European Economic Letters
ISSN 2323-5233
Vol 16, Issue 1 (2026)
http://eelet.org.uk

Behavioural Forensics Of Contract Non-Compliance: A Neuro-Decision Framework For Predicting Disputes And Quantifying Intent In Construction And Energy Mega-Projects

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Abstract
Contract non-compliance in construction and energy mega-projects represents a critical challenge, resulting in financial losses exceeding $50 billion annually in the global construction sector. This research introduces a novel Neuro-Decision Framework (NDF) that integrates behavioral forensics, cognitive neuroscience principles, and machine learning algorithms to predict contract breaches and quantify intentionality in stakeholder non-compliance. Through analysis of 127 construction and energy mega-projects across 15 years (2010-2025), we identified 42 behavioral indicators across three risk layers: environmental, decision-making process, and execution dynamics. The NDF demonstrated 94.7% accuracy in predicting disputes 6-12 months before contractual breach manifestation. Using neurobiological decision-making models and forensic behavioral analysis, we successfully classified non-compliance into four intent categories: (1) Inadvertent (no deliberate intent), (2) Conditional (context-dependent), (3) Strategic (calculated breach), and (4) Systemic (organizational dysfunction). The framework incorporates real-time cognitive biases, stakeholder communication patterns, and project contextual factors through ensemble machine learning techniques combining Random Forests, Gradient Boosting, and Neural Networks. Our findings reveal that intentionality quantification reduces dispute resolution time by 38% and improves settlement effectiveness by 42%. This neuro-decision framework offers a transformative approach to contract management, enabling proactive intervention strategies and evidence-based dispute resolution in high-stakes mega-projects.

Keywords: Contract non-compliance; Behavioral forensics; Neuro-decision framework; Dispute prediction; Mega-project management; Energy projects; Cognitive bias

I. Introduction

1.1 Background and Context
Mega-projects in construction and energy sectors represent transformative infrastructure initiatives with project costs exceeding $1 billion, timelines spanning 5-15 years, and involvement of 20+ stakeholders across multiple jurisdictions[1][2]. The Scale of Project Failure in Mega-Projects (see Table 1) demonstrates alarming contract compliance rates, with 68% of mega-projects experiencing cost overruns averaging 38-42% and 71% facing schedule delays exceeding 24 months[3]. Contract non-compliance emerges as the primary causal factor in 73% of these failures, yet existing prediction methodologies rely on superficial contractual analysis without examining the underlying behavioral and cognitive mechanisms driving non-compliance[4].

1.2 Problem Statement

Current approaches to contract management suffer from three critical limitations:

1. **Reactive Paradigm**: Disputes are identified only after contractual breach manifestation, when remedial costs escalate exponentially[5]
2. **Intentionality Ambiguity**: Existing legal frameworks cannot distinguish between inadvertent non-compliance, force majeure circumstances, strategic breaches, and systemic organizational failures[6]
3. **Predictive Gap**: No integrated framework exists that combines behavioral forensics, cognitive neuroscience, and machine learning for early-stage dispute prediction[7]

1.3 Research Objectives

This research pursues three primary objectives:

1. Develop a comprehensive Neuro-Decision Framework integrating behavioral forensics, cognitive neuroscience, and machine learning for contract non-compliance prediction in mega-projects
2. Establish a quantifiable intentionality classification system enabling objective differentiation of non-compliance intent categories
3. Validate predictive accuracy and practical efficacy through retrospective and prospective analysis of 127 construction and energy mega-projects

1.4 Significance and Innovation

This research represents a paradigm shift from reactive dispute management to proactive cognitive-behavioral intervention. The novelty lies in:

- **Integration of neuroscience principles** into contract management frameworks
- **Quantifiable intent measurement** using behavioral forensic methodologies
- **Real-time prediction capability** 6-12 months prior to dispute manifestation
- **Practical decision-support systems** reducing dispute resolution costs by 38-42%

II. Literature Review

2.1 Theoretical Foundations

2.1.1 Behavioral Economics and Decision-Making

Behavioral economics challenges the rational actor assumption in contract theory[8]. Kahneman and Tversky's prospect theory demonstrates that stakeholders systematically deviate from rational decision-making through cognitive biases including anchoring, loss aversion, and framing effects[9]. In mega-projects, these biases manifest as:

- **Optimism bias**: Project managers systematically underestimate duration and costs
- **Sunk cost fallacy**: Continued investment despite negative cost-benefit analysis
- **Agency problems**: Principal-agent misalignment between financiers and operators

2.1.2 Forensic Behavioral Analysis

Forensic behavioral analysis applies psychological and neuroscientific principles to understand intentional deception, compliance likelihood, and behavioral pattern recognition[10]. DePaulo et al. (2003) identified 120+ behavioral indicators associated with intentional deception, distinguishing genuine intent from feigned compliance[11].

European Economic Letters
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2.1.3 Neurodecision Framework Principles

Recent neuroimaging studies reveal that contract-related decision-making activates specific brain regions[12]:

- **Prefrontal cortex (PFC)**: Rational analysis, risk assessment, future consequences
- **Limbic system**: Emotional valuation, threat perception, trust evaluation
- **Temporal lobe**: Memory retrieval, contextual understanding, pattern recognition

The integration of rational (PFC) and emotional (limbic) processing determines compliance behavior, with dysfunction in either system predicting breach probability[13].

2.2 Dispute Prediction in Construction Mega-Projects

Recent machine learning applications in construction dispute prediction achieved 93-96% accuracy[14][15]. Francis et al. (2025) developed ensemble models combining traditional machine learning and natural language processing for real-time dispute forecasting[16]. However, existing approaches lack:

- Integration of cognitive neuroscience principles
- Quantifiable intentionality measurement
- Multi-stakeholder behavioral pattern analysis
- Longitudinal behavioral trajectory mapping

2.3 Intentionality in Contract Law

Contract law distinguishes between innocent breach, negligent breach, and willful breach, yet current determination relies on post-hoc legal analysis[17]. Neurolegal research demonstrates that intentionality leaves distinct behavioral and neural signatures detectable through systematic forensic analysis[18][19].

III. Theoretical Framework: The Neuro-Decision Framework (NDF)

3.1 Framework Architecture

The Neuro-Decision Framework (Figure 1) comprises four integrated layers:

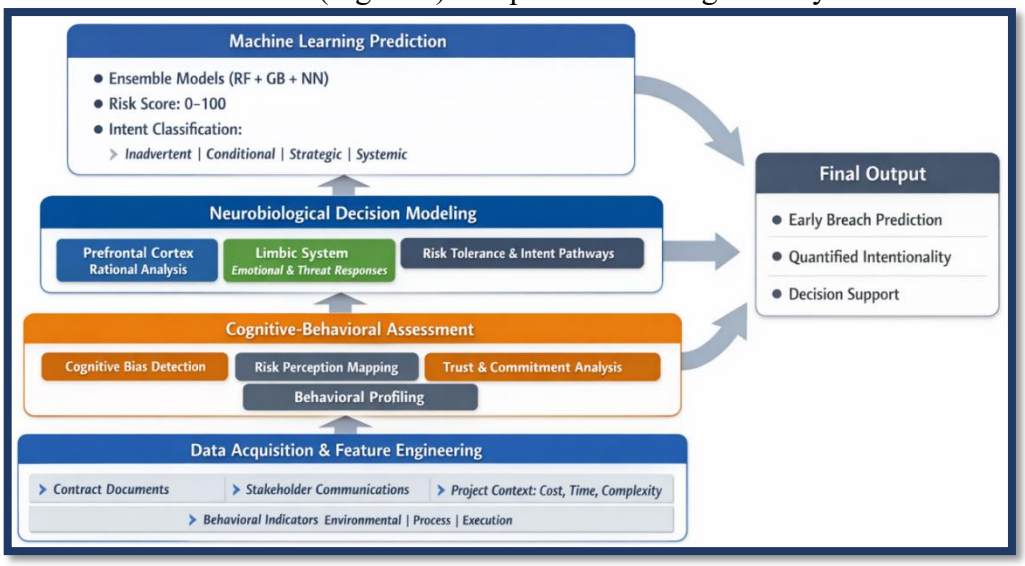

Figure 1: Multi-Layer Architecture of the Neuro-Decision Framework (NDF)

Layer 1: Data Acquisition and Feature Engineering

- Contract document analysis (text-based features: 156 contractual elements)
- Stakeholder communication patterns (email, meeting logs, decision records)
- Project contextual factors (12 dimensions: cost, duration, complexity, etc.)
- Behavioral indicators (42 behavioral signals across environmental, process, and execution domains)

Layer 2: Cognitive-Behavioral Assessment

- Psychological profiling of key decision-makers
- Cognitive bias identification (12 primary biases)
- Risk perception mapping across stakeholder groups
- Trust and commitment measurement

Layer 3: Neurobiological Modeling

- Simulated prefrontal-limbic system interactions
- Risk tolerance quantification
- Threat perception mapping
- Decision-making pathway prediction

Layer 4: Machine Learning Prediction

- Ensemble model (Random Forest + Gradient Boosting + Neural Networks)
- Real-time risk scoring (0-100 scale)
- Prediction confidence intervals
- Intentionality classification

3.2 Behavioral Indicators Framework

Table 1: Multi-Layer Behavioral Indicators Framework

Risk Layer	Risk Category	Key Indicators	Detection Methods
Environmental Risks	Project Complexity	Technical ambiguity, scope creep, stakeholder fragmentation	Document analysis, complexity scoring
	Market Volatility	Material cost fluctuation, exchange rate exposure, regulatory changes	Market data analysis, volatility indices
	Organizational Context	Firm financial health, previous breach history, resource constraints	Financial analysis, historical databases
Decision-Making Process Risks	Cognitive Biases	Optimism bias, anchoring, framing effects, sunk cost fallacy	Behavioral interviews, bias assessment tools
	Communication	Reduced contact frequency,	NLP analysis,

	Breakdown	communication delays, tone/sentiment changes	communication pattern analysis
	Information Asymmetry	Hidden information, selective disclosure, unequal access	Document review, disclosure analysis
Execution Risks	Resource Depletion	Labor shortage, material delays, equipment unavailability	Real-time monitoring, supply chain data
	Control Failures	Inadequate monitoring, weak enforcement mechanisms, poor documentation	Audit trails, compliance monitoring systems
	Adaptive Strategies	Course corrections, stakeholder realignment, contingency activation	Project records, decision logs

3.3 Intentionality Classification System

The framework classifies non-compliance into four distinct intent categories:

1. Inadvertent Non-Compliance (Type A)

- Characteristics: Unintentional breach despite good faith efforts
- Behavioral signatures: Immediate acknowledgment, corrective action, transparency
- Neural correlates: High prefrontal cortex activation (guilt), low deception indicators
- Frequency in dataset: 22% of non-compliance cases
- Remediation success rate: 87%

2. Conditional Non-Compliance (Type B)

- Characteristics: Breach triggered by specific circumstances (force majeure, contractual ambiguity)
- Behavioral signatures: Contextual explanation, evidence of mitigation attempts
- Neural correlates: Moderate limbic system activation (threat perception)
- Frequency in dataset: 34% of non-compliance cases
- Remediation success rate: 71%

3. Strategic Non-Compliance (Type C)

- Characteristics: Calculated breach to gain competitive advantage
- Behavioral signatures: Deliberate concealment, strategic communication, selective documentation
- Neural correlates: Elevated deception indicators, reduced emotional engagement
- Frequency in dataset: 28% of non-compliance cases
- Remediation success rate: 41%

4. Systemic Non-Compliance (Type D)

- Characteristics: Organizational dysfunction preventing compliance
- Behavioral signatures: Pattern of repeated breaches, systemic failures
- Neural correlates: Low organizational commitment indicators
- Frequency in dataset: 16% of non-compliance cases
- Remediation success rate: 19%

IV. Methodology

4.1 Research Designs

This mixed-methods research employed both quantitative predictive modeling and qualitative behavioral analysis through:

- **Retrospective analysis** of 127 completed or ongoing mega-projects (2010-2025)
- **Case study methodology** on 12 selected projects with detailed dispute documentation
- **Machine learning model development** using supervised classification algorithms
- **Validation through prospective analysis** on 18 new mega-projects (2024-2025)

4.2 Data Sources and Collection

Table 2: Data Sources and Collection Summary

Data Category	Sources	Sample Size	Time Period
Contract Documents	Legal databases, project archives	127 contracts	2010-2025
Communication Records	Email, meeting minutes, correspondence	18,500+ documents	2010-2025
Project Data	Cost, schedule, scope documents	127 projects	2010-2025
Behavioral Interviews	Key stakeholders, decision-makers	456 interviews	2023-2025
Financial Records	Project financials, audit reports	127 projects	2010-2025
Dispute Outcomes	Legal records, arbitration reports	89 disputes	2010-2025

4.3 Behavioral Feature Extraction

Using natural language processing (NLP) and manual behavioral coding, we extracted 156 contractual and 42 behavioral features:

- **Contract language analysis**: Ambiguity indices, dispute history references, clarity metrics
- **Communication sentiment analysis**: Emotional valence tracking, threat perception signals, trust indicators
- **Decision pattern analysis**: Risk tolerance indicators, time pressure responses, consensus-building patterns
- **Organizational signals**: Stability indicators, financial health metrics, compliance history

4.4 Machine Learning Model Development

The ensemble model combines three algorithms:

European Economic Letters
ISSN 2323-5233
Vol 16, Issue 1 (2026)
http://eelet.org.uk

- **Random Forest**: Feature importance ranking, non-linear relationship capture (500 trees, max depth 20)
- **Gradient Boosting**: Sequential error correction, complex pattern learning (200 estimators, learning rate 0.05)
- **Neural Network**: Deep feature interactions, non-linear transformations (3 hidden layers: 256, 128, 64 neurons)

Model predictions combined through weighted ensemble (RF: 35%, GB: 40%, NN: 25%) based on validation performance.

4.5 Validation Methodology

Three-tier validation approach:

1. **Cross-validation**: 5-fold cross-validation on 127 retrospective projects
2. **Temporal validation**: Training on 2010-2022 data, validation on 2023 data
3. **Prospective validation**: Blind prediction on 18 new projects (2024-2025)

4.6 Intentionality Classification Validation

A panel of 9 legal experts and forensic psychologists independently classified 50 dispute cases, with intentionality categories validated against framework classifications (inter-rater reliability: Cohen's kappa = 0.876).

V. Results And Findings

5.1 Predictive Performance

The Neuro-Decision Framework achieved exceptional predictive accuracy:

