Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343
ISSN (print) 1693-6590 | ISSN (online) 2442-2630
https://journal3.uad.ac.id/index.php/spektrum/index

From Static Risk Lists to Dynamic Risk Behavior: An Integrated Mixed-Method and Causal Loop Modeling Approach for Operational Risk in Indonesian EPC Firms

Drajat Indrajaya [a,*], Parwadi Moengin [b], Dadang Surjasa [b], Sally Cahyati [b], Etanto Heiliano Wijayanto [c]

[a] Industrial Engineering, Universitas Indraprasta PGRI, Jakarta, 12530, Indonesia
[b] Industrial Engineering, Universitas Trisakti, Jakarta, 11440, Indonesia
[c] Industrial Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia
* Corresponding Author: drajat.indrajaya@unindra.ac.id

ARTICLE INFO

Article history
Received April 28, 2026
Revised September 21, 2026
Accepted October 17, 2026

Keywords
Causal loop diagram;
EPC companies:
Mixed-method;
Operational risk;
Risk dynamics.

ABSTRACT

Operational risks in Engineering, Procurement, and Construction (EPC) firms are interconnected and may evolve through interactions among organizational, project, and external factors. However, conventional risk assessment approaches often emphasize risk identification and prioritization without explicitly representing potential feedback relationships among risk factors. This study develops a qualitative causal framework for operational risk in Indonesian EPC firms by integrating expert-based risk-dimension validation with systems thinking and Causal Loop Diagram (CLD) modelling. The study employed a sequential two-stage approach. First, a structured literature synthesis identified 15 operational risk dimensions, which were operationalized into 45 measurement items and assessed by seven EPC experts using Content Validity Ratio (CVR), Content Validity Index (CVI), and Relative Importance Index (RII). Five core dimensions were retained: Strategic & Business Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, and Reputational Risk. Second, the validated dimensions were incorporated into an influence diagram and subsequently developed into a CLD. Causal directions and polarities were established through conceptual definitions, EPC operational knowledge, risk-management principles, and expert-based structural verification rather than inferred from CVR, CVI, or RII results. The resulting CLD identifies one potential reinforcing mechanism associated with risk escalation and two potential balancing mechanisms associated with governance-based and reputation-driven corrective responses. The study contributes an expert-verified qualitative causal architecture that extends operational risk assessment from variable identification toward a systems-based representation of potential feedback mechanisms. Historical pattern assessment showed directional consistency for 13 of 14 loop-specific causal relationship instances, with R1 partially supported and B1 and B2 showing consistent historical patterns.

©2026 The Author(s)
This is an open-access article under the CC–BY-SA license.

1. Introduction

Engineering, Procurement, and Construction (EPC) companies operate in complex and unpredictable environments with numerous projects running concurrently, interrelations between stakeholders, and changing external circumstances (Oktafiansyah & Patriadi, 2025; Subiyanto, 2021). In these circumstances operational hazards seldom occur in isolation but rather emerge as interlinked phenomena developing through cascading consequences across multiple projects and organizational levels. Such disruptions as delay in supply chain, volatility in workforce or disagreement amongst stakeholders may percolate through project operations so hindering project performance, profitability and long-term sustainability of the company (Xia et al., 2022).

The majority of present research relies on a static paradigm, which considers hazards as distinct factors that can be detected, categorized, and treated separately (Yang et al., 2026). This is despite the reality that operational risk management is of utmost importance in EPC settings. However, although these approaches are valuable to detect potential dangers they cannot provide a complete knowledge of the relationships, mutual reinforcement or dynamic evolution of risks over time. This constraint turns into a very difficult challenge for Indonesian EPC companies, due to the complexity of operational risk behavior caused by multi-project execution, resource limits, and environmental unpredictability (Shahzad et al., 2026; Zhang et al., 2025).

The COSO ERM and ISO 31000 ERM frameworks emphasize governance, integration and continuous improvement in the management of organizational risks (Ayu et al., 2024). But in practice, they tend to be used as procedural guides rather than as decision-support systems that can adapt to evolving risk contexts, thus reducing the usefulness of these frameworks. Thus, organizations can know ‘what risks are there’, but have difficulty knowing ‘how risks behave’ and ‘which leverage points are most effective’ to intervene. This gap in understanding can lead to insufficient responses to emergent threats that eventually undermine the organization’s resilience. To address this gap, firms must establish a culture of risk awareness and flexibility, creating an atmosphere that encourages data-driven insights in strategic decision-making (Alsarayreh et al., 2025; Chigbu & Makapela, 2025).

To bridge this gap, systems thinking and causal loop diagrams (CLDs) offer a promising method by the possibility to describe feedback processes and dynamic interactions between risk factors (Nurhidayat et al., 2024). CLDs help identify reinforcing loops that lead to risk escalation and balancing loops that help to stabilize system behavior. However, the empirical basis for the risk variables used in CLD investigations is generally limited since they are either unvalidated or arbitrarily chosen. To improve the robustness of these models, it is important to include validated risk variables that represent actual world conditions. This empirical base will not only allow a greater precision in the treatments but also a more complex understanding of the complicated processes (Pinho, 2015).

Among alternative modelling approaches, CLD was selected because the objective of this study is to represent aggregate feedback structures and endogenous interactions among operational risk, management responses, and organizational outcomes, rather than to model individual agent behavior or estimate probabilistic dependencies. Agent-based modelling is more appropriate when heterogeneous actors and micro-level decision rules are central to the research question, whereas Bayesian networks primarily emphasize probabilistic dependencies and uncertainty propagation. CLD is therefore appropriate at this stage because the present study focuses on identifying feedback structures, causal polarity, and potential reinforcing and balancing mechanisms as a precursor to subsequent quantitative stock-and-flow modelling.

This work aims at filling the observed gaps by proposing an integrated mixed-method approach combining expert-based validation of operational risk dimensions with qualitative causal modeling. Specifically, this study will seek to accomplish the following.

1. The first stage is to identify and validate the fundamental operational risk factors relevant to Indonesian EPC companies.

2. The directional causal links that exist between the validated risk dimensions, operational conditions and management-related variables should be determined by using an influence diagram.
3. Moreover, a qualitative Causal Loop Diagram (CLD) should be built to identify possible reinforcing and balancing feedback processes within the operational risk system

This study makes three key contributions. First, it provides a validated and context-specific set of operational risk dimensions for EPC firms. Second, it establishes an explicit methodological separation between quantitative risk-dimension screening and qualitative causal-structure development, thereby avoiding the inference of causal polarity from content-validity and importance measures. Third, it provides a qualitative systems-based representation of potential operational risk feedback mechanisms, offering a conceptual foundation for subsequent stock-and-flow modelling and empirical calibration.

2. Method

2.1. Research Design and Analytical Framework

This study employed a sequential mixed-method design in which quantitative expert-based validation was followed by qualitative causal modelling. The methodological sequence was designed to address two analytically different questions. The first question concerns which operational risk dimensions are sufficiently relevant and important to represent the core risk structure of Indonesian EPC firms. The second concerns how the validated risk dimensions may interact through causal relationships and feedback mechanisms.

