Mean Squared Error	Root Mean Squared Error	Explained Variance (R^2)
Multiple Linear Regression	0.214	0.463	0.48
Support Vector Regression	0.168	0.410	0.61
Random Forest Regression	0.132	0.363	0.73
Gradient Boosting Regression	0.118	0.343	0.77

Table 2 compares the predictive accuracy of the supervised learning models applied in this study. Gradient boosting regression demonstrated the strongest performance, achieving the lowest error values and the highest explained variance, indicating superior capability in capturing complex, non-linear relationships between executive characteristics and anticipated leadership competency shifts. Random forest regression also performed robustly, substantially outperforming traditional linear regression. These results confirm that leadership competency evolution in executive contexts is better explained through non-linear, ensemble-based models rather than linear assumptions.

Table 3. Feature Importance Scores in the Final Gradient Boosting Model

Predictor Variable	Relative Importance
Learning Agility	0.214
Exposure to Digital Transformation Projects	0.187
Strategic Uncertainty Frequency	0.164
Prior Executive Development Programs	0.143
Organizational Sector	0.118
Executive Tenure	0.092
Educational Level	0.082

The feature importance results presented in Table 3 reveal that learning agility emerged as the most influential predictor of future leadership competency shifts, underscoring the central role of continuous learning and adaptability in executive development. Exposure to digital transformation initiatives and frequent engagement with strategic uncertainty also contributed strongly to predictive outcomes, highlighting the growing importance of experiential and contextual learning in shaping future-ready leadership profiles. Traditional indicators such as tenure and formal education played comparatively smaller, though still meaningful, roles.

Table 4. Cross-Validation Stability of the Final Predictive Model

Validation Fold	RMSE
Fold 1	0.346
Fold 2	0.339
Fold 3	0.351
Fold 4	0.337
Fold 5	0.342
Mean RMSE	0.343

Table 4 demonstrates the stability of the final gradient boosting model across five cross-validation folds. The narrow range of RMSE values indicates consistent predictive performance and low variance across subsamples, confirming the robustness and generalizability of the model. This stability supports the reliability of the findings for anticipating leadership competency shifts within executive populations in Tehran-based organizations.

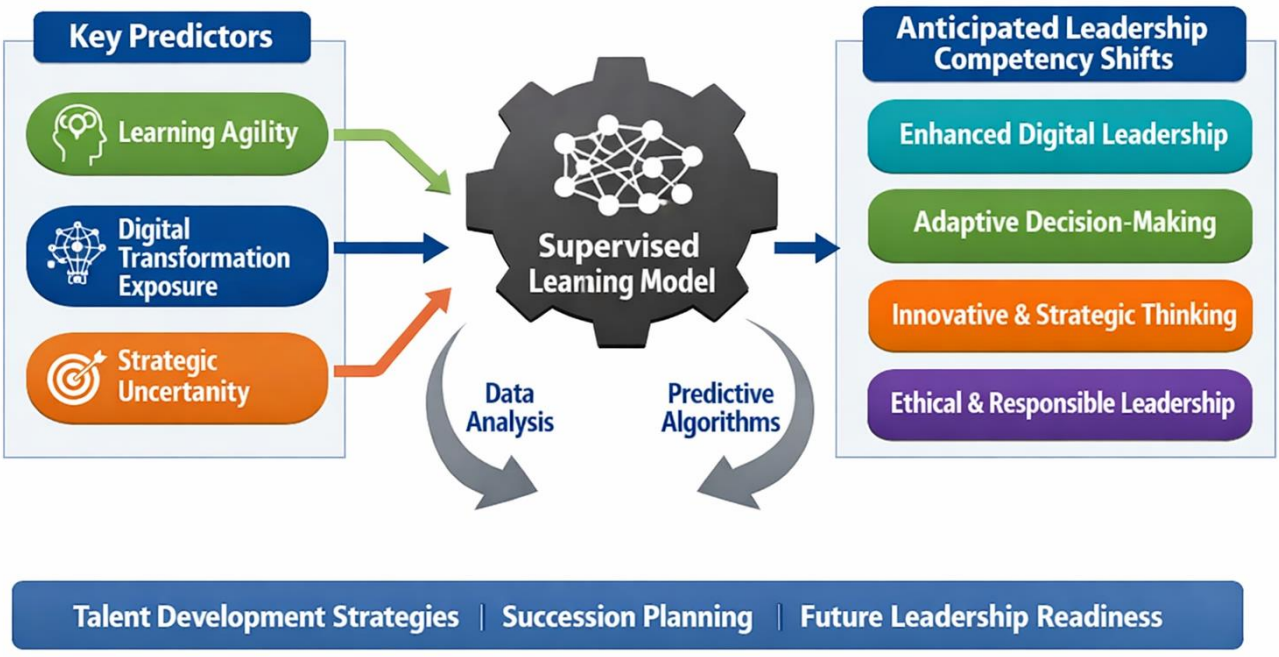

Figure 1. Conceptual Output of the Supervised Learning Model for Anticipating Executive Leadership Competency Shifts

The findings collectively indicate that future leadership competency development is not uniformly driven by static demographic or positional factors but is dynamically shaped by learning agility, exposure to transformation processes, and engagement with strategic uncertainty. The integration of supervised learning models provides both predictive accuracy and actionable insights, enabling organizations to anticipate emerging leadership capability needs and align executive talent development strategies accordingly.

