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Impact of Organizational Context on Construction Project-based Organizations' Learning from Incidents based on Structural Equation Modelling and System Dynamics

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Current research paradigms examining factors influencing Learning from Incidents (LFI) primarily rely on static, unidirectional, and linear frameworks that fail to account for nonlinear interactions between causal elements and systemic dependencies, consequently perpetuating structural deficiencies in LFI implementation. Addressing this critical gap, our research develops an integrated SEM-SD analytical framework through a socio-psychological lens and Conservation of Resource (COR) theory, systematically mapping both exogenous and endogenous determinants alongside their synergistic co-evolution trajectories within construction project systems. Utilizing 154 valid questionnaires from Chinese construction organizations, the study employs dual validation approaches – SEM and SD to analyze multi-level relationships between factors. Key findings demonstrate that psychological safety exerts greater influence on the LFI systems in dynamic environments than in static conditions. Leader inclusiveness shows a significant positive impact on psychological safety alongside nonlinear progressive effects on LFI behaviors. Organizational support maintains direct positive correlations with both psychological safety and leader inclusiveness while dynamically enhancing relational identification and LFI outcomes through evolutionary system interactions. Incentive mechanisms operate as double-edged swords, necessitating context-sensitive calibration to balance their effects. Crucially, positive organizational contexts significantly improve LFI performance, which subsequently strengthens contextual conditions through performance feedback, creating self-reinforcing improvement cycles. This methodological advancement combines empirical validation with dynamic feedback analysis, surpassing traditional static approaches and deepening theoretical understanding of behavioral mechanisms driving effective LFI implementation in construction contexts.

Keywords: Conservation of resource (COR) theory, Learning from incidents, Organizational context, System dynamics

Introduction

Learning from Incidents (LFI) enables Construction Project-based Organizations (CPOs) to integrate incident knowledge through collaboration, boosting performance.[1] Paradoxically, CPOs context both facilitates LFI and sustains blame culture, causing managers to disengage from systematic learning as leaders prioritize replicating success over analyzing failure. This risks reducing LFI to superficial documentation rather than substantive learning. Organizational context, as a complex ecosystem of structures, management, and culture (norms, procedures, climate)[2] exhibits high variability and unpredictability. It significantly influences learning motivation and behaviors across individual, team, and organizational levels. Analyzing LFI implementation in construction thus requires comprehensive consideration of these contextual factors.

Supportive organizational context and strong stakeholder relationships are critical for effective LFI. However, conventional project management prioritizing efficiency and "zero-accident" targets hinders LFI by creating performance barriers.[1] These observations find empirical validation in Low *et al.*'s sectoral analysis of Singaporean construction practices.[3] Research reveals systemic knowledge dissemination shortcomings and absent context-sensitive learning cultures in CPOs.[4] This deficiency creates barriers to institutionalizing tacit knowledge, preventing mature LFI capabilities. To address this, the study models the evolution of LFI behavior through diverse organizational context perspectives, aiming to develop actionable strategies for optimizing active learning mechanisms in construction projects.

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Organizational context enables effective cross-boundary LFI performance—a current research gap noted in LFI studies.[5] Interdisciplinary analysis (integrating social psychology to engineering) expands LFI perspectives. This paper highlights LFI's social psychology angle, where learning entails enduring behavioral changes from experience.[6] Since incident knowledge embeds in minds and tools, LFI relies on social interactions, psychological perceptions, and practices. Thus, LFI constitutes an interactive "psychology → motivation → behavior → outcome" process within organizational contexts.[6]

Current LFI research relies heavily on mixed-methods with empirical validation but remains limited by reductionist, unidirectional analyses of static organizational factors.[7,8] Studies using methods like Accimap[9] and SEM[10] reveal primarily linear relationships, overlooking systemic feedback mechanisms. A critical gap persists in understanding LFI's dynamic, multidirectional causal architecture within CPOs. Existing literature focuses on identifying antecedents and verifying basic relationships, neglecting three key dimensions: 1) nonlinear interdependencies among contextual factors, 2) dynamic interaction mechanisms affecting LFI, and 3) reciprocal feedback between LFI outcomes and organizational learning systems.

Addressing research gaps, this study innovatively explores LFI behavior's dynamic evolution through a social psychological lens, focusing on: 1) What organizational antecedents systematically hinder LFI implementation? 2) What structural configurations sustain these barriers? 3) How does emergent LFI behavior reciprocally influence organizational contexts through feedback loops? It advances beyond static frameworks by establishing a dynamic behavioral evolution model integrating psychological drivers with organizational learning. Combining empirical investigation and system dynamics modeling elucidates multidirectional interactions between cognition and constraints. The paper first presents theoretical foundations and hypotheses, then details methodology, modeling, and sample validation. Subsequent sections analyze experimental results and propose strategies, concluding with discussion and implications.

Theoretical Background and Research Hypotheses

LFI in Construction Project Context

Within construction project contexts, LFI is defined as the organizational process of acquiring actionable experience and understanding from historical safety events—both internal and external—and institutionalizing these lessons as tacit knowledge and preventive practices to enhance project safety.[4] Scholarly investigations of LFI in CPOs bifurcate into technical and organizational lens. The technical lens emphasizes developing epistemic infrastructures like lessons-learned platforms and knowledge management systems to facilitate information updating and pedagogical integration, exemplified by semantic network architectures[11], ontology-based frameworks, and Building Information Modeling (BIM) integrations.[12]Contrastingly, such technocentric approaches risk inducing cognitive offloading that erodes organizational memory consolidation through overdependence on digital repositories.[13] The organizational lens instead foregrounds contextual determinants, framing LFI as a socio-cognitive phenomenon shaped by organizational architecture (structural characteristics, influencing variables, regulatory frameworks) and field-level dynamics. Furthermore, given the inherently multistakeholder nature of LFI processes in CPOs, escalating interorganizational complexity amplifies implementation challenges, necessitating a mindset shift toward active learning mechanisms that mitigate behavioral volatility caused by unstable cross-organizational knowledge exchanges.