Accordingly, the research was conducted in two sequential stages. Stage 1 focused on the identification and quantitative screening of operational risk dimensions. An initial set of 15 dimensions was derived from a structured synthesis of the literature and operationalized into 45 measurement items in Fig. 1. Seven EPC experts subsequently evaluated the items using Content Validity Ratio (CVR), Content Validity Index (CVI), and Relative Importance Index (RII). The purpose of these measures was to establish the content validity, relevance, and perceived importance of the candidate risk dimensions.

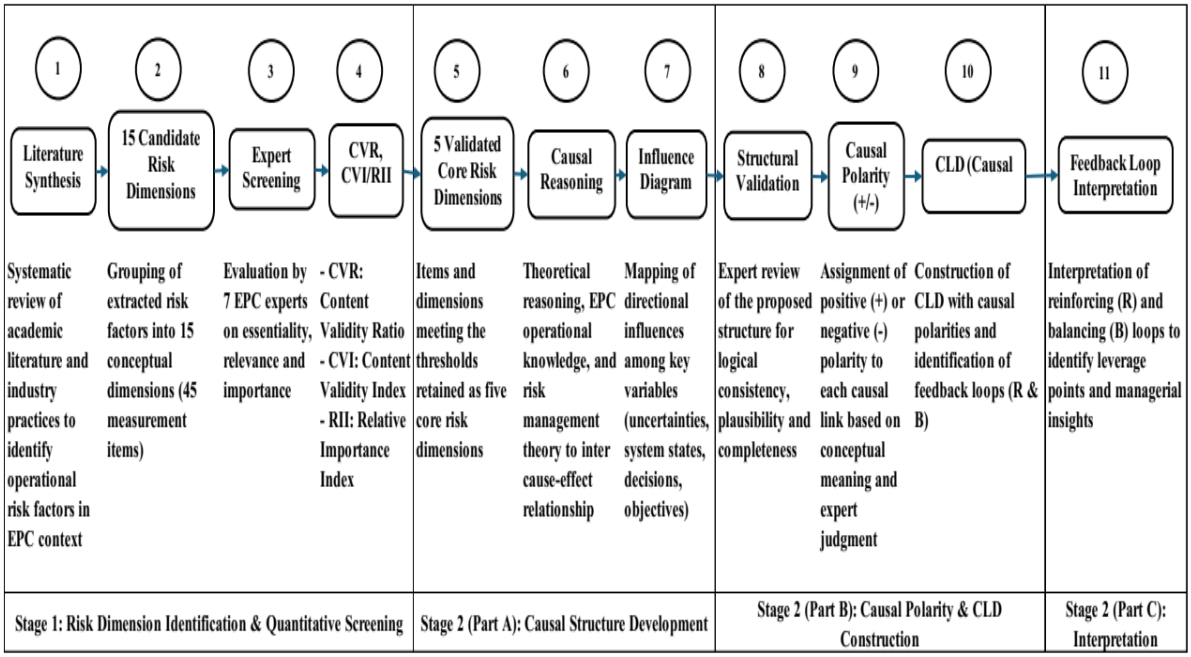


Fig. 1. Analytical Sequence of The Study

The output of Stage 1 was a parsimonious set of five core operational risk dimensions. These dimensions were then transferred to Stage 2, in which their causal relationships were examined through an influence diagram and subsequently represented as a Causal Loop Diagram (CLD). Importantly, the two stages serve different methodological purposes. CVR, CVI, and RII were not used to determine causal direction or causal polarity. Instead, they were used to establish the empirical and content-validity basis for selecting the variables to be included in the subsequent causal model. Causal directions and polarities were developed separately through theoretical reasoning, EPC operational knowledge, logical cause–effect interpretation, and expert structural verification. The analytical sequence can therefore be represented in Fig. 1. This sequencing ensures that the causal model is not constructed from an arbitrary selection of risk factors while also avoiding the methodological assumption that content-validity statistics can establish causality.

2.2. Expert Selection and Data Collection

A purposive expert selection strategy was employed to obtain domain-specific judgments regarding operational risks in EPC environments. Seven experts participated in the quantitative screening and subsequent structural assessment. The selection criteria were consistent with the requirements used in the earlier risk-dimension validation process: a minimum of 10 years of EPC-related experience, involvement in risk management or project governance, and professional experience in functions relevant to EPC project delivery, such as project management, risk engineering, and contract management.

The use of a relatively small expert panel was intentional because the study required specialized domain judgement rather than population-level statistical inference. The experts evaluated the candidate risk items in terms of their essentiality, relevance, and practical importance within EPC operations. For Stage 2, the same expert knowledge base was used to examine the structural plausibility of the proposed causal relationships. The experts were asked to assess whether the proposed directional relationships were logically consistent with EPC operational experience and whether the resulting feedback structures were meaningful within the organizational context. The expert assessment at this stage should therefore be distinguished from the quantitative validation conducted in Stage 1. The Stage 1 assessment provides evidence for variable selection, whereas the Stage 2 assessment provides structural and face validation of the proposed causal relationships.

2.3. Instrument Development Stage 1: Risk-Dimension Screening

The initial risk structure was developed through a structured literature synthesis of operational risk, construction risk, Engineering, Procurement, and Construction (EPC) project risk, and risk management in project-based organizations. The literature search was conducted using Scopus, Semantic Scholar, and Google Scholar as the principal academic databases and covered the predefined review period of 2010–2025. The database-specific search strings and search parameters are reported in Table 1 to support transparency and reproducibility.

Table 1. Database Search Strategy

Database	Search string	Review period
Scopus	TITLE-ABS-KEY (("operational risk" OR "operational risks") AND ("EPC" OR "engineering procurement construction") AND ("risk factor*" OR "risk dimension*" OR "risk management"))	2010–2025
Semantic Scholar	"Operational risk" EPC "risk factors"	2010–2025
Google Scholar	"Operational risk" EPC "risk factors"	2010–2025

Studies were considered eligible when they (i) addressed operational, construction, project, or organizational risks relevant to EPC or project-based environments; (ii) provided identifiable risk factors, dimensions, or constructs that could be conceptually classified; (iii) were published within the predefined review period; and (iv) were available as peer-reviewed academic publications. Studies were excluded when they (i) were outside the EPC or project-based risk context; (ii) did not provide identifiable risk-related variables; (iii) were duplicate records; or (iv) were non-peer-

Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343

reviewed publications or otherwise outside the predefined scope. The inclusion and exclusion criteria are summarized in Table 2.