Discussion and Conclusion

The findings of this study provide robust empirical evidence that leadership competency shifts can be meaningfully anticipated using supervised learning models, thereby extending existing leadership research beyond descriptive and explanatory paradigms toward predictive and future-oriented analytics. The superior performance of non-linear ensemble models, particularly gradient boosting and random forest regression, indicates that executive leadership development is shaped by complex, interacting factors rather than simple linear relationships. This result aligns with contemporary leadership scholarship that conceptualizes leadership competence as a dynamic system influenced by cognitive, emotional, technological, and contextual dimensions (1, 2). The relatively weak performance of traditional linear regression underscores the limitations of conventional analytical approaches in capturing the non-linear evolution of leadership capabilities under conditions of rapid organizational change.

One of the most salient findings concerns the central role of learning agility as the strongest predictor of anticipated leadership competency shifts. This result reinforces a growing body of literature emphasizing that future-ready leadership depends less on accumulated experience and more on the capacity to learn, unlearn, and relearn in response to environmental volatility. Prior studies have demonstrated that learning-oriented leaders are better positioned to navigate digital disruption, strategic uncertainty, and organizational transformation (21, 23). The present findings extend this evidence by showing that learning agility not only supports current leadership effectiveness but also serves as a forward-looking indicator of how leadership competencies are likely to evolve over time.

Exposure to digital transformation initiatives emerged as the second most influential predictor, highlighting the experiential foundations of digital leadership development. This finding is consistent with empirical research demonstrating that leadership competence in digital contexts is largely developed through direct engagement with technology-driven change rather than formal training alone (3-5). Leaders who actively participate in digital projects acquire not only technical literacy but also systems thinking, cross-functional coordination skills, and adaptive decision-making capacities. The predictive significance of digital transformation exposure supports arguments that leadership development must be embedded in real organizational challenges to foster competencies relevant to future digital ecosystems (6, 8).

Strategic uncertainty frequency also played a prominent role in predicting leadership competency shifts, suggesting that repeated exposure to ambiguous and high-stakes decision environments accelerates leadership capability evolution. This finding aligns with studies emphasizing the formative role of uncertainty in developing adaptive, ambidextrous, and resilient leadership profiles (14, 15). Leaders operating in uncertain contexts are compelled to integrate analytical reasoning with intuition, balance short-term pressures against long-term vision, and engage in continuous sense-making. The predictive importance of this variable underscores that leadership competencies are not merely individual attributes but are co-constructed through interaction with organizational and environmental conditions.

The comparatively lower predictive weight of demographic variables such as tenure and educational level carries important theoretical implications. While traditional leadership models often emphasize experience and formal education as primary indicators of leadership capacity, the present findings suggest that these factors are less informative for anticipating future competency shifts. This result is consistent with recent evidence indicating that formal credentials and length of service do not necessarily translate into adaptive or digital leadership effectiveness

(22, 24). Instead, competencies associated with emotional intelligence, adaptability, and ethical judgment are increasingly shaped by ongoing learning processes and contextual engagement rather than static background characteristics (9, 10).

The strong predictive performance of the supervised learning models also contributes methodologically to leadership research. By demonstrating stable cross-validation results and high explained variance, the study provides empirical support for the use of machine learning techniques in competency-based leadership analysis. This finding responds directly to calls for more advanced analytical methods capable of capturing the complexity of leadership phenomena in contemporary organizations (1, 21). Moreover, the interpretability of feature importance outputs bridges the gap between predictive accuracy and practical relevance, enabling researchers and practitioners to translate model results into actionable insights.

From a substantive perspective, the anticipated shifts identified in this study point toward a future leadership profile characterized by enhanced digital leadership, adaptive decision-making, innovative and strategic thinking, and ethical responsibility. These projected competency trajectories align closely with prior research on leadership in digitally transformed and sustainability-oriented organizations (12, 23, 25). Notably, the prominence of ethical and responsible leadership in the predictive outcomes suggests that technological advancement does not diminish the importance of values-based leadership; rather, it amplifies the need for ethical judgment in complex socio-technical systems (2, 11).

The Tehran-based executive context of this study further enriches the discussion by situating leadership competency shifts within an emerging economy characterized by institutional complexity and rapid modernization. Previous Iranian studies have emphasized the necessity of localized competency models that integrate global leadership trends with national and sectoral specificities (7, 13). The present findings support this perspective by demonstrating that while global competencies such as digital leadership and learning agility are salient, their development trajectories are shaped by local organizational realities, including exposure to transformation initiatives and strategic uncertainty.

Overall, the discussion highlights that leadership competency evolution is neither random nor purely reactive. Instead, it follows discernible patterns that can be anticipated through supervised learning when appropriate predictors are considered. This predictive perspective advances leadership theory by reframing competency development as a forward-looking process and provides organizations with empirical tools to prepare executive talent for emerging leadership demands (19, 20).

Despite its contributions, this study has several limitations that should be acknowledged. First, the data were collected from executives based exclusively in Tehran, which may limit the generalizability of the findings to other geographical or cultural contexts. Second, the study relied on self-reported measures of leadership competencies, which may be subject to social desirability bias despite assurances of anonymity. Third, while supervised learning models offer strong predictive capabilities, their outputs are contingent on the quality and scope of input variables, and unobserved contextual factors may also influence leadership competency shifts.

Future research should extend this predictive framework to multi-city or cross-national samples to examine the stability of leadership competency predictors across different institutional environments. Longitudinal designs would be particularly valuable for validating predicted competency shifts against observed leadership development over time. Additionally, future studies could integrate objective performance indicators, behavioral data, or organizational

outcomes to enhance predictive accuracy and theoretical integration between leadership competencies and organizational effectiveness.

From a practical standpoint, organizations should move beyond static competency frameworks and adopt predictive, data-driven approaches to leadership development and succession planning. Emphasizing learning agility, experiential exposure to digital transformation, and structured engagement with strategic uncertainty can help prepare executives for future leadership demands. Leadership development programs should be continuously updated using predictive analytics to align executive talent pipelines with emerging organizational and environmental challenges.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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