Conservation of Resource Theory

Learning from incidents constitutes a dynamic multilevel process involving the interplay of psychological, informational, and relational resources across individual, organizational, and social domains.[14] Within this framework, organizational contexts function as malleable resource reservoirs, positioning Conservation of Resources (COR) theory, a stress-theoretical branch emphasizing resource management under constraints, as a robust explanatory lens for LFI behavioral mechanisms. COR theory postulates that systems at all levels (individual, organizational, interorganizational) inherently pursue resource acquisition, retention, and optimization to maintain operational equilibrium.[15] This conceptual framework elucidates behavioral decision-making through two sequential axioms: First, organizations leverage existing resource capital (e.g., prior knowledge) to generate new resource streams, creating self-reinforcing cycles that enhance cognitive-behavioral states;[16] Second, knowledge accumulation operates through feedback-mediated resource exchanges, where stakeholders providing incident-related insights become critical resource conduits for organizational learning systems.

From the Safety II standpoint, leader inclusiveness, organizational support, relational identification along with incentive mechanisms constitute essential prerequisites for effective learning from both successful and unsuccessful experiences in construction settings.[17–20] The Conservation of Resources (COR) theory posits that leader inclusiveness, organizational support, relational identification, and incentive mechanisms function as the input layer, mediating layer, and moderating layer, respectively, influencing the output layer (i.e., individual psychology and behavior) through resource gains or losses. Specifically:

Leader inclusiveness and organizational support act as external resource inputs, directly increasing members' resource reserves (e.g., psychological safety, social support).[21]

- Under the resource gain mechanism, inclusive leaders enhance psychological safety (e.g., accepting mistakes, encouraging innovation), reducing employees' fear of resource loss and promoting resource investment behaviors (e.g., proactive learning, undertaking challenging tasks), thereby forming a "gain spiral" (resource gains facilitate further resource acquisition).

- Organizational support, as a structural resource (e.g., training), directly replenishes individual resource reserves and strengthens capacity to address challenges. It reinforces relational identification by fostering social resource exchanges (e.g., trust, information sharing) through team collaboration, creating a collective resource pool.

Relational identification, as a manifestation of social resources, serves both as an outcome of resource gains and a channel for resource flow. High relational identification promotes social resource circulation (e.g., cross-departmental collaboration), generating a "resource caravan effect" (i.e., interconnected resources reinforcing one another).

Incentive mechanisms regulate the balance between resource investment and returns, shaping decisions about resource protection or allocation.

Guided by COR theory, this study argues that external resource inputs (leader inclusiveness, organizational support) are transmitted through social resource networks (relational identification), while incentive mechanisms moderate the efficiency and direction of resource flow, collectively shaping system LFI behaviors.

Formation of LFI

The formation of LFI behavior is conceptualized through the convergence of organizational learning theory and safety management theory, which posit that socio-organizational determinants (e.g., leadership engagement, safety climate) and cross-functional accident management competencies collectively shape LFI implementation through psychosocial mediators such as cognitive efficacy and risk perception.[22] Integrating systems theories (e.g., high-reliability, lessons-learned, safety models) further explains how organizational systems and collective psychology influence LFI.[23] Mixed-method investigations encompassing textual analysis of incident reports and systematic literature syntheses empirically confirm that organizational contextual elements will inhibit or promote LFI behavior by altering collective psychological schemas. Ren *et al.*[2] employ regression analysis to validate organizational context attributes, demonstrating that incentive mechanisms significantly enhance knowledge mobility in project-based organizations. Building upon proactive safety management and resilience engineering paradigms, Martins *et al.*[19] developed a dual-mode learning architecture synthesizing Safety I (traditional post-incident learning) and Safety II (proactive learning from daily work operations), establishing their dual necessity for sustainable organizational adaptation through targeted resource allocation.

To sum up, the organizational perspective systematically examines systemic deficiencies within institutional frameworks, predominantly attributing behavioral constraints to structural and managerial shortcomings. Conversely, the psychological lens interrogates the cognitive schemas and mental architectures underlying behavioral impediments. This study posits that LFI behavioral formation mechanisms encompass multilevel organizational dynamics (direct/indirect interrelations), contextual mediation effects, and the psychosociological interplay of perceptual determinants. Building upon extant analyses of organizational contextual variables, the study aims to deconstruct the behavioral black box by elucidating how key organizational context dimensions (e.g., leader inclusiveness, organizational support, relational identification, and incentive) interact with psychological safety to shape LFI behavioral trajectories. Grounded in COR theory, a concept model (Fig. 1) is formulated, delineating factor interdependencies and pathways. Subsequent

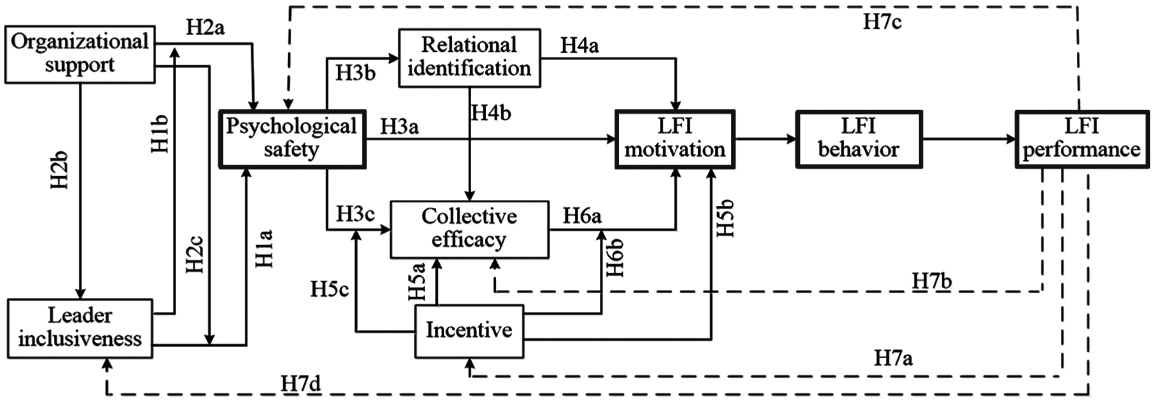

Fig. 1 — Conceptual relationship model

parts expound these constructs' relationships and derive research hypotheses.