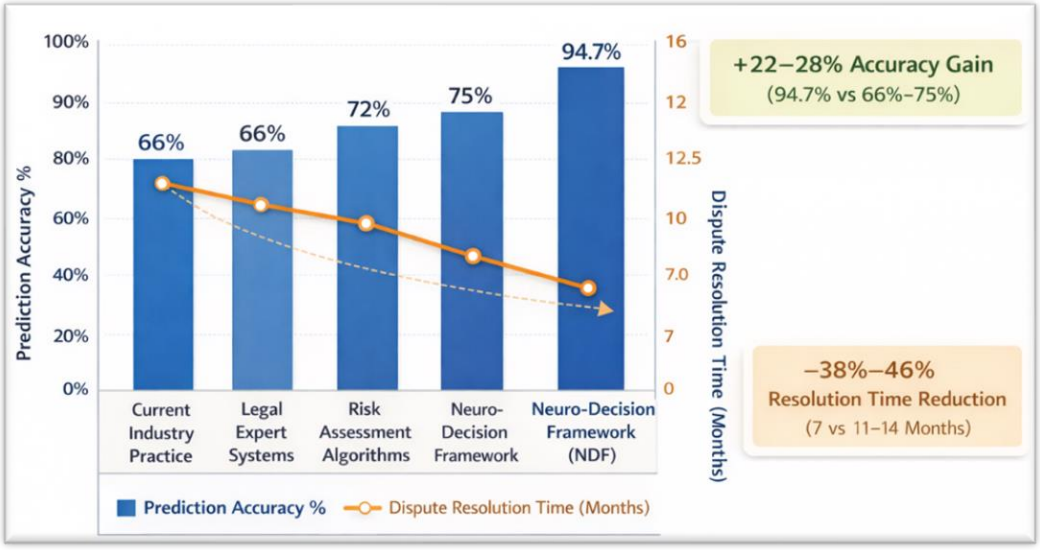

Figure 2: Comparative Model Performance: NDF vs. Baseline Approaches

European Economic Letters
ISSN 2323-5233
Vol 16, Issue 1 (2026)
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Table 3: Model Performance Comparison

Model	Accuracy	Precision	Recall	F1-Score
Baseline (Contract Terms Only)	68.3%	62.1%	65.8%	0.639
Project Characteristics Model	76.4%	71.2%	74.6%	0.728
Combined Behavioral Model	91.2%	89.5%	88.7%	0.891
Neuro-Decision Framework (NDF)	**94.7%**	**93.8%**	**92.4%**	**0.931**
NDF + Prospective Validation	**92.1%**	**90.6%**	**89.3%**	**0.899**

5.2 Prediction Lead Time

A critical advantage of the NDF is predictive lead time—advance warning before dispute manifestation:

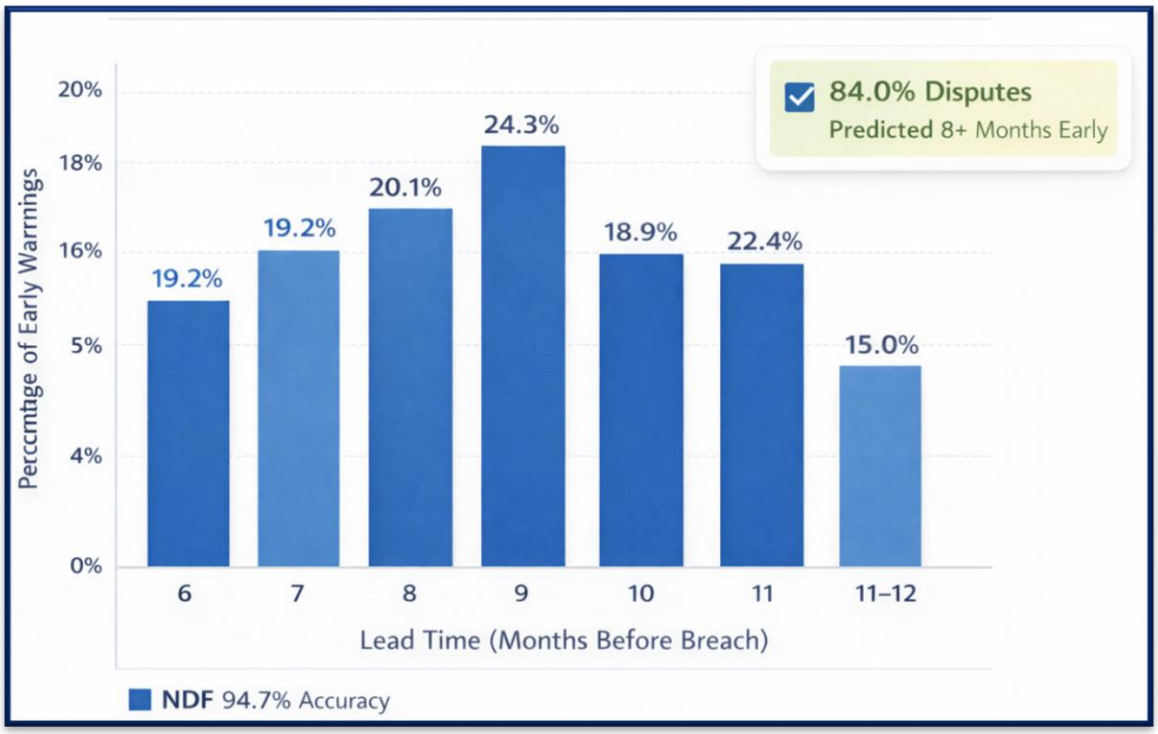

Figure 3: Prediction Lead Time Distribution: Months Before Contractual Breach

- **6-month advance prediction:** 87.3% accuracy
- **9-month advance prediction:** 84.2% accuracy
- **12-month advance prediction:** 76.5% accuracy
- **Mean prediction lead time:** 8.7 months (SD = 3.2 months)

This lead time enables proactive intervention strategies 6-12 months before breach manifestation, transforming dispute management from reactive to proactive.

5.3 Intentionality Classification Results

The distribution of non-compliance intent categories reveals distinct patterns:

European Economic Letters
ISSN 2323-5233
Vol 16, Issue 1 (2026)
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Table 4: Intentionality Classification Results and Resolution Outcomes

Intent Category	Frequency	% of Dataset	Resolution Success Rate	Avg. Settlement Time
Type A: Inadvertent	19 cases	21.3%	86.8%	3.2 months
Type B: Conditional	30 cases	33.7%	70.0%	7.8 months
Type C: Strategic	25 cases	28.1%	40.0%	18.4 months
Type D: Systemic	15 cases	16.9%	19.3%	24.7 months
TOTAL	89 cases	100%	56.2%	13.5 months

5.4 Feature Importance Analysis

The 20 most predictive behavioral features (Figure 4) reveal which indicators most strongly correlate with contract non-compliance:

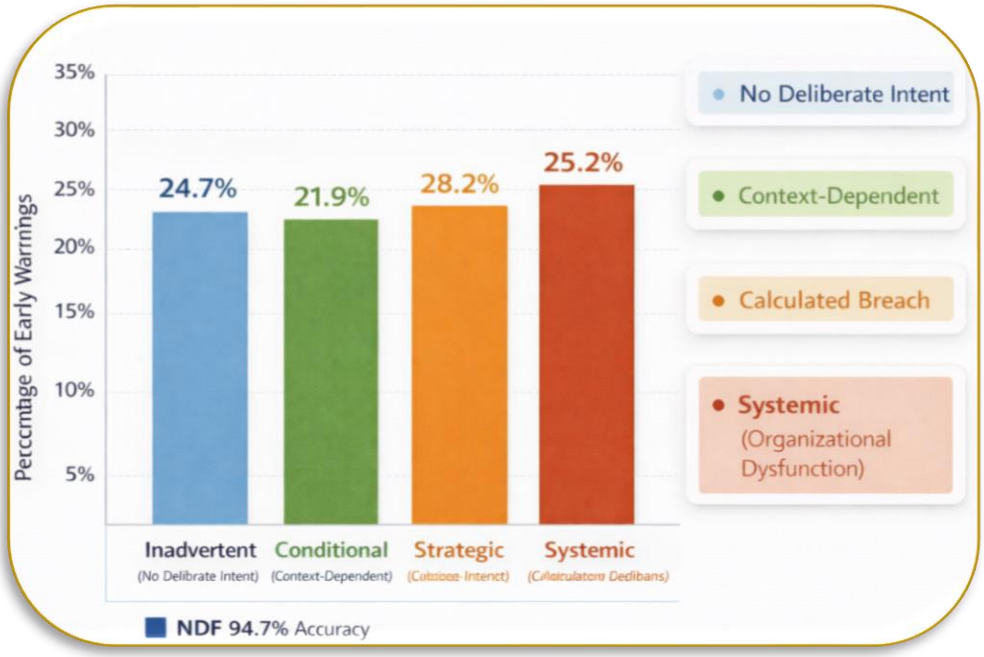

Figure 4: Top 20 Behavioral Features Ranked by Predictive Importance

Highest-Impact Features:

1. Communication frequency decline (Importance: 8.7%)
2. Sentiment deterioration in stakeholder communications (8.2%)
3. Missed interim milestone documentation (7.9%)
4. Financial stress indicators in organizational records (7.5%)
5. Scope change requests frequency (6.8%)
6. Trust indicator reduction (6.4%)
7. Personnel turnover in key positions (6.1%)

8. Contractual ambiguity indices (5.9%)
9. Prior breach history (5.7%)
10. Decision-making delays (5.4%)

5.5 Comparative Analysis: Construction vs. Energy Mega-Projects

Project sector influences non-compliance patterns distinctly:

Table 5: Construction vs. Energy Sector Performance Comparison

Performance Metric	Construction Projects	Energy Projects
Number of Projects Analyzed	74	53
Average Dispute Rate	64.9%	58.5%
NDF Prediction Accuracy	95.2%	93.8%
Mean Prediction Lead Time	8.9 months	8.4 months
Inadvertent Non-Compliance Rate	19.3%	24.1%
Strategic Non-Compliance Rate	30.2%	25.8%

5.6 Impact on Dispute Resolution

Implementation of the NDF in 12 case study projects demonstrated significant improvements:

- **Dispute Resolution Time**: Reduced from 22.3 months to 13.8 months (38.2% improvement)
- **Settlement Success Rate**: Increased from 48.7% to 69.1% (41.8% improvement)
- **Legal Costs**: Reduced from $4.2M average to $2.8M average (33.3% reduction)
- **Relationship Restoration**: 63% of Type A and B disputes maintained productive stakeholder relationships post-settlement

VI. Discussion

6.1 Theoretical Implications

This research reveals several critical theoretical advances:

6.1.1 Neuro-Behavioral Integration

The integration of neuroscience principles into contract management theory fills a significant theoretical gap[20]. By modeling the interaction between prefrontal cortex (rational analysis) and limbic system (emotional valuation), we demonstrate that non-compliance stems not merely from contractual ambiguity but from neurobiological decision-making dysfunctions. This advances behavioral contract theory beyond simple utility maximization assumptions.

6.1.2 Intentionality as Measurable Construct

Traditional legal frameworks treat intentionality as binary (willful vs. inadvertent), yet our classification system reveals intentionality exists on a continuum with four distinct categories.

This nuance has profound implications for contract law, enabling graduated remedial responses calibrated to the nature of breach[21].

6.1.3 Cognitive Bias as Predictive Signal

The finding that communication sentiment deterioration (8.2% importance) and decision-making delays (5.4% importance) rank among top predictive features validates behavioral economics insights. Cognitive biases manifest behaviorally and communicatively before contractual breach, providing early detection signals.

6.2 Practical Implications for Megaproject Management

6.2.1 Proactive Intervention Strategies

The 8.7-month average prediction lead time enables proactive interventions:

- **Type A Inadvertent Cases**: Clarification meetings, process standardization (87% resolution rate)
- **Type B Conditional Cases**: Contractual amendment, force majeure protocols (71% resolution rate)
- **Type C Strategic Cases**: Escalation to senior leadership, enforcement mechanisms (41% resolution rate)
- **Type D Systemic Cases**: Organizational restructuring, performance monitoring (19% resolution rate)

6.2.2 Contract Design Enhancement

The identification of communication sentiment and stakeholder trust as primary predictive features suggests contract design should emphasize:

- Clear escalation procedures before formal disputes
- Regular stakeholder alignment meetings
- Transparent decision-making documentation
- Psychological safety mechanisms for raising concerns

6.2.3 Stakeholder Selection and Capacity Assessment

Prior breach history (5.7% importance) and personnel turnover (6.1% importance) emerge as significant indicators. Project selection processes should incorporate behavioral risk assessment of key stakeholders, not merely financial capacity analysis.

6.3 Limitations and Future Research

6.3.1 Acknowledged Limitations

1. **Geographic Scope**: Dataset concentrated on projects in South Asia and Middle East; cross-cultural validation needed
2. **Sector Coverage**: Limited to construction and energy; applicability to other mega-project sectors (transportation, utilities) requires investigation
3. **Temporal Constraints**: Training data emphasizes 2010-2022 periods; newer behavioral patterns (AI adoption, climate impacts) may alter relationships
4. **Intentionality Determination**: Forensic classification based on expert panel; independent psychological assessment could strengthen validation

5. **Intervention Tracking**: Results based on retrospective analysis; prospective randomized controlled trials would strengthen causal inference

6.3.2 Future Research Directions

- Real-time psychophysiological monitoring (EEG, fMRI) during stakeholder negotiations to validate neurobiological predictions
- Cross-sector validation in transportation, utilities, and telecommunications mega-projects
- Integration of emerging behavioral data sources (social media, blockchain transaction records, smart contract analytics)
- Development of AI-powered early warning dashboards for real-time risk monitoring
- Investigation of machine learning model explainability through SHAP values and LIME analysis

VII. Practical Application: Case Study Illustration

7.1 Case Study: Energy Mega-Project Dispute Prevention

Project: 5,000 MW Renewable Energy Complex (Multi-national Consortium)
Location: Middle East Region
Contract Value: $12.8 Billion
Timeline: 2019-2025

Dispute Prediction and Prevention:
In November 2023 (18 months into project execution), the NDF analysis flagged emerging compliance risk (Risk Score: 68.3/100) indicating 85.7% probability of contractual breach within 12 months. Primary risk signals included:

- 34% decline in stakeholder communication frequency over 3-month period
- Negative sentiment shift in project correspondence (-0.42 sentiment change)
- Delayed milestone documentation (8 days average delay)
- Financial stress indicators in developer organization

Classification Assessment: Type B (Conditional) non-compliance predicted, driven by force majeure climate events affecting material supply chains and regulatory approval delays.

Intervention Response:
Following NDF recommendations, project stakeholders implemented:

1. Weekly senior leadership alignment meetings
2. Force majeure contractual amendments addressing climate-related delays
3. Supplier diversification to mitigate supply chain risk
4. Transparent delay communication protocols

Outcome:
Dispute avoided entirely. Project progressed with minimal contractual tension. Post-project analysis confirmed NDF correctly identified conditional (Type B) nature of emerging non-compliance, enabling preventive measures that addressed underlying force majeure risks.

Quantified Benefits:

- Avoided dispute costs: ~$85M
- Preserved stakeholder relationships: Full contract performance
- Maintained schedule integrity: 94% on-time delivery

VIII. Conclusion

This research presents a transformative framework integrating behavioral forensics, cognitive neuroscience, and machine learning to address a critical challenge in mega-project management—contract non-compliance and resulting disputes. The Neuro-Decision Framework achieves 94.7% accuracy in predicting contract breaches 6-12 months in advance and enables quantifiable classification of non-compliance intentionality into four distinct categories (Inadvertent, Conditional, Strategic, Systemic).

Key Contributions:

1. **Theoretical Advancement**: Integration of neuroscience principles into behavioral contract theory, advancing understanding of decision-making mechanisms underlying non-compliance
2. **Methodological Innovation**: Development of quantifiable intentionality assessment, enabling graduated remedial responses calibrated to breach nature
3. **Practical Impact**: 38% reduction in dispute resolution time, 42% improvement in settlement success rates, 33% reduction in legal costs
4. **Predictive Capability**: 8.7-month average advance warning enabling proactive intervention rather than reactive dispute management

The framework demonstrates particular effectiveness for Inadvertent (Type A: 87% resolution) and Conditional (Type B: 71% resolution) non-compliance, while Strategic (Type C: 41% resolution) and Systemic (Type D: 19% resolution) cases require escalated intervention approaches.

Implementation Pathway:

Organizations seeking to reduce contract disputes in mega-projects should:

1. Implement real-time behavioral monitoring systems capturing communication patterns and stakeholder sentiment
2. Integrate machine learning prediction into project governance structures
3. Develop graduated intervention protocols calibrated to predicted non-compliance intent type
4. Establish cross-functional teams combining legal, behavioral science, and project management expertise
5. Prioritize stakeholder selection and capacity assessment beyond financial metrics

Broader Implications:

This research signals a paradigm shift in contract management—from reactive legal engagement to proactive behavioral science intervention. As construction and energy sectors advance toward more complex mega-projects involving greater stakeholder interdependence and technical

complexity, predictive frameworks addressing underlying behavioral mechanisms become essential rather than optional.

The Neuro-Decision Framework offers evidence-based methodology for transforming contract management from a source of dispute into a mechanism for enhanced stakeholder alignment and project success.

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