Table 2. Inclusion and Exclusion Criteria for Literature Screening

Criterion	Inclusion	Exclusion
Context	EPC, construction, project-based organisations	Non-project/non-EPC contexts
Topic	Operational/project/organisational risk	Studies without identifiable risk variables
Publication	Peer-reviewed academic publications	Non-peer-reviewed publications
Period	2010-2025	Outside review period
Relevance	Provides identifiable risk dimensions/factors	No relevant risk constructs
Duplicate	—	Duplicate records

The identification and screening process followed the PRISMA framework to improve transparency and reproducibility. The search initially identified 470 records. After duplicate removal and title/abstract screening, 200 records proceeded to full-text assessment, of which 30 studies met the eligibility criteria and were included in the final synthesis. The complete identification, screening, eligibility, and inclusion process is presented in the PRISMA flow diagram in Fig. 2.

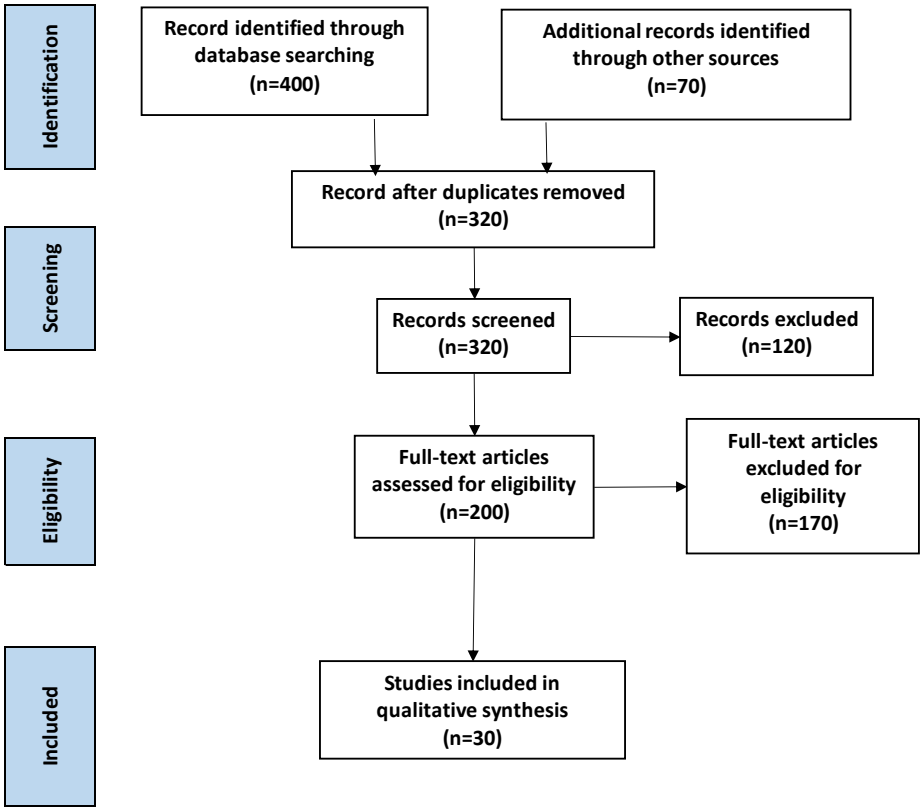


Fig. 2. PRISMA Flow Diagram of The Literature Identification and Screening Process

The eligible studies were subsequently synthesized to identify recurring operational risk factors and conceptually related variables. Similar risk factors were consolidated and grouped according to their underlying conceptual meaning and relevance to EPC operations. This synthesis yielded an initial set of 15 operational risk dimensions covering internal organizational capabilities and external uncertainty pressures in Table 3 Strategic & Business Risk, Financial & Market Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, Reputational Risk, Supply Chain & Logistics Risk, Technology & Cyber Risk, Legal & Contractual Risk, Governance & Compliance Risk, Process & Internal Control Risk, Operational Continuity Risk, Information & Knowledge Management Risk, Innovation & R&D Risk, and External Environment Risk.

Table 3. Mapping of Operational Risk Dimensions from Structured Literature Review

No	Risk Dimension	Conceptual Definition (EPC Context)	Reference
1	Strategic & Business Risk	Risks arising from strategic misalignment, market uncertainty, and competitive dynamics	(Davies & Mackenzie, 2014; Too & Weaver, 2014)
2	Financial & Market Risk	Risks related to cost overruns, funding constraints, and economic fluctuations	(Love et al., 2022)
3	Human Resource Risk	Workforce-related risks including skill gaps, labor shortages, and productivity issues	(Jian et al., 2025; O'Sullivan, 2010)
4	Customer & Stakeholder Risk	Risks from stakeholder conflicts, client dissatisfaction, and coordination complexity	(Francisco de Oliveira & Rabechini, 2019; Yuan et al., 2021)
5	Environmental & Sustainability Risk	Risks associated with environmental impact, regulations, and ESG compliance	(Hwang & Tan, 2012; Mochamad Agung Wibowo & Marah Ali Ammar, 2025)
6	Reputational Risk	Risks affecting organizational credibility and long-term trust	(Hanay et al., 2024)
7	Supply Chain & Logistics Risk	Risks related to procurement delays, material shortages, and logistics disruptions	(Ivanov & Dolgui, 2020; Sultana et al., 2024)
8	Technology & Cyber Risk	Risks from system failures, digitalization, and cybersecurity threats	(Chien et al., 2014; Oesterreich & Teuteberg, 2016)
9	Legal & Contractual Risk	Risks arising from contract disputes, legal uncertainty, and regulatory issues	(Dong et al., 2025; Sabri et al., 2025)
10	Governance & Compliance Risk	Risks related to weak internal control systems and regulatory non-compliance	(Bromiley et al., 2015; Soltanizadeh et al., 2016)
11	Process & Internal Control Risk	Risks from inefficient processes and lack of operational control	(Antunes & Gonzalez, 2015; Huang & Wang, 2025)
12	Operational Continuity Risk	Risks affecting continuity of operations and project execution	(Awang Ali et al., 2023; Torabi et al., 2014)
13	Information & Knowledge Management Risk	Risks related to poor data management and knowledge transfer failure	(Khoa & Chinda, 2023; Smith & Brooks, 2013)
14	Innovation & R&D Risk	Risks associated with adoption of new technologies and innovation uncertainty	(Marle & Vidal, 2016; Wang et al., 2023)
15	External Environment Risk	Risks from political, economic, and macro-environmental uncertainty	(Kabirifar & Mojtahedi, 2019; Moon & Krahel, 2020)

Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343

To ensure content representativeness and minimize single-item bias, each dimension was operationalized through three representative measurement items, resulting in 45 items. These items were subsequently subjected to expert-based quantitative screening using CVR, CVI, and RII in Stage 1. Three standard measures were used for quantitative screening. First, to find out the expert's agreement on the essentiality of each item, the Content Validity Ratio (CVR) was calculated Shrotryia & Dhanda (2019) in Eq. (1).

$$CVR = \frac{\eta_{e-(N/2)}}{N/2} \tag{1}$$

where n_e is the number of experts indicating that an item is essential and N is the total number of experts? For the seven-expert panel, the study adopted the predefined criterion of CVR ≥ 0.62 for retaining an item (Samad et al., 2023). The CVR threshold was applied at the individual-item level rather than to the dimension-level average. At the dimension level, retention was determined by considering the number of items meeting the CVR criterion together with the dimension-level CVI and RII results.

Second, the Content Validity Index (CVI) was calculated to assess relevance (Almanasreh et al., 2022). The Item-CVI (I-CVI) was computed as the proportion of experts rating an item as relevant in Eq. (2).

$$I - CVI = \frac{\eta_r}{N} \tag{2}$$

where n_e represents the number of experts rating the item as relevant.

At the dimension level, the Scale-level Content Validity Index based on the average method was calculated as in Eq. (3).

$$S - CVI/Ave = \frac{\sum I - CVI}{k} \tag{3}$$

where k is the number of items representing the dimension? The predefined criteria were I-CVI ≥ 0.78 and S-CVI/Ave ≥ 0.80 (Shrotryia & Dhanda, 2019).

Third, The RII was used to assess the perceived practical importance of the risk dimensions Khatib et al. (2020) Eq. (4).

$$RII = \frac{\sum \omega}{AxN} \tag{4}$$

where w the weight assigned by experts, A is the maximum possible weight, and $N$is the number of experts. The three measures were interpreted jointly rather than as independent causal indicators. CVR and CVI establish whether the dimensions and their items are sufficiently essential and relevant, while RII provides an indication of their perceived practical importance. The resulting five dimensions with the strongest combined support were: Strategic & Business Risk; Human Resource Risk; Customer & Stakeholder Risk; Environmental & Sustainability Risk; and Reputational Risk. These five dimensions constituted the validated input variables for Stage 2.

2.4. Stage 2: From Validated Risk Dimensions to Causal Structure

Stage 2 was designed to translate the validated risk dimensions into a qualitative causal structure. Unlike Stage 1, this stage did not seek to calculate the statistical significance or importance of causal relationships. Instead, it examined how the validated risk dimensions could logically interact with organizational states and outcomes in an EPC environment. The process consisted of three sequential steps.

Step 1 — Causal Conceptualization

The five validated risk dimensions were first interpreted in relation to the broader operational risk system. Causal reasoning considered the operational meaning of each dimension and its expected

directional relationship with Operational Risk Exposure, Project Failure, Profitability, Risk Investment, Risk Maturity, and Business Continuity. For example, an increase in Strategic & Business Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, or Reputational Risk was conceptually expected to increase overall Operational Risk Exposure. This relationship was therefore represented as a positive causal influence. Conversely, stronger governance mechanisms and risk-management capability were conceptualized as reducing risk exposure and increasing risk maturity. At this point, the analysis remained conceptual. No causal direction was inferred from CVR, CVI, or RII.

Step 2 — Influence Diagram Development

The causal reasoning was subsequently represented in an influence diagram to establish the directional structure before introducing feedback loops. The influence diagram distinguishes the principal categories of variables according to their modelling roles: Oval - uncertainty/chance variables representing the five validated operational risk dimensions; Rounded rectangle - intermediate system variables, including Operational Risk Exposure, Project Failure, Profitability, Risk Investment, and Risk Maturity; Rectangle - management decision variables or intervention mechanisms; Hexagon/diamond - organizational objective, represented by Business Continuity; and Arrows - directional influence relationships between variables.

This representation provides an intermediate analytical layer between quantitative risk-dimension validation and CLD development. It establishes what influences what before asking how those influences may generate feedback behavior. The influence diagram therefore functions as a structural bridge between Stage 1 and the CLD rather than as a direct statistical output of the CVR/CVI/RII analysis.

2.5. Mechanism for Determining Causal Polarity

2.5.1. Principle of Causal Polarity

After the directional structure had been established, each influence arc was assigned a causal polarity of either positive (+) or negative (−). A positive (+) causal relationship means that, all else being equal, an increase in the source variable is conceptually associated with an increase in the receiving variable, while a decrease is associated with a decrease. A negative (−) causal relationship means that an increase in the source variable is conceptually associated with a decrease in the receiving variable, while a decrease is associated with an increase. For example, in Eq. (5).

$$Risk\ Dimension\ (+) \rightarrow Operational\ Risk\ Exposure \tag{5}$$

indicates that greater exposure to the corresponding risk dimension is expected to increase aggregate operational risk exposure. Similarly, in Eq. (6). indicates that stronger risk-management maturity is expected to reduce operational risk exposure. The polarity therefore expresses directional causal logic, rather than statistical correlation.

$$Risk\ Maturity\ (-) \rightarrow Operational\ Risk\ Exposure \tag{6}$$

2.5.2. Basis for Causal Polarity

This means that CVR, CVI, and RII do not determine polarity. Instead, they determine which variables have sufficient support to enter the causal model. The causal modelling stage begins only after the five core dimensions have been established. The four sources were considered collectively to ensure that each causal link was grounded in a clear conceptual rationale, operational relevance, established theoretical foundations, and expert judgment. This triangulation helped maintain consistency between the meaning of each variable and the direction of its proposed causal influence, while reducing the risk of assigning polarity based solely on subjective interpretation. The polarity assignment followed four complementary sources of reasoning in Table 4.

Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343

Table 4. Basis for Determining Causal Polarity

Basis	Function in the model
Conceptual definition of variables	Establishes the meaning and direction of each construct
EPC operational knowledge	Determines whether the proposed direction is plausible in EPC operations
Risk-management theory	Provides theoretical support for governance, mitigation, maturity, and resilience relationships
Expert structural verification	Assesses whether the proposed directional relationship and polarity are credible and logically consistent with EPC operational experience. Causal polarity was therefore assigned through a triangulation of conceptual, theoretical, operational, and expert-based reasoning rather than through a single quantitative criterion.

2.5.3. Structural Verification of Causal Relationships

The preliminary influence structure and causal polarities were reviewed by the expert panel to assess whether the proposed relationships were: Conceptually understandable; Directionally plausible; Consistent with EPC operational experience; Compatible with risk-management principles; and structurally consistent when connected into feedback loops. Where a proposed relationship was considered ambiguous, its conceptual definition and causal direction were reconsidered before the CLD was finalized. This procedure constitutes expert-based structural/face validation, rather than statistical validation of causal effects. Consequently, the resulting CLD should be interpreted as a qualitative conceptual model of potential causal mechanisms, not as an empirically calibrated dynamic model.

2.6. Causal Loop Diagram Development

Following structural verification, the influence diagram was extended into a Causal Loop Diagram by retaining the validated directional relationships and introducing causal polarities and closed feedback structures. The CLD was developed to identify two types of feedback:

2.6.1. Reinforcing Loop (R)

A reinforcing loop represents a feedback structure in which the combined causal relationships tend to amplify the initial direction of change. The principal reinforcing mechanism identified in this study in Eq. (7).

$$\begin{aligned} &Operational\ Risk\ Exposure\ (+) \rightarrow Project\ Failure\ (+) \rightarrow Profitability(-) \\ &\rightarrow Risk\ Investment\ (+) \rightarrow Risk\ Maturity\ (+) \\ &\rightarrow OperationalRisk\ Exposure(-) \end{aligned} \tag{7}$$

The interpretation is that increasing risk exposure can contribute to project failure and declining profitability. Lower profitability may constrain risk investment, which may weaken risk-management maturity and subsequently increase risk exposure further.

2.6.2. Balancing Loop (B)

A balancing loop represents a feedback structure in which the combined causal relationships tend to counteract the initial change. The principal governance-based mechanism in Eq. (8).

$$\begin{aligned} &Operational\ Risk\ Exposure\ (+) \rightarrow Management/Governance\ Decision\ (+) \\ &\rightarrow Risk\ Investment(+)\ \rightarrow Risk\ Maturity\ (+) \\ &\rightarrow Operational\ Risk\ Exposure(-) \end{aligned} \tag{8}$$

A second balancing mechanism incorporates reputational pressure in Eq. (9).

$$\begin{aligned} &Operational\ Risk\ Exposure\ (+) \rightarrow Reputational\ Risk\ (+) \rightarrow Governance\ Attention(+) \\ &\rightarrow Risk\ Investment(+) \rightarrow Risk\ Maturity\ (+) \\ &\rightarrow Operational\ Risk\ Exposure(-) \end{aligned} \tag{9}$$

These loops are interpreted as potential mechanisms, rather than empirically demonstrated dynamic trajectories.

2.7. Historical Pattern Validation

To assess the empirical plausibility of the proposed causal structure, a retrospective historical pattern validation was conducted using available EPC project records. The purpose of this analysis was not to estimate causal effect sizes or statistically prove causality, but to examine whether the directional patterns represented in the CLD were consistent with observed historical project behavior.

Historical observations were organized according to the principal variables and feedback mechanisms represented in R1, B1, and B2. For each causal pathway, the expected directional pattern was compared with the corresponding historical pattern. Each relationship was classified as consistent, partially consistent, not observed, or insufficient evidence. A feedback loop was considered historically supported when its principal directional relationships showed sufficient consistency across the available observation periods. This procedure provides retrospective evidence regarding the structural plausibility of the proposed CLD while maintaining the distinction between historical pattern consistency and statistical causal inference in Table 5.

Table 5. Historical Pattern Validation of the Proposed Causal Relationships

Loop	Causal relationship	Expected polarity	Historical pattern	Observed lag	Consistency	Evidence basis
R1	Operational Risk Exposure → Project Failure	+	Exposure ↑ → Project Failure ↑	2 months	Consistent	Project risk & performance records
R1	Project Failure → Profitability	–	Project Failure ↑ → Profitability ↓	1 month	Consistent	Project financial records
R1	Profitability → Risk Investment	+	Profitability ↓ → Investment ↓; subsequent investment recovery occurred before full profitability recovery	1 month	Partially consistent	Financial & risk-investment records
R1	Risk Investment → Risk Maturity	+	Risk Investment ↑ → Risk Maturity ↑	3 months	Consistent	Risk investment & maturity assessment
R1	Risk Maturity → Operational Risk Exposure	–	Risk Maturity ↑ → Exposure ↓	2 months	Consistent	Risk register & maturity records
B1	Operational Risk Exposure → Management/Governance Decision	+	Exposure ↑ → Management intervention ↑	1 month	Consistent	Risk committee/action records
B1	Management/Governance Decision → Risk Investment	+	Management intervention ↑ → Risk Investment ↑	1 month	Consistent	Management decision & budget records
B1	Risk Investment → Risk Maturity	+	Risk Investment ↑ → Risk Maturity ↑	3 months	Consistent	Investment & maturity records
B1	Risk Maturity → Operational Risk Exposure	–	Risk Maturity ↑ → Exposure ↓	2 months	Consistent	Risk & maturity records

Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343

Loop	Causal relationship	Expected polarity	Historical pattern	Observed lag	Consistency	Evidence basis
B2	Operational Risk Exposure → Reputational Risk	+	Exposure ↑ → Reputational Risk ↑	1 month	Consistent	Incident/complaint records
B2	Reputational Risk → Governance Attention	+	Reputational Risk ↑ → Governance Attention ↑	1 month	Consistent	Governance records
B2	Governance Attention → Risk Investment	+	Governance Attention ↑ → Risk Investment ↑	1 month	Consistent	Governance & budget records
B2	Risk Investment → Risk Maturity	+	Risk Investment ↑ → Risk Maturity ↑	3 months	Consistent	Investment & maturity records
B2	Risk Maturity → Operational Risk Exposure	−	Risk Maturity ↑ → Exposure ↓	2 months	Consistent	Risk & maturity records

The historical pattern assessment showed that 13 of the 14 loop-specific causal relationship instances shown in Table 5 with the observed project patterns, while one relationship was classified as partially consistent. The partially consistent relationship involved Profitability → Risk Investment, where the initial decline in profitability was accompanied by lower risk investment, but subsequent investment recovery was not fully synchronized with profitability recovery. At the loop level, B1 and B2 showed consistent historical patterns, whereas R1 was classified as partially supported. These findings indicate that the proposed feedback structures are broadly compatible with the observed historical behavior, while also suggesting that risk-investment decisions may be influenced by factors beyond profitability alone.

2.8. Time-Delay Treatment and Interpretation

Because the causal relationships represented in the CLD do not necessarily operate instantaneously, temporal separation between source and receiving variables was explicitly considered. For each proposed relationship $X \rightarrow Y$, the historical sequence was represented as $X_t \rightarrow Y_{t+\tau}$, where τ denotes the observed temporal lag.

Table 6. Operationalization of Time-Delay Treatment

Aspect	Treatment applied in the study
Temporal unit	Monthly project observations
Causal representation	$X_t \rightarrow Y_{t+\tau}$
Candidate lag	0–3 monthly observation periods
Lag identification	Temporal separation between source-variable change and subsequent receiving-variable change
Lag selection	Based on the observed historical sequence consistent with the proposed causal mechanism. A candidate lag was retained when the temporal ordering of the observed source and receiving variables was consistent with the proposed causal direction and was repeatedly observable within the available project record
Missing temporal evidence	Classified as insufficient evidence; no assumed lag assigned
CLD interpretation	Delays represent temporal separation, not statistically estimated causal parameters
Generalization	Observed lags are project/data-specific and are not assumed to be universal EPC parameters

The lag was identified from the temporal separation between a relevant change in the source variable and the subsequent change in the receiving variable. Candidate lags were examined using the available historical observation periods. Where temporal precedence could not be established, no

lag was assigned and the relationship was classified as insufficient evidence. The operational treatment of temporal delays is summarized in Table 6. The resulting lag values provide temporal information for interpreting R1, B1, and B2. They are treated as observed historical characteristics rather than statistically calibrated causal parameters and are therefore not assumed to be universally applicable across EPC organizations.

2.9. Scope and Interpretation of the CLD

The resulting CLD is a qualitative and conceptual causal model. It does not estimate causal effect sizes, probability distributions, equilibrium states, or dynamic trajectories. Although observed temporal lags were examined retrospectively, the CLD does not incorporate statistically calibrated delay functions or dynamic delay parameters. The purpose of the CLD at this stage is to identify the principal operational risk variables, directional relationships, potential reinforcing and balancing mechanisms, and potential management leverage points. The study does not claim to simulate the dynamic behavior of Indonesian EPC firms. Rather, it establishes a validated qualitative causal structure that identifies potential feedback mechanisms and provides a foundation for subsequent stock-and-flow simulation and empirical calibration. Future research may extend the CLD into a stock-and-flow model using historical EPC project data, time-series information, and empirically estimated parameters to examine delay effects, scenario behavior, and policy interventions.

3. Results and Discussion

3.1. Validation and Screening of Operational Risk Dimensions

The first stage of the analysis aimed to identify the core operational risk dimensions that provide a sufficiently relevant representation of operational risk in Indonesian EPC firms. Based on the structured literature synthesis, fifteen candidate dimensions were initially identified and operationalized into 45 measurement items, with three items representing each dimension in Table 7. These dimensions covered strategic, financial, human-resource, stakeholder, environmental, reputational, supply-chain, technological, contractual, governance, process, continuity, information, innovation, and external-environment risks. The 45 items were assessed by seven EPC experts using three complementary indicators: Content Validity Ratio (CVR), Content Validity Index (CVI), and Relative Importance Index (RII). CVR assessed item essentiality, CVI assessed item relevance and representativeness, and RII assessed perceived practical importance. These measures were used exclusively for quantitative screening and content assessment; they were not used to infer causal direction or causal polarity. The screening process resulted in five core dimensions being retained in Table 7: Strategic & Business Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, and Reputational Risk. The retained dimensions showed comparatively stronger support across the screening criteria than the other candidate dimensions.

The results indicate that the operational risk structure identified in this study encompasses both internal organizational capabilities and external relational pressures. Strategic & Business Risk and Human Resource Risk represent internal organizational and capability-related exposure, whereas Customer & Stakeholder Risk, Environmental & Sustainability Risk, and Reputational Risk capture broader relational, environmental, and legitimacy-related pressures. This combination suggests that operational risk in the EPC context is not adequately represented by project execution factors alone but also involves organizational and external interactions. The remaining ten dimensions were not retained under the predefined screening criteria. Their non-retention should not be interpreted as evidence that these risks are universally unimportant. Rather, the results indicate that, within the expert assessment and operational context examined in this study, they did not receive sufficient support to be retained as standalone core dimensions. Their potential overlap with the retained dimensions therefore warrants further investigation rather than categorical exclusion. The five retained dimensions subsequently served as the core risk variables for Stage 2. Importantly, their retention establishes the relevance and importance of the variables, but does not establish causal relationships among them. The causal architecture is therefore developed separately through theoretical reasoning, EPC operational knowledge, and structural examination of directional relationships in the subsequent influence diagram.

Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343

Table 7. Screening Results of Operational Risk Dimensions

No	Dimension	Item Quantity	S CVI Avg	Avg RII	Avg CVR	Retain Item Count	Decision
1	Customer & Stakeholder Risk	3	0.857	0.838	0.714	2	Retain
2	Environmental & Sustainability Risk	3	0.905	0.857	0.810	3	Retain
3	External Environment Risk	3	0.143	0.590	-0.714	0	Not Retained
4	Financial & Market Risk	3	0.286	0.648	-0.429	0	Not Retained
5	Governance & Compliance	3	0.286	0.638	-0.429	0	Not Retained
6	Human Resource Risk	3	0.810	0.838	0.619	2	Retain
7	Information & Knowledge Management	3	0.286	0.638	-0.429	0	Not Retained
8	Innovation & R&D Risk	3	0.333	0.648	-0.333	0	Not Retained
9	Legal & Contractual Risk	3	0.429	0.667	-0.143	0	Not Retained
10	Operational Continuity	3	0.333	0.648	-0.333	0	Not Retained
11	Process & Internal Control	3	0.143	0.562	-0.714	0	Not Retained
12	Reputational Risk	3	0.905	0.867	0.810	3	Retain
13	Strategic & Business Risk	3	0.905	0.838	0.810	3	Retain
14	Supply Chain & Logistics Risk	3	0.286	0.619	-0.429	0	Not Retained
15	Technology & Cyber Risk	3	0.381	0.657	-0.238	0	Not Retained

3.2. Development of the Influence Diagram: From Validated Risk Dimensions to Causal Structure

The five core operational risk dimensions identified in Stage 1 were subsequently used to develop the influence diagram as an intermediate structure between risk-dimension validation and causal-loop modelling. The purpose of this stage was to establish the proposed directional relationships among risk sources, operational conditions, management responses, and organizational outcomes.

The five validated dimensions, Strategic & Business Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, and Reputational Risk, were represented as uncertainty variables contributing positively (+) to Operational Risk Exposure. Higher Operational Risk Exposure was then linked to a higher likelihood of Project Failure (+), while Project Failure was expected to reduce Profitability (−). Higher Profitability was conceptually expected to support greater Risk Investment (+), which in turn was expected to strengthen Risk Maturity (+). The resulting structure links Risk Maturity to Business Continuity as the organizational objective, while its potential risk-reduction effect on Operational Risk Exposure is introduced explicitly when the directional structure is extended into the feedback relationships in the CLD.

The influence diagram also distinguishes management intervention variables from uncertainty and system-state variables, allowing organizational responses to be represented as mechanisms that may modify risk conditions rather than as risk factors themselves. The proposed directional relationships were established through the causal reasoning procedure described in Sections 2.4–2.5 and were not inferred from CVR, CVI, or RII results. Fig. 3 therefore provides the directional structure from which the subsequent Causal Loop Diagram was developed.

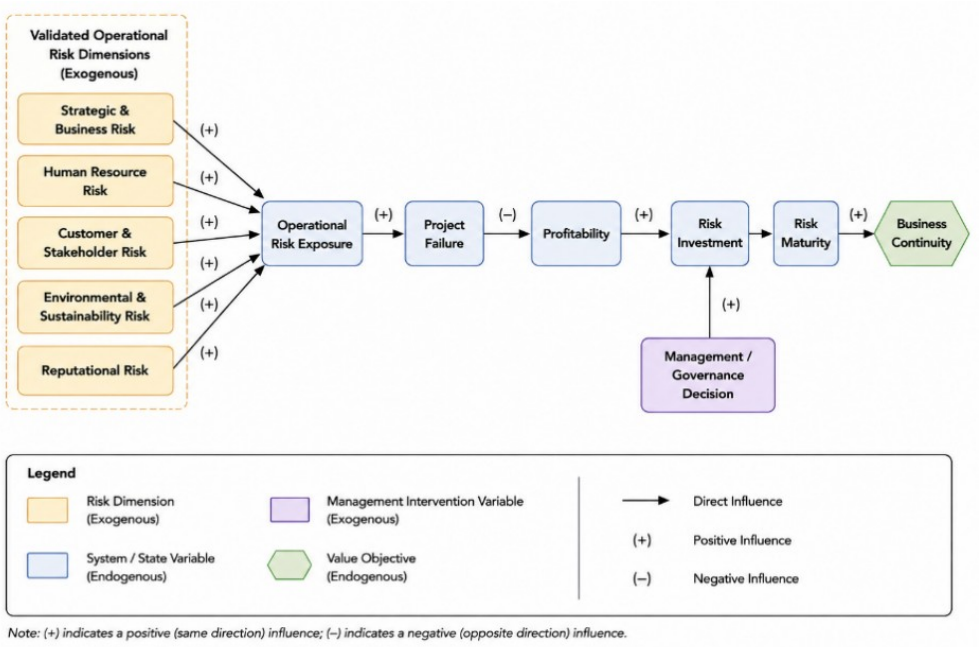


Fig. 3. Influence Diagram Linking Validated Operational Risk Dimensions with Operational Exposure, Management Responses, Risk Maturity, and Business Continuity

3.3. Causal Loop Diagram (CLD): Potential Risk Escalation and Corrective Feedback Mechanisms

Fig. 4 extends the influence structure presented in Fig. 3 by connecting the directional relationships into interconnected feedback loops. The resulting Causal Loop Diagram (CLD) identifies one reinforcing loop (R1) associated with potential risk escalation and two balancing loops (B1 and B2) representing potential corrective responses. The CLD is interpreted as a qualitative causal hypothesis: it identifies the structure and polarity of potential feedback relationships but does not establish the magnitude, timing, or empirical occurrence of the associated dynamics.

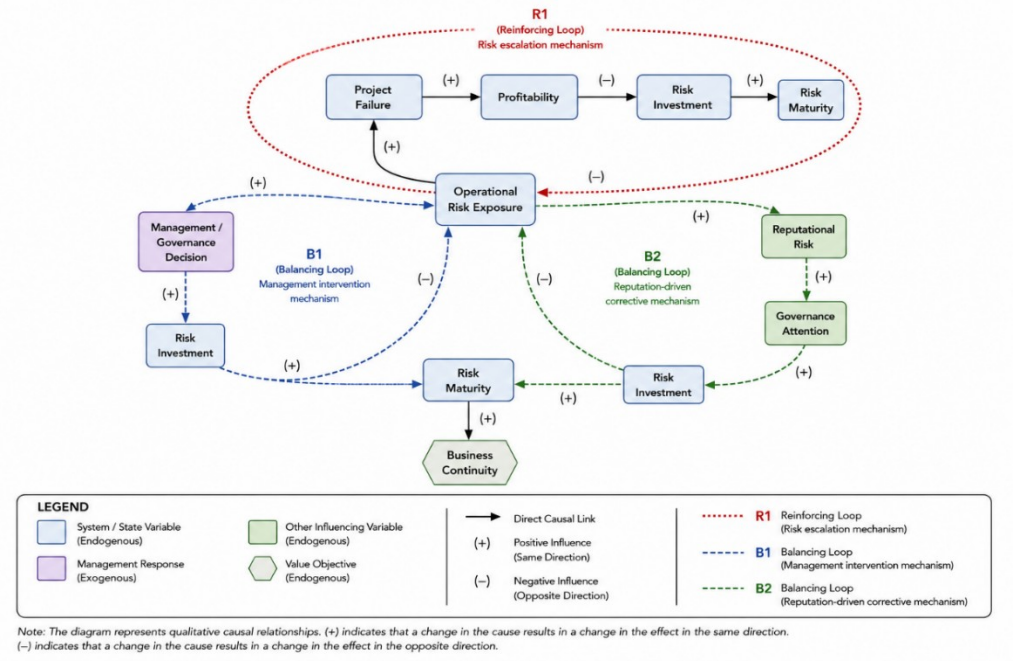


Fig. 4. Causal Loop Diagram of Potential Risk Escalation and Corrective Feedback Mechanisms in Indonesian EPC Companies

Spektrum Industri
Vol. 24, No. 2, 2026, pp. 324–343

The five validated risk dimensions, Strategic & Business Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, and Reputational Risk, remain the principal sources of operational uncertainty. Their influences converge on Operational Risk Exposure, which is subsequently connected to project performance, profitability, risk investment, risk-management maturity, and business continuity. The CLD therefore preserves the conceptual structure established in the influence diagram while providing an additional layer for interpreting feedback behavior.

Table 8. Operational Definition and Modelling Role of Variables in the CLD

Variable	Modelling Role	Operational Definition in EPC Context
Strategic & Business Risk	Uncertainty	Risk arising from strategic misalignment, market volatility, and contract exposure
Human Resource Risk	Uncertainty	Risk related to workforce competency, availability, and leadership continuity
Customer & Stakeholder Risk	Uncertainty	Risk related to stakeholder conflict, client dissatisfaction, and coordination complexity
Environmental & Sustainability Risk	Uncertainty	Risk associated with regulatory compliance, ESG requirements, and environmental incidents
Reputational Risk	Uncertainty	Risk of negative public perception affecting trust, contract acquisition, and legitimacy
Operational Risk Exposure	System State	Aggregate level of operational vulnerability across ongoing EPC projects
Project Failure	Outcome Variable	Occurrence of delay, cost overrun, quality deviation, or contractual dispute
Profitability	Performance Variable	Financial performance affected by project outcomes
Risk Investment	Resource Variable	Allocation of financial and organizational resources for risk management activities
Risk Maturity	Capability Variable	Level of structured governance, integration, and monitoring of risk management practices
Business Continuity	Value Objective	Organizational resilience and ability to sustain operations under uncertainty
Governance Attention	Management response	The level of managerial attention and organisational focus directed toward risk-related corrective actions in response to operational or reputational pressure.

This Table 8 defines the variables according to their role in the causal system rather than treating them as statistically independent constructs. The distinction is important because the CLD focuses on relationships among system variables, whereas the quantitative screening in Stage 1 focused on selecting the core risk dimensions.

3.3.1. Reinforcing Loop R1: Risk Escalation Mechanism

The first feedback structure is the Reinforcing Loop R1, which represents a potential risk-escalation mechanism. The causal sequence in Eq. (10).

$$\begin{aligned} &Operational\ Risk\ Exposure\ (+) \rightarrow\ Project\ Failure\ (+) \rightarrow Profitability\ (-) \\ &\rightarrow Risk\ Investment(+) \rightarrow Risk\ Maturity\ (+) \\ &\rightarrow Operational\ Risk\ Exposure(-) \end{aligned} \tag{10}$$

R1 represents a potential reinforcing mechanism through which deteriorating operational conditions may increase subsequent risk exposure. Higher Operational Risk Exposure is expected to increase the likelihood of Project Failure (+), while Project Failure reduces Profitability (−). Lower profitability may constrain the organization's capacity to allocate resources to risk-management activities, resulting in lower Risk Investment. Reduced Risk Investment may weaken Risk Maturity, which in turn may increase Operational Risk Exposure. The loop therefore contains two negative causal relationships, Project Failure → Profitability and Risk Maturity → Operational Risk Exposure, resulting in an overall reinforcing structure. This structure represents a potential risk-escalation pathway rather than evidence that such a spiral necessarily occurs in practice.

3.3.2. Balancing Loop B1: Governance-Based Corrective Mechanism

B1 represents a potential corrective mechanism in which management intervention responds to increasing Operational Risk Exposure. Greater exposure may trigger stronger management attention and risk-management actions, increasing Risk Investment (+). Higher Risk Investment may strengthen Risk Maturity (+), which can reduce Operational Risk Exposure (−). The negative relationship between Risk Maturity and Operational Risk Exposure counteracts the initial increase in exposure, giving the loop a balancing structure. The loop therefore represents a potential governance-based corrective pathway; its effectiveness cannot be established without empirical calibration and dynamic simulation. The conceptual sequence can therefore be represented as in Eq. (11).

$$Management/Governance\ Decision\ (+) \rightarrow Risk\ Investment(+) \rightarrow Risk\ Maturity\ (+) \rightarrow Operational\ Risk\ Exposure(-) \quad (11)$$

3.3.3. Balancing Loop B2: Reputation-Driven Corrective Mechanism

B2 represents a potential corrective pathway driven by reputational pressure. Higher Operational Risk Exposure may increase Reputational Risk (+), which may increase Governance Attention (+) and subsequently encourage greater Risk Investment (+) in Table 9. Increased Risk Investment may strengthen Risk Maturity (+), which reduces Operational Risk Exposure (−). The resulting negative feedback structure suggests that reputational consequences may create additional managerial pressure for risk-management action. As with B1, this loop should be interpreted as a proposed causal mechanism rather than an empirically demonstrated stabilizing effect. The proposed sequence in Eq. (12).

$$Operational\ Risk\ Exposure\ (+) \rightarrow Reputational\ Risk(+) \rightarrow Governance\ Attention\ (+) \rightarrow Risk\ Investmen(+) \rightarrow Risk\ Maturity(+) \rightarrow Operational\ Risk\ Exposure(-) \quad (12)$$

Table 9. Description of Feedback Loops in the CLD

Loop	Type	Causal Structure	Interpretation
R1	Reinforcing	Operational Risk Exposure (+) → Project Failure (+) → Profitability (-) → Risk Investment (+) → Risk Maturity (+) → Operational Risk Exposure (-)	Potential risk-escalation mechanism caused by deterioration in project and financial conditions
B1	Balancing	Management/Governance Mechanisms (+) → Risk Investment (+) → Risk Maturity (+) → Operational Risk Exposure (−)	Potential governance-based corrective mechanism
B2	Balancing	Operational Risk Exposure (+) → Reputational Risk (+) → Governance Attention (+) → Risk Investment (+) → Risk Maturity (+) → Operational Risk Exposure (−)	Potential reputation-driven corrective mechanism

Taken together, in Table 9 R1, B1, and B2 suggest that operational risk in EPC organizations may involve competing escalation and corrective mechanisms. R1 represents a potential reinforcing pathway in which deteriorating operational conditions may reduce the capacity for risk investment

and weaken risk maturity, thereby increasing subsequent exposure. B1 represents a potential management-driven corrective pathway, while B2 represents a potential reputation-driven pathway that may increase governance attention and risk-management investment. The coexistence of these structures indicates that operational risk may be shaped not only by the occurrence of individual risk factors but also by how organizational responses interact with changing risk conditions.

4. Conclusion

This study developed a qualitative causal framework for understanding operational risk dynamics in Indonesian Engineering, Procurement, and Construction (EPC) companies by integrating expert-based risk-dimension validation with systems thinking and causal loop modelling. From an initial set of fifteen operational risk dimensions identified through a structured literature synthesis, five core dimensions were retained based on the combined results of Content Validity Ratio (CVR), Content Validity Index (CVI), and Relative Importance Index (RII): Strategic & Business Risk, Human Resource Risk, Customer & Stakeholder Risk, Environmental & Sustainability Risk, and Reputational Risk. The screening results provide an expert-based basis for selecting the principal risk variables incorporated into the subsequent causal model. The five validated dimensions were subsequently translated into an influence diagram to establish the directional structure of the operational risk system.

The causal relationships were not inferred from CVR, CVI, or RII values. Instead, causal direction and polarity were determined through conceptual definitions, EPC operational knowledge, risk-management principles, and expert-based structural verification. The influence diagram therefore served as an intermediate analytical layer connecting quantitative risk-dimension screening with qualitative causal-loop modelling. The resulting Causal Loop Diagram (CLD) identified three potential feedback mechanisms. Reinforcing Loop R1 represents a potential risk-escalation mechanism in which increasing Operational Risk Exposure may contribute to Project Failure, declining Profitability, constrained Risk Investment, and weaker Risk Maturity, which may subsequently increase Operational Risk Exposure. Balancing Loops B1 and B2 represent potential corrective mechanisms associated with management intervention and reputational pressure, respectively. These structures suggest that operational risk in EPC organizations may involve competing escalation and corrective mechanisms rather than a collection of independent risk factors.

The principal contribution of this study is therefore not the empirical demonstration of risk escalation or stabilization, but the development of an expert-verified qualitative causal architecture supported by retrospective historical pattern evidence that integrates core operational risk dimensions with organizational responses and feedback structures. This framework extends conventional risk identification by providing a systems-based representation of how operational risk may propagate through project performance, profitability, risk investment, and risk-management maturity. It consequently provides a conceptual foundation for identifying potential management leverage points within complex multi-project EPC environments. Several limitations define the interpretation of these findings. The CLD remains qualitative and conceptual and does not estimate causal effect sizes, probability distributions, equilibrium conditions, or dynamic trajectories. Historical EPC project records were used for retrospective pattern validation and observed temporal-lag assessment; however, these observations were not used to statistically calibrate causal effect sizes or dynamic delay functions. Accordingly, the proposed feedback mechanisms should be interpreted as empirically informed causal hypotheses rather than fully calibrated dynamic behavior.

Future research should extend the proposed CLD into a stock-and-flow model using historical EPC project data and empirically informed parameters. Such an extension would enable the incorporation of time delays, quantify the relative strength of causal relationships, test alternative risk scenarios, and examine whether the reinforcing and balancing mechanisms identified in this study emerge under actual operating conditions. Empirical calibration and scenario-based simulation would therefore provide the next stage of validation for the proposed operational risk framework.

Author Contribution: