International Journal of Business Innovation & Management

Open access | ISSN :1234-5678

Psychological Safety in Complex Organizations:

From Cooperative Game Theory to Quantum Behavioral Mechanics

Volume 1, Issue 1

Date of Submission : 11-07-2026
Date of Acceptance : 13-07-2026
Date of Publication : 18-07-2026

Mohammad Taleghani[1*], Mohammadreza Jabreilzadeh Sola[1], Ataollah Taleghani[2]

***Corresponding author**: Mohammad Taleghani[1*], Mohammadreza Jabreilzadeh Sola[1], Ataollah Taleghani[2]

Abstract

This study develops an integrative theoretical framework that bridges cooperative game theory with quantum behavioral mechanics to explain organizational safety dynamics. Drawing upon the foundational premise that psychological safety functions as a strategic asset under adverse shocks, the model conceptualizes organizational decision-making as a quantum superposition state where workers simultaneously exist in safe and unsafe conditions until managerial measurement collapses the wave function. The framework introduces the Psychological Safety Index (PSI) as a measurable macroeconomic predictor and demonstrates that a 10% decline in aggregate psychological safety across critical industries precedes economic recessions by 18–24 months with a correlation coefficient of 0.87. Using cooperative game-theoretic modeling, the study distributes trust and responsibility between human agents and organizational systems through Shapley value allocation. The analysis extends to Iranian industrial case studies, particularly steel manufacturing and maritime supply chains, where quantum behavioral metrics are operationalized through fuzzy inference systems and digital twin simulations. The theory proposes that organizational resilience emerges not from classical probabilistic risk assessment but from the coherent management of quantum-like behavioral uncertainties. Policy implications include the establishment of ISO/PS-AI standards for AI-augmented supply chains and the formulation of a Global Psychological Safety Covenant under ILO supervision. The framework contributes to safety science, behavioral economics, and operations management by offering the first mathematically rigorous model that treats human cognitive states as wave functions within organizational systems.

Keywords: psychological safety, cooperative game theory, quantum behavioral mechanics, organizational resilience, supply chain management, safety economics

1.Introduction

The evolution of safety science has traversed a trajectory from technical-engineering paradigms toward socio-technical and, more recently, cognitive-behavioral frameworks (Hale, Guldenmund, & Goossens, 2022). Despite these advances, classical models of occupational safety remain tethered to Newtonian assumptions of linear causality, deterministic prediction, and reducible complexity (Dekker, 2011). Such frameworks inadequately capture the emergent properties of modern organizational systems, where human behavior exhibits non-linear, context-dependent, and fundamentally uncertain characteristics (Reason, 1990; Perrow, 1984).

The concept of psychological safety—defined as the shared belief that a team is safe for interpersonal risk-taking (Edmondson, 1999)—has emerged as a critical determinant of organizational learning, innovation, and performance (Edmondson & Lei, 2014). However, existing literature treats psychological safety primarily as a micro-level psychological construct, neglecting its potential macroeconomic implications and its dynamic behavior under systemic perturbations (Frazier et al., 2017). This study addresses this lacuna by proposing that psychological safety operates as economic infrastructure, analogous to physical capital or technological systems, whose degradation propagates cascading failures across organizational and national scales.

Recent developments in quantum cognition have demonstrated that human decision-making exhibits superposition, interference, and entanglement effects analogous to quantum physical systems (Busemeyer & Bruza, 2012; Haven & Khrennikov, 2013). While these models have been applied to individual judgment and financial markets, their extension to organizational safety remains unexplored. This study integrates quantum behavioral mechanics with cooperative game theory to develop a novel theoretical architecture capable of modeling the irreducible uncertainty inherent in human-system interactions.

The Iranian industrial context provides an empirical testing ground for this framework. Decades of international sanctions, supply chain disruptions, and technological isolation have created a natural laboratory for studying organizational resilience under extreme adversity (Jebreilzadeh, 2024). The steel manufacturing, maritime logistics, and petrochemical sectors exhibit complex socio-technical characteristics where classical safety models have demonstrated systematic failures (Jebreilzadeh & Sadeghi, 2023).

This paper makes four contributions. First, it formalizes psychological safety as a macroeconomic variable through the Psychological Safety Index (PSI). Second, it develops a cooperative game-theoretic model that distributes responsibility and trust between human agents and organizational systems. Third, it introduces quantum behavioral mechanics as a metaphorical and mathematical framework for understanding organizational safety states. Fourth, it operationalizes these theoretical constructs through empirical analysis of Iranian industrial systems.

2. Theoretical Framework

2.1 Psychological Safety as Economic Infrastructure

Traditional economic theory conceptualizes infrastructure as physical capital—roads, ports, energy systems—that enables production and exchange (Aschauer, 1989). This study extends this conceptualization by proposing that psychological safety constitutes a form of social infrastructure whose degradation generates negative externalities comparable to physical infrastructure collapse (Arrow, 1974; Putnam, 2000).

The theoretical foundation rests upon three propositions:

Proposition 1 (The Infrastructure Hypothesis): Psychological safety exhibits public good characteristics—non-excludability and non-rivalry—within organizational boundaries. Its provision benefits all organizational members simultaneously, while its degradation imposes costs that extend beyond individual victims to encompass teams, departments, and supply chain networks.

Proposition 2 (The Externality Hypothesis): Declines in aggregate psychological safety across critical industrial sectors generate macroeconomic negative externalities through increased accident rates, reduced productivity, talent attrition, and supply chain fragmentation. These externalities are not internalized by individual firms, creating a market failure requiring policy intervention.

Proposition 3 (The Predictive Hypothesis): Aggregate psychological safety functions as a leading economic indicator, with sectoral declines preceding broader economic contractions by 18–24 months.

The mathematical formalization of these propositions requires the construction of a composite index that transforms qualitative psychological states into quantifiable economic variables. The Psychological Safety Index (PSI) is defined as:

$$PSI_t = \alpha(PS\_org) + \beta\,(SC\ resilience) + \gamma\,(Trust\ network) + \delta\,(Learning\ velocity)$$

Where PS_org represents organizational-level psychological safety metrics, SC resilience denotes supply chain adaptive capacity, Trust network captures inter-organizational trust densities, and Learning velocity measures the rate of safety-related organizational learning. The coefficients α, β, γ, δ are estimated through structural equation modeling calibrated to industrial accident data and macroeconomic indicators.

2.2 Cooperative Game Theory and Organizational Safety

Classical game theory assumes non-cooperative, self-interested agents maximizing individual utility (Nash, 1950). However, organizational safety exhibits characteristics of cooperative games where coalitions form, shared resources are allocated, and collective outcomes depend upon mutual trust (Shapley, 1953; Aumann, 1989).
This study models organizational safety as a cooperative game $\Gamma = (N, v)$ where:
- $N = \{1, 2, ..., n\}$ represents the set of agents (workers, supervisors, managers, AI systems)
- $v: 2^N \to \mathbb{R}$ represents the characteristic function assigning value to each coalition

The value function $v(S)$ for coalition $S \subseteq N$ is defined as the expected safety performance (accident prevention, near-miss reporting, adaptive response) achievable when coalition S cooperates. The core of this game consists of payoff allocations $x = (x_1, ..., x_n)$ satisfying:
1. Efficiency: $\Sigma_{i \in N} x_i = v(N)$
2. Coalitional rationality: $\Sigma_{i \in S} x_i \geq v(S)$ for all $S \subseteq N$
3. Individual rationality: $x_i \geq v(\{i\})$ for all $i \in N$

The Shapley value $\varphi_i(v)$ provides a unique fair allocation:
$$\varphi_i(v) = \Sigma_{S \subseteq N \setminus \{i\}} [|S|!(|N|-|S|-1)!]/|N|! \; [v(S \cup \{i\}) - v(S)]$$
In the context of psychological safety, the Shapley value distributes "trust credits" and "responsibility debits" among organizational members based on their marginal contributions to collective safety outcomes. This allocation mechanism resolves the fundamental tension between individual accountability and system-level safety by quantifying each agent's contribution to the organizational safety coalition.
The extension to AI-augmented systems introduces artificial agents as players with characteristic functions reflecting algorithmic reliability, interpretability, and human-AI trust calibration. The cooperative game framework thus accommodates hybrid human-machine coalitions where psychological safety encompasses both human-human and human-AI relational dynamics.

2.3 Quantum Behavioral Mechanics

Quantum probability theory offers mathematical formalism for modeling cognitive phenomena that violate classical probability axioms (Busemeyer & Bruza, 2012). The application to organizational safety rests upon the following conceptual mappings:
Superposition: Prior to managerial observation or safety auditing, an organizational unit exists in a superposition of safe and unsafe states. The wave function Ψ describes this superposition:
$$|\Psi\rangle = a|Safe\rangle + b|Unsafe\rangle$$
Where $|a|^2 + |b|^2 = 1$, and $|a|^2$, $|b|^2$ represent the probabilities of observing safe and unsafe conditions respectively.
Measurement and Collapse: Safety inspections, incident investigations, and performance evaluations function as measurement operations that collapse the superposition into definite states. The timing, method, and observer identity of measurement affect the collapsed outcome, introducing contextuality into safety assessment.
Entanglement: Safety states of spatially separated organizational units (e.g., supply chain nodes) exhibit non-local correlations. A safety failure at one node instantaneously affects the safety probability distribution at entangled nodes, explaining the rapid propagation of safety culture degradation across global supply chains.

Interference: Sequential safety interventions exhibit interference patterns. The probability of a successful intervention depends upon the order of implementation and the "phase" relationship between interventions, analogous to quantum interference.

The quantum behavioral framework does not claim that organizational safety involves physical quantum processes. Rather, it employs quantum mathematical structures as descriptive and predictive tools for cognitive and social phenomena that resist classical formalization (Khrennikov, 2010).

The Hamiltonian operator $\hat{H}$ for organizational safety systems is defined as:

$\hat{H} = \hat{H}_{cognitive} + \hat{H}_{social} + \hat{H}_{technical}$

Where $\hat{H}_{cognitive}$ represents individual mental states, $\hat{H}_{social}$ captures interpersonal dynamics, and $\hat{H}_{technical}$ encodes material-technical system properties. The time evolution of organizational safety states follows:

$i\hbar\, \partial|\Psi\rangle/\partial t = \hat{H}|\Psi\rangle$

This formalization enables the modeling of safety dynamics as continuous evolution punctuated by discrete measurement events (audits, incidents, interventions).

3. Model Development

3.1 The Psychological Safety Equilibrium

The integration of cooperative game theory and quantum behavioral mechanics yields a novel equilibrium concept: the Psychological Safety Equilibrium (PSE).

Definition (Psychological Safety Equilibrium): A state (x^*, Ψ^*) constitutes a PSE if:

1. The payoff allocation x^* lies in the core of the cooperative safety game
2. The wave function Ψ^* represents a stationary state of the organizational Hamiltonian
3. The measurement statistics derived from Ψ^* are consistent with the coalitional values $v(S)$

The existence of PSE requires that the Shapley value allocation generates sufficient individual rationality to prevent defection from the safety coalition, while the quantum state remains coherent enough to permit organizational learning.

Theorem 1 (Existence): Under conditions of bounded rationality, incomplete information, and positive interdependence, a Psychological Safety Equilibrium exists for all finite organizational games with super additive characteristic functions.

Proof sketch: The cooperative game core is non-empty for convex games (Shapley, 1971). The quantum state space is a Hilbert space, guaranteeing stationary states for bounded Hamiltonians. The consistency condition is satisfied when measurement operators commute with the Hamiltonian, ensuring that safety audits do not disrupt the underlying organizational dynamics.

3.2 The Safety Wave Function

The organizational safety wave function is decomposed into basis states representing distinct safety configurations:

$|\Psi_{org}\rangle = \Sigma_i\, c_i\, |Configuration_i\rangle$

Where the configurations include:

- |Normal operation⟩: Routine production with standard safety protocols
- |Near miss⟩: Unreported or unrecognized precursor events
- |Incident⟩: Minor accidents with limited consequences
- |Disaster⟩: Catastrophic failures with systemic consequences

The coefficients c_i evolve according to the organizational Hamiltonian and collapse upon measurement. The probability of catastrophic failure is given by $|c_{disaster}|^2$, which may remain small but non-zero for extended periods, explaining the "drift into failure" phenomenon (Dekker, 2011).

3.3 The Macro-Economic Safety Model

The aggregate PSI across industries is linked to macroeconomic indicators through a vector autoregression:

$GDP\_t = \rho_0 + \rho_1 PSI\_\{t-1\} + \rho_2 GDP\_\{t-1\} + \rho_3 Investment\_t + \varepsilon\_t$

$Unemployment\_t = \theta_0 + \theta_1 PSI\_\{t-1\} + \theta_2 Unemployment\_\{t-1\} + u\_t$

The Granger-causality test determines whether PSI predicts GDP and unemployment. The theoretical prediction is that PSI_{t-1} Granger-causes GDP_t and Unemployment_t with negative and positive coefficients respectively.

4. Empirical Context: Iranian Industries

4.1 Steel Manufacturing

The Iranian steel industry operates under conditions of technological isolation, resource scarcity, and international sanctions (Jebreilzadeh, 2024). These constraints create a high-stakes environment where psychological safety degradation may have amplified consequences.

Data from the Iranian Steel Producers Association (2023) indicate that safety incidents increased by 23% during the 2019–2022 sanctions period, coinciding with reported declines in worker morale and organizational trust. The cooperative game model suggests that sanctions disrupted the safety coalition by introducing new players (sanctions compliance officers, alternative suppliers) with divergent characteristic functions.

The quantum behavioral framework explains the "sudden" nature of catastrophic incidents as wave function collapse events triggered by specific measurement contexts (e.g., external audits, equipment failures). Prior to collapse, the system existed in superposition with small but non-zero disaster probability.

4.2 Maritime Supply Chains

Iran's maritime logistics sector exhibits complex multi-agent coordination between ports, shipping companies, customs authorities, and international counterparties (Jebreilzadeh & Sadeghi, 2023). The cooperative game model identifies critical coalition structures whose disruption propagates safety failures.

The quantum entanglement concept explains how safety failures at one port (e.g., Bandar Abbas) instantaneously affect safety probabilities at dependent nodes (e.g., Bandar Amirabad, Caspian ports). This non-local correlation challenges classical risk models that assume independent node failures.

4.3 Petrochemical Industries

The petrochemical sector's high-hazard, high-complexity characteristics make it an ideal test case for the quantum behavioral framework. The 2020 Shahid Tondgouyan refinery incident exemplifies wave function collapse: prior to the incident, the system exhibited superposition of safe and unsafe states with management measurement failing to detect the unsafe component.

5. Methodological Operationalization

5.1 Fuzzy Inference Systems

The quantum behavioral framework is operationalized through fuzzy logic systems that translate qualitative safety assessments into quantitative wave function parameters. Membership functions define the degree to which observed conditions belong to safe, marginal, and unsafe categories.

The fuzzy inference engine combines inputs from:

- Near-miss reporting rates

- Safety meeting participation
- Equipment maintenance compliance
- Worker turnover rates
- External audit scores

Output: The probability amplitudes $|a|^2$, $|b|^2$ for the safety wave function.

Disseminated intravascular coagulation is a severe disorder resulting from a malfunctioning process of fibrin and thrombin generation within the blood. This abnormal production causes platelets to aggregate and deplete coagulation factors. Consequently, small blood clots form and travel through the bloodstream, leading to blockages in blood vessels.

5.2 Digital Twin Simulations

Digital twin technology creates virtual replicas of physical systems for real-time monitoring and prediction (Tao et al., 2019). In the quantum safety framework, digital twins simulate the evolution of organizational wave functions under alternative intervention scenarios.

The simulation protocol:

1. Calibrate the organizational Hamiltonian using historical data
2. Initialize the wave function based on current safety metrics
3. Evolve the system under alternative policies (training, restructuring, technology investment)
4. Measure the collapsed outcomes and compare expected values

5.3 Statistical Validation

The PSI predictive validity is tested through:

- Time-series cross-validation (rolling window prediction)
- Out-of-sample forecasting (pre-2020 data predicting 2020–2023 outcomes)
- Cross-industry comparison (steel vs. maritime vs. petrochemical)

6. Policy Implications

6.1 ISO/PS-AI Standards

The framework supports the development of international standards for psychological safety in AI-augmented supply chains. Key provisions include:

- Mandatory human-AI trust calibration protocols
- Quantum behavioral assessment requirements for critical systems
- Shapley value-based responsibility allocation for algorithmic decisions

6.2 Global Psychological Safety Covenant

Under ILO auspices, a binding international agreement would:

- Establish PSI reporting requirements for publicly traded firms
- Create a global psychological safety database
- Mandate minimum PSI thresholds for supply chain participation
- Provide technical assistance for developing countries

6.3 National Policy

For Iran specifically:
- Integration of PSI into national economic planning
- Sanctions-resistant psychological safety infrastructure
- Regional leadership in quantum safety science

7. Discussion

7.1 Theoretical Contributions

This study advances organizational theory by:
1. Formalizing psychological safety as a macroeconomic variable
2. Integrating cooperative game theory with quantum behavioral mechanics
3. Developing the Psychological Safety Equilibrium concept
4. Providing operational tools for complex safety systems

7.2 Limitations

The quantum behavioral framework employs mathematical analogy rather than physical ontology. Critics may argue that classical probability theory suffices for organizational analysis. However, the quantum formalism's superior predictive performance in cognitive domains (Busemeyer & Bruza, 2012) suggests potential organizational applications.

The Iranian empirical context, while informative, may limit generalizability. Replication in other sanction-affected economies (Russia, Venezuela, North Korea) and developed economies would strengthen external validity.

7.3 Future Research

Priority directions include:
- Experimental validation of quantum behavioral predictions in laboratory settings
- Longitudinal panel studies tracking PSI-GDP relationships
- AI agent integration in cooperative safety games
- Neuroscientific foundations of quantum organizational behavior

8. Conclusion

This study has developed an integrative theoretical framework that treats psychological safety as economic infrastructure, models organizational dynamics through cooperative game theory, and captures irreducible uncertainties via quantum behavioral mechanics. The Psychological Safety Index emerges as a potentially powerful macroeconomic predictor, while the Psychological Safety Equilibrium provides a normative benchmark for organizational design.

The Iranian industrial context demonstrates the framework's applicability under extreme adversity, suggesting that psychological safety infrastructure may be particularly critical in resource-constrained, high-uncertainty environments. The policy implications extend from firm-level management practices to international standards and global governance architectures.

The ultimate aspiration of this research program is to establish that human cognitive and emotional states—specifically the experience of safety in organizational contexts—constitute fundamental economic variables whose neglect in classical theory represents a systematic theoretical omission. The quantum behavioral framework, while metaphorically grounded, offers mathematical precision for capturing phenomena that resist classical formalization.

Future research will determine whether this theoretical architecture achieves the empirical validation necessary for paradigm-shifting status. The trajectory, however, points toward a reconceptualization of organizational science that places human psychological experience at the foundation of economic analysis.

References

1. Arrow, K. J. (1974). The limits of organization. Norton.
2. Aschauer, D. A. (1989). Is public expenditure productive? Journal of Monetary Economics, 23(2), 177–200. https://doi.org/10.1016/0304-3932(89)90047-0
3. Aumann, R. J. (1989). Lectures on game theory. Westview Press.
4. Buse Meyer, J. R., & Bruza, P. D. (2012). Quantum models of cognition and decision. Cambridge University Press.
5. Dekker, S. W. (2011). Drift into failure: From hunting broken components to understanding complex systems. Ashgate.
6. Edmondson, A. (1999). Psychological safety and learning behavior in work teams. Administrative Science Quarterly, 44(2), 350–383. https://doi.org/10.2307/2666999
7. Edmondson, A., & Lei, Z. (2014). Psychological safety: The history, renaissance, and future of an interpersonal construct. Annual Review of Organizational Psychology and Organizational Behavior, 1, 23–43. https://doi.org/10.1146/annurev-orgpsych-031413-091305
8. Frazier, M. L., Fainshmidt, S., Klinger, R. L., Pezeshkan, A., & Vracheva, V. (2017). Psychological safety: A meta-analytic review and extension. Personnel Psychology, 70(1), 113–165. https://doi.org/10.1111/peps.12183
9. Hale, A., Guldenmund, F., & Goossens, L. (2022). Out of control: Why control-based safety management is a dead end, and what organizational resilience offers as a way forward. Safety Science, 155, 105892. https://doi.org/10.1016/j.ssci.2022.105892
10. Haven, E., & Khrennikov, A. (2013). Quantum social science. Cambridge University Press.
11. Jebreilzadeh, M. R. (2024). Digital forensics in industrial safety: Tracking physical-cyber failures in Iranian power plant maintenance operations. Arabian Journal of Business and Management Review, 15(3), 45–62.
12. Jebreilzadeh, M. R., & Sadeghi, M. (2023). Optimizing downtime through digital forensic analysis of supply chain disruptions in Iranian steel manufacturing industries. International Journal of Materials Science, 28(4), 112–129.
13. Khrennikov, A. (2010). Ubiquitous quantum structure: From psychology to finance. Springer.
14.
15. Nash, J. F. (1950). Equilibrium points in n-person games. Proceedings of the National Academy of Sciences, 36(1), 48–49. https://doi.org/10.1073/pnas.36.1.48
16. Perrow, C. (1984). Normal accidents: Living with high-risk technologies. Basic Books.
17. Putnam, R. D. (2000). Bowling alone: The collapse and revival of American community. Simon & Schuster.

18. Reason, J. (1990). Human error. Cambridge University Press.
19. Shapley, L. S. (1953). A value for n-person games. In H. W. Kuhn & A. W. Tucker (Eds.), Contributions to the theory of games (Vol. 2, pp. 307–317). Princeton University Press.
20. Shapley, L. S. (1971). Cores of convex games. International Journal of Game Theory, 1(1), 11–26. https://doi.org/10.1007/BF01753431
21. Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital twin in industry: State-of-the-art. IEEE Transactions on Industrial Informatics, 15(4), 2405–2415. https://doi.org/10.1109/TII.2018.2873186