What are the direct effects of leader inclusiveness and organizational support on psychological safety? Furthermore, through what dual mediating and moderating mechanisms might these factors interact in this process? As a pivotal LFI element, leader inclusiveness establishes relational bedrock for cross-boundary learning, demonstrating empirically validated correlations with enhanced psychosocial safety climates.[39] Complementary empirical work by Hirak *et al.*[23] substantiates organizational support's capacity to fortify psychological safety through structured incident management protocols. Extending this conceptualization, Casse and Caroly[24] employ ergonomic principles to frame organizational reinforcement of experiential learning and teamwork as critical enablers of routine risk mitigation. Shen *et al.*[25] proposed the organizational mechanisms to improve the psychological perception atmosphere from the perspectives of structure, perception, interaction, and culture. Further, they discussed the importance of inclusiveness and organizational support to the psychological perception atmosphere. These factors, in turn, express the organization's view of the lessons learned system about explicit and tacit knowledge after a safety incident. Therefore, the following hypotheses are proposed:

H1a. Leader inclusiveness exhibits a direct positive association with psychological safety.

H2a. Organizational support is positively related to psychological safety.

H1b. Leader inclusiveness has a positive moderating effect on the relationship between organizational support and psychological safety.

H1c. Leader inclusiveness plays an intermediary role in the process of organizational support influence on psychological safety.

Elevated organizational support mitigates cognitive dissonance, enhances collective alignment, and fosters inclusive climate.[15] Progressive intensification of organizational support amplifies the synergistic linkage between leader inclusiveness and psychological safety. Therefore, the following hypotheses are proposed:

H2b. Organizational support is positively related to leader inclusiveness.

H2c. Organizational support has a positive moderating effect on the relationship between leader inclusiveness and psychological safety.

Can psychological safety enhance LFI motivation, and if so, through what mechanisms does this transformation occur? Edmondson[26] proposed that learning behavior and performance are related to psychological safety. The three approaches proposed by Shen *et al.*[25] to increase organization's psychological safety imply the organizations' identification of their relationship.[27] Traditional safety procedures are usually a top-down control form[28], and some managers use disciplinary meetings as parts of the corrective actions for injury reports[29], which are unpleasant for participants. Such organizational bullying behavior[28], which causes psychological hazards, often leads to the disidentification between organizations, and hinders their learning motivation and collective efficacy. Based on social cognitive theory, collective efficacy is related to CPOs' shared beliefs about their combinative capacities to execute a series of actions required to implement the assigned project goals.[30] Therefore, the following hypotheses are proposed:

H3a. Psychological safety is positively related to LFI motivation.

H3b. Psychological safety is positively related to relational identification.

H3c. Psychological safety is positively related to collective efficacy.

Does relational identification strengthen the relationship between psychological safety and LFI? If so, through what mediating mechanisms does this enhancement occur? Psychological safety boosts LFI, especially with strong relationship management.[8,21] When organizations achieve cognitive alignment on LFI's value, it motivates behavior, making process safety training a strategic priority. Evidence shows incident-derived knowledge embedded in structured training holds greater strategic value than superficial learning. Furthermore, exposure to incongruent or adversarial signals from peers erodes collective efficacy perceptions related to target behaviors.[30] Within LFI systems, relational identification operates as both a social-cognitive scaffold that frames organizational interpretations of LFI's relational significance and a dual manifestation of collective consciousness and institutional mechanisms. Through this lens, participants calibrate collective efficacy to shape LFI attitudes and decisions. Therefore, the following hypotheses are proposed:

H4a. Relational identification is positively related to LFI motivation.

H4b. Relational identification is positively related to collective efficacy.

H4c. Relational identification plays an intermediary role in the process of psychological safety influence on LFI motivation.

Does incentive moderate the relationship between psychological safety and collective efficacy, and if so, through what mechanisms does this moderation occur? Incentive mechanisms facilitate the optimization of participants' learning satisfaction while enhancing perceived benefits of LFI, a process exhibiting dual dependency on the depth of learning internalization and measurable performance attainment.[31] Functioning as a pivotal engagement catalyst, incentives generate episodic commitment alignment among participants, concurrently satisfying CPOs' learning requirements through their inherent capacity to operationalize learning-centric behavioral contingencies. Here, the following hypotheses are proposed:

H5a. Incentive is positively related to collective efficacy.

H5b. Incentive is positively related to LFI motivation.

H5c. Incentive can positively moderate the relationship between psychological safety and collective efficacy. That is, the greater the incentive, the more significant the impact of psychological safety on collective efficacy.

Collective efficacy embodies the socio-cognitive dynamics emerging from group collaboration processes, functioning as a critical determinant of both the intensity of collaborative engagement and the cognitive orientation team exhibits when approaching LFI initiatives. Within the psychological framework of LFI mechanisms, empirical evidence suggests a positive reinforcement cycle where heightened collective efficacy correlates with increased intrinsic motivation for cross-member knowledge acquisition. This synergistic relationship becomes particularly pronounced when supported by strategically designed incentive mechanisms that amplify motivational triggers while optimizing group learning pathways. Therefore, the following hypotheses are proposed:

H6a. Collective efficacy is positively related to motivation.

H6b. Incentive can positively moderate the relationship between collective efficacy and motivation. That is, the greater the incentive, the higher the impact of collective efficacy on motivation.

H6c. Collective efficacy plays an intermediary role in the process of incentive influence on motivation.

Does enhanced LFI effectiveness create a reciprocal impact on organizational contexts, establishing a self-reinforcing cycle where successful incident learning stimulates systemic improvements driving greater LFI adoption? The framework given in Fig. 1 shows the "psychology → motivation → behavior → outcome" progression (bold box), plus four organizational context factors. Collective efficacy emerges as a direct outcome of incentives, relational identification, and psychological safety. The integrated feedback loop (dashed arrows) demonstrates how operational results reciprocally influence systemic drivers. Prior study by Chen *et al.*[31] substantiated the observable interdependence between performance outcomes and incentive mechanisms in organizational learning contexts, a relationship the framework of the current study extends by proposing that enhanced LFI performance progressively increases incentive mechanisms and collective efficacy, thereby reinforcing psychological safety and leader inclusiveness in cyclical reinforcement. Therefore, the following hypotheses are proposed:

H7a. LFI performance is positively associated with incentive.

H7b. LFI performance is positively associated with collective efficacy.

H7c. LFI performance is positively associated with psychological safety.

H7d. LFI performance is positively associated with leader inclusiveness.

Methodology

Existing reductionist models oversimplify LFI behavior as linear relationships, ignoring complex multi-factor interactions.[32] Studying LFI requires systemic analysis of internal/external elements, their interconnections, and co-evolution patterns.[33] System Dynamics (SD) effectively models nonlinear feedback mechanisms in complex systems, addressing dynamic behaviors and decision-making. Though underused for LFI antecedents in CPOs, SD has proven effective in related domains like organizational learning and safety management.[4] Illustratively, Nasir and Hadikusumo[34] developed an owner-contractor (O/C) relationship management SD framework integrating contractual functions during construction phases. As LFI constitutes a core practice community activity in CPOs, integrating SD modeling with empirical survey data could enhance both theoretical validity and practical applicability.

Establishment of SD Model

Guided by the pathway relationships (Fig. 1), the SD model was developed to delineate the intrinsic interplay between organizational mental processes and learning mechanisms driving LFI behavior, integrating four critical feedback structures within its framework (Fig. 2). The R0 loop captures the core mechanism of LFI formation, where relational identification is directly influenced by asymmetric dependence and relationship duration. Notably, asymmetric dependence may trigger opportunistic conduct[35] or organizational bullying[28], thereby diminishing relational identification.[29] Aligned with H3, the R1 feedback structure was formulated to represent psychological safety and its antecedents. Furthermore, leveraging the mental process model (Fig. 1), the R2 and R3 feedback structures in Fig. 2 systematically model the dynamic interconnections among LFI motivation, behavioral execution, and outcome feedback mechanisms.

Sample and Procedures

The study utilized data from 200 questionnaires distributed to owners, contractors, consultants, and designers, with 154 valid responses collected (77% response rate). Respondent demographics revealed 7.1% under age 30, 73.4% aged 30–50, and 19.5%

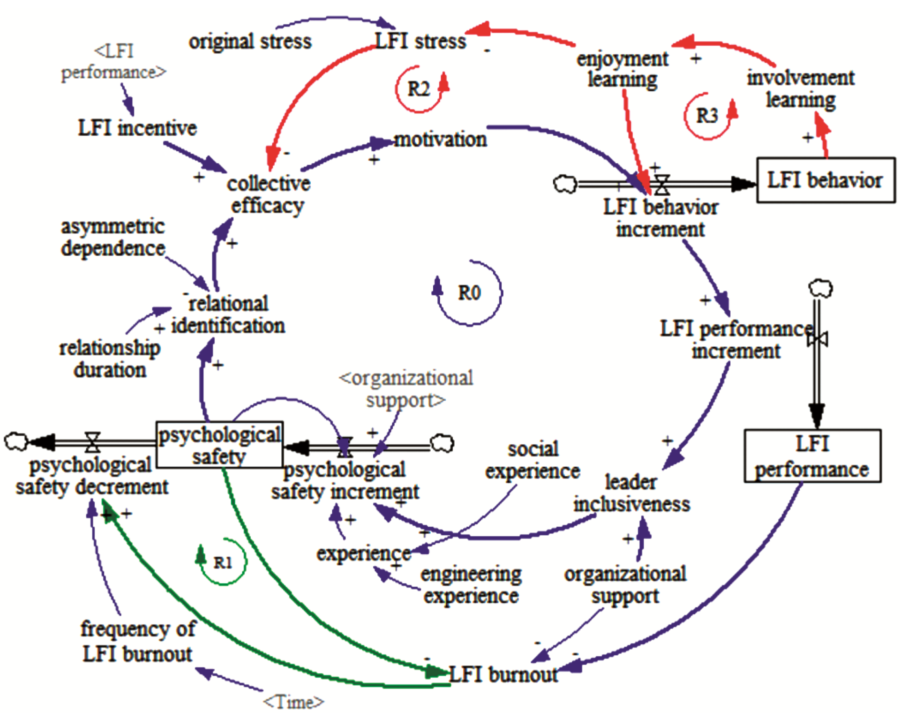

Fig. 2 — System flow diagram of LFI mechanisms

over 50; educational backgrounds comprised 4.5% with college degrees or below, 54.5% bachelor's holders, and 40.9% master's graduates or higher. Work experience distribution showed 22.7% with 3–5 years, 35.1% with 6–10 years, 24.7% with 11–15 years, and 14.9% exceeding 15 years. Regarding recent 5 years' project involvement, 7.8% participated in fewer than 3 projects, 26% in 3–6 projects, and 66.2% in over 6 projects.

Measures

Psychological safety: A 3-item psychological safety scale adapted from Edmondson.[26] Sample item is: "No one in this organization would deliberately act to undermine my efforts", α = 0.635. ***Leader inclusiveness:*** A 3-item leader inclusiveness scale adapted from Carmeli and Dothan[14] and Carmeli and Gittell.[36] Sample item is: "The manager encourages me to access him/her on emerging issues (accessibility)", α = 0.806. ***Organizational support:*** A 7-item incentive scale adapted from Eisenberger *et al*.[37] Sample item is: "Superior/leader encourages employees to speak freely", α = 0.902. ***Relational identification:*** A 3-item relational identification scale adapted from Sluss *et al*.[27] Sample item is: "When I talk about this organization, I usually say 'we' rather than 'they'", α = 0.833. ***Incentive:*** A 4-item incentive scale adapted from Sheung and Canon.[38] Sample item is: "Organization provides the right incentives to encourage incidents learning", α = 0.812. ***Collective efficacy:*** A 3-item scale adapted from Guzzo *et al*.[39] Sample item is: "My team feels it can solve any problem it encounters", α = 0.803. ***LFI motivation:*** A 6-item scale adapted from Kyndt *et al*.[40] Sample item is: "I intend to look for information about job-related courses and learn activities that I could participate in", α = 0.896. ***LFI behavior:*** A 5-item scale adapted from Carmeli and Gittell.[36] Sample item is: "When an employee makes a mistake, his leader will talk with him, not to blame him, but for the value of learning", α = 0.836. ***LFI performance:*** A 3-item scale adapted from Carmeli and Gittell[36] and Hirak *et al*.[23] Sample item is: "Learning from incidents between organizations often helps identify safety issues", α = 0.752. All variables were measured with multiple items using five-point Likert scales (1="do not agree" to 5="completely agree").

Results and Discussion

Reliability Analysis

The sample demonstrated strong adequacy with a Kaiser-Meyer-Olkin (KMO) value of 0.864, surpassing the 0.50 threshold, while Bartlett's sphericity test yielded a significant result of 3473.633 ($p < 0.001$), confirming substantial variable correlations. Using principal component analysis and Varimax with Kaiser normalization, nine factors were extracted based on variable loadings in the rotated component matrix, achieving a cumulative variance of 70.22% that exceeded the 60% validity benchmark. All variables exhibited factor loadings above 0.5 for their respective common factors, aligning with established analytical standards for data representation and factor-variable correlations.

Path Analysis and Hypothesis Testing

The stepwise regression analysis of 'organizational support → leader inclusiveness → psychological safety' revealed leader inclusiveness as a significant mediator, with the correlation coefficient decreasing from 0.454** ($p < 0.001$) to 0.221* ($p = 0.012$), supporting H1c (Fig. 3(a)). Leader inclusiveness also demonstrated a notable moderating effect between

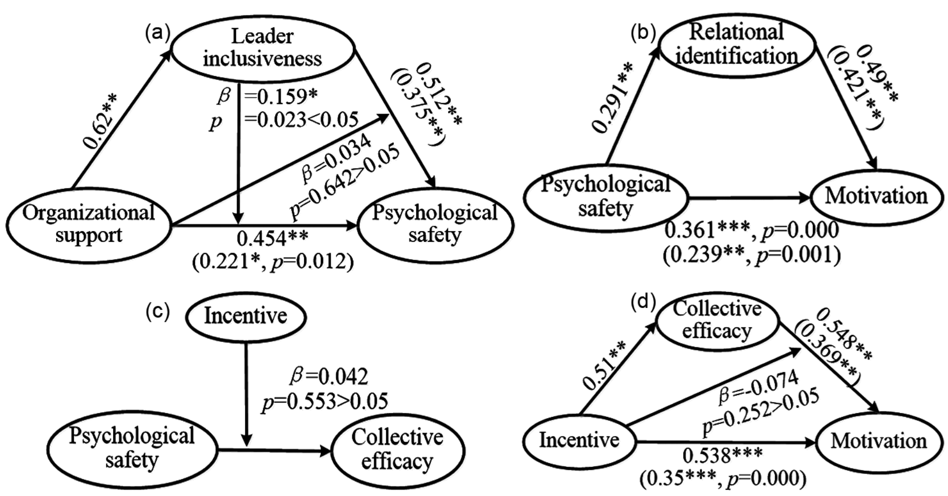

Fig. 3 — Indirect effect analysis

organizational support and psychological safety (β = 0.159, p = 0.023), confirming H1b. However, organizational support's moderating effect on the leader inclusiveness-psychological safety relationship was nonsignificant (β = 0.034, p = 0.642), rejecting H2c (Fig. 3(a)). Analysis of Fig. 3(b) indicated relational identification partially mediated the psychological safety-motivation linkage, with coefficients declining from 0.361*** ($p < 0.001$) to 0.239** (p = 0.001), validating H4c. Fig. 3(c) showed insignificant moderating effects of incentive on psychological safety-collective efficacy relations (β = 0.042, p = 0.553), rejecting H5c, while Fig. 3(d) revealed no significant incentive moderation between collective efficacy and motivation (β = -0.074, p = 0.252), disproving H6b. Collective efficacy emerged as a partial mediator between incentive and motivation, evidenced by coefficient reduction from 0.538*** ($p < 0.001$) to 0.35*** ($p < 0.001$), thereby supporting H6c.

Structural Equation Modeling (SEM), widely employed in construction management research, effectively represents hypothesized linear relationships between observed and latent variables. The model demonstrated acceptable fit indices: RMSEA = 0.058 (below the 0.08 threshold), CFI = 0.904, TLI = 0.891, and GFI = 0.778, meeting the recommended GFI standard of ≥0.76.[41] The χ^2/df ratio of 1.513 remained well below the maximum threshold of 3.00.[(42)] The standardized path coefficients between latent variables, collectively validating the model's robustness in explaining structural relationships are illustrated in Fig. 4.

The SEM results reveal three nonsignificant relationships (psychological safety → motivation, relational identification → collective efficacy, and incentive → motivation) with p-values exceeding 0.05, while all remaining paths demonstrated statistical significance at $p < 0.05$, indicating robust associations across the model except for these specified exceptions.

Basic Settings of Model and Simulation

The model employed table functions to quantify the incentive-performance relationship, with organizational support initialized at its mean value. CPO experiences were categorized as social and engineering dimensions[43], initialized at 0.5.[(38)] Asymmetric dependence, defined as knowledge demanders' power imbalance favoring less dependent parties.[44] was parameterized on a [0, +∞] scale where 1 indicates balanced knowledge needs.[35] Relationship duration, representing cooperative partnership longevity[44], aligned with the 36-month simulation period. Initial stress level was empirically approximated as 0.8 based on survey data. Model equations, developed in Vensim PLE, incorporated coefficients derived from correlation and regression analyses of empirical data (Table 1).

Scenario Simulation, Results Analysis and Discussion

All current schemes in the following scenarios simulation represented the results of the initial parameters.

The Impact of Psychological Safety on LFI

Increasing the level of psychological safety (Table 1 Scenario 1), and the system results are shown in Fig. 5.

All four modified schemes outperform the original, with LFI motivation and collective efficacy displaying system-driven U-shaped trajectories (Figs. 5(a) & 5(d)). While SEM revealed psychological safety's indirect influence on LFI motivation via mediators like collective efficacy and relational identification (Fig. 4), SD simulations demonstrated

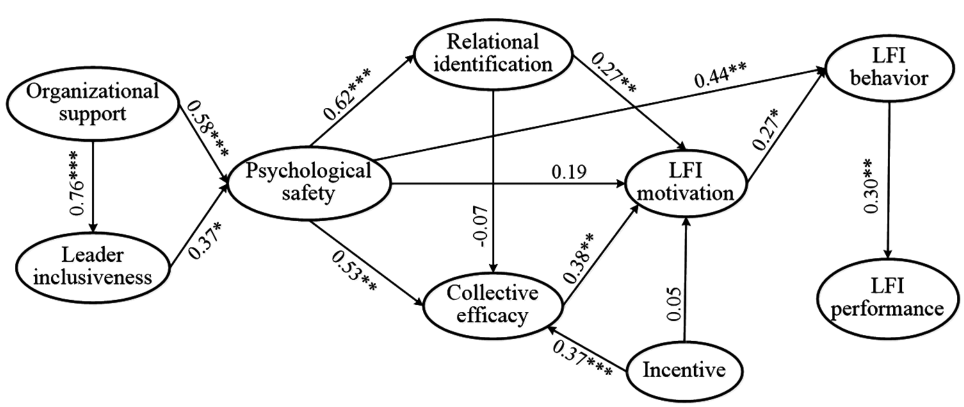

Fig. 4 — The final SEM results

Table 1 — Parts of the changed parameters and their initial values: *Scenario 1*(Improve the level of psychological safety directly); *Scenario 2* (Improve the level of leader inclusiveness indirectly); *Scenario 3* (Decrease the level of organizational support directly); *Scenario 4* (Improve the level of relational identification indirectly); *Scenario 5* (Increase the level of incentive indirectly); *Scenario 6* (Increase the level of performance indirectly)

Variables	Default	Scenario simulation			
	Current	Current 1	Current 2	Current 3	Current 4
Scenario 1: Psychological safety (Fig. 5)	The initial value is 3.708	2 × 3.708	3 × 3.708	6 × 3.708	8 × 3.708
Scenario 2: Leader inclusiveness (Fig. 6)	leader inclusiveness = 0.258 × LFI performance increment + 0.62 × organizational support	leader inclusiveness s=0.516 × LFI performance increment + 0.62 × organizational support	leader inclusiveness = 0.258 × LFI performance increment + 1.24 × organizational support	—	—
***Scenario 3*:** Organizational support (Fig. 7)	The initial value is 3.714	3.714/2	3.714/3	3.714/4	0
***Scenario 4*:** Relational identification (Fig. 8)	relational identification = 0.291 × psychological safety + 0.3 × relationship duration-0.05 × asymmetric dependence	Pathway 1: relational identification = 0.582 × psychological safety + 0.3 × relationship duration −0.05 × asymmetric dependence	Pathway 2: relational identification = 0.291 × psychological safety + 0.6 × relationship duration −0.05 × asymmetric dependence	Pathway 3: relational identification = 0.291 × psychological safety + 0.3 × relationship duration −0.025 × asymmetric dependence	—
***Scenario 5*:** Incentive (Fig. 9)	incentive=WITH LOOKUP （performance， ([(0,0) – (10000,1)], (0,0), (368,0.15), (876,0.3), (1489,0.3), (2547,0.5), (3250,0.55), (4987,0.6), (5890,0.6), (6457,0.6), (7889,0.7), (10000,0.7)))	incentive =WITH LOOKUP （performance， ([(0,0) –(10000, 1)], (0,0), (368,0.21), (876,0.43), (1489,0.58), (2547,0.62), (3250,0.67), (4987,0.71), (5890,0.72), (6457,0.77), (7889,0.8), (10000,0.86)))	—	—	—
***Scenario 6*:** Performance (Fig. 10)	The initial value is 3.78	3.78 × 100	3.78 × 500	3.78 × 1000	—

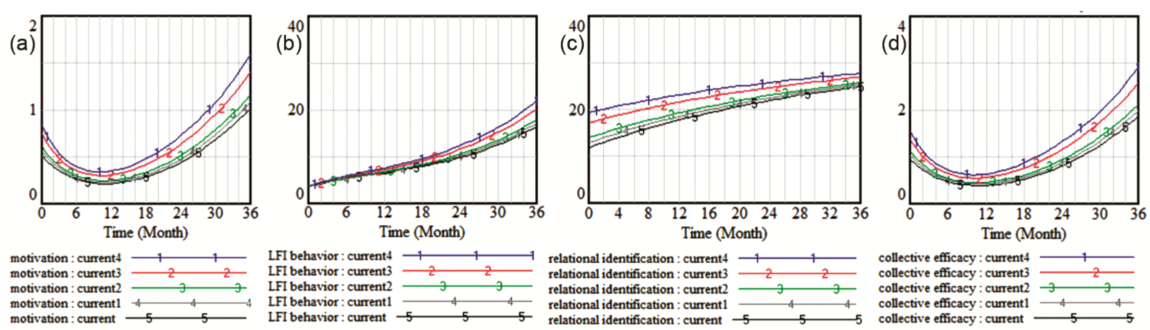

Fig. 5 — System simulation results after improving the value of psychological safety: (a) motivation, (b) LFI behavior, (c) relational identification, (d) collective efficacy

positive nonlinear associations between psychological safety and mediators/LFI outcomes (Fig. 5), indicating enhanced efficacy in synergistic environments versus static conditions. Implementation barriers primarily stem from psychological perception biases.[12] As both inputs and outputs, psychological safety and shared routines necessitate integration into adaptive regulatory frameworks for LFI mechanisms, emphasizing their dual role in dynamic system optimization.

Dynamic Effect of LFI Mechanisms

How does leader inclusiveness impact the system? It is demonstrated in Fig. 6 that the enhancement of leader inclusiveness (Table 1, Scenario 2) positively amplifies LFI behavioral outcomes and elevates psychological safety levels, revealing its catalytic role in optimizing collaborative dynamics through systemic feedback mechanisms.

Leader inclusiveness's impact on psychological safety aligns with empirical findings (Fig. 6(c) vs. Fig. 4), while SD simulations reveal its nonlinear upward trajectory in shaping LFI over time (Fig. 6(a)). CPOs should cultivate discussion norms for diverse views, incident-sharing, and opinion acceptance. Leader inclusiveness encompasses not only fostering incident reporting but also attentively monitoring members' workplace dynamics, situational factors, and behavioral patterns to cultivate their psychological safety. Such inclusive practices must permeate all organizational tiers, as longitudinal studies confirm.[1,23]

How does organizational support impact the system? As demonstrated in Fig. 7, organizational support dynamically shapes system outcomes, with specific parameter configurations detailed in Table 1 (Scenario 3).

Aligning with SEM findings (Fig. 4), organizational support demonstrated direct positive associations with psychological safety and leader inclusiveness, while SD simulations revealed its dual functionality - not only maintaining these direct relationships but also mediating enhanced relational identification and LFI performance through dynamic system evolution. This synergistic mechanism suggests organizational support facilitates psychological barrier mitigation[24] while cultivating collaborative LFI climates, critically exhibiting multilevel synergistic effects that amplify systemic outcomes through feedback-loop interactions within organizational dynamics.

How does relational identification influence the system? The impact of relational identification on system is shown in Fig. 8, with specific parameter configurations detailed in Table 1 (Scenario 4).

SD simulations show Pathways 1 and 2 significantly boost collective efficacy (Fig. 8(b)), with Pathway 2 having greater sensitivity. Pathway 3 failed to meaningfully alter collective efficacy, revealing knowledge seekers' asymmetric dependency minimally impact shared cognition. This indicates incident learning transfers bidirectionally among

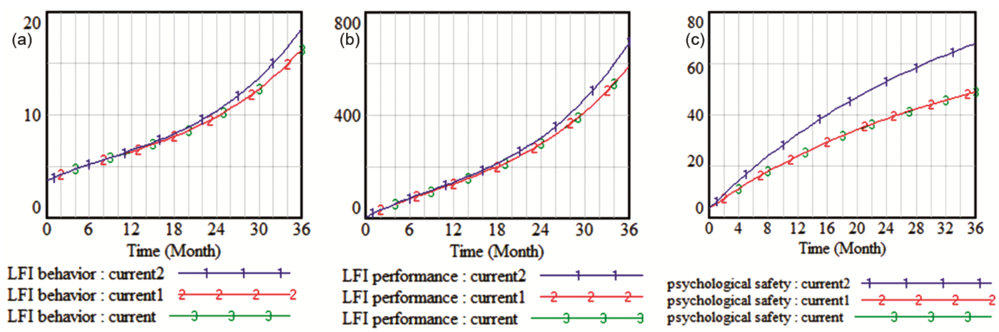

Fig. 6 — The impact of leader inclusiveness on system: (a) LFI behavior, (b) LFI performance, (c) psychological safety

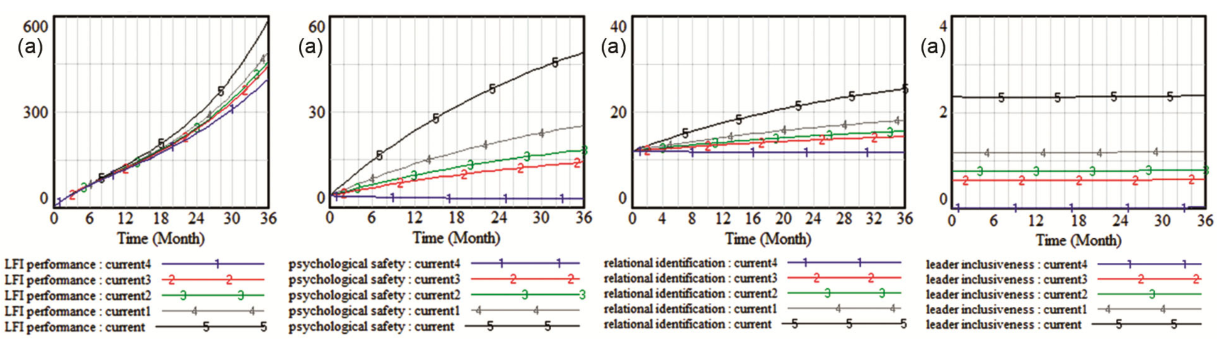

Fig. 7 — The impact of organizational support on system: (a) LFI performance, (b) psychological safety, (c) relational identification, (d) leader inclusiveness

peers rather than unidirectionally from experts to operators. Consequently, management strategies require multidimensional assessment of knowledge types, breadth, and depth. Fig. 8(d) demonstrates Pathway 2 accelerates incentive stabilization through systemic feedback, where sustained relationship quality management optimizes incentives via organizational learning cycles.

How does incentive influence the system? Through holding other parameters constant and augmenting performance-contingent incentive responsiveness, the current 1 scheme yields the configuration presented in Fig. 9.

SEM/SD confirmed incentives' strong positive effect on collective efficacy (Fig. 4: β=0.37***; Fig. 9(a)), yet SEM showed no direct impact on LFI motivation (Fig. 4: β=0.05). Conversely, SD revealed latent positive correlation between incentives and motivation under evolutionary conditions (Fig. 9(b)). Dynamic analyses exposed incentives' limited ability to enhance psychological safety systemically, aligning with Geller's[28] research on the contextual boundedness. Though incentives transiently compensate learning effort costs[31], misapplication degrades psychological safety[28], illustrating their double-edged role in LFI. These findings advance epistemological understanding of LFI dynamics in construction management.

Feedback Mechanisms of System

The feedback of LFI is depicted in Fig. 10 (Table 1, Scenario 6)

SD simulations validate that performance enhancement exerts substantial positive effects on

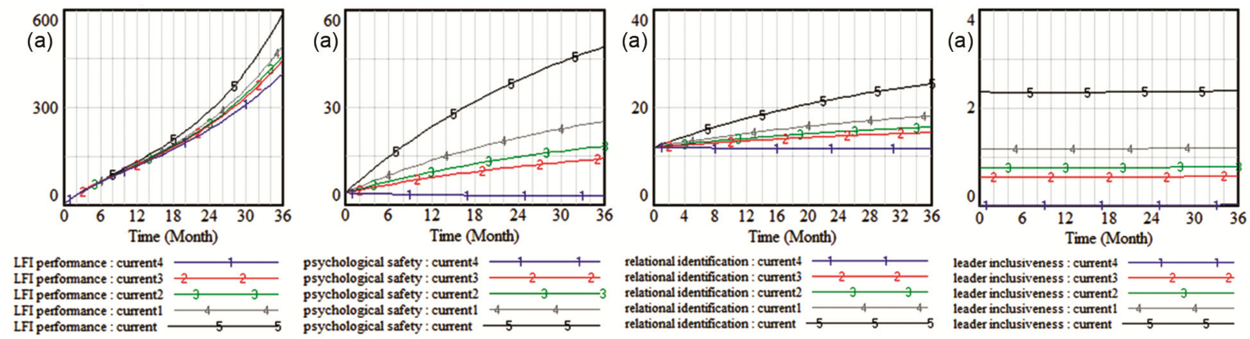

Fig. 8 — The impact of relational identification on system: (a) motivation, (b) collective efficacy, (c) LFI behavior, (d) LFI incentive

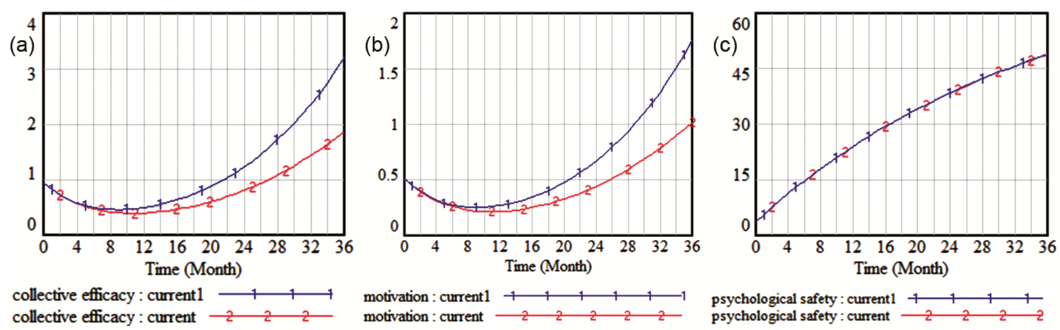

Fig. 9 — The influence of incentive on system: (a) collective efficacy, (b) motivation, (c) psychological safety

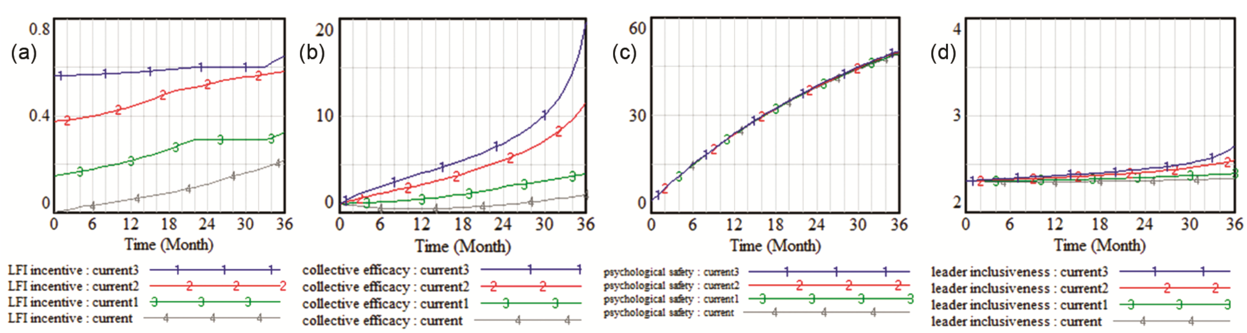

Fig. 10 — The results of system feedback: (a) LFI incentive, (b) collective efficacy, (c) psychological safety, (d) leader inclusiveness

incentive mechanism, collective efficacy, and psychological safety, while demonstrating non-significant impacts on leader inclusiveness, thereby confirming H7a, H7b, and H7d while refuting H7c. This operationalizes LFI's systemic efficacy through reinforcing feedback loops where positive organizational contexts (characterized by elevated support and inclusiveness) cultivate enhanced cognitive-affective states (high psychological safety, relational identification, collective efficacy), which reciprocally amplify organizational performance to further optimize contextual conditions. The systemic feedback paradigm addresses critical gaps in extant static LFI investigations by establishing dynamic organizational pathways for sustainable LFI feedback mechanisms through continuous improvement cycles.

Conclusions

Our study differentiates itself within organizational learning literature by systematically examining mechanisms driving LFI behavioral improvements, particularly through leader inclusiveness, organizational support, and relational identification. The identified "psychological safety → collective efficacy → LFI behavior" pathway reveals optimal strategies including cultivating psychologically safe environments, integrating safety incidents into workflows, establishing behavioral guidelines, and facilitating knowledge transfer. By combining empirical validation and dynamic feedback analysis, this methodological advancement exceeds the limitations of static traditional approaches, there by deepening the theoretical grasp of the behavioral mechanisms that facilitate effective LFI implementation in construction environments. However, the limited sample size and demographic coverage constrain generalizability. Future research should implement comprehensive scales and quantitative methods to cross-validate findings. The temporal dimensionality of construction projects necessitates examination of phase-specific behavioral contingencies among different stakeholders, thereby requiring longitudinal assessments to verify the contextual dynamics and operational viability of proposed LFI frameworks across progressive project lifecycles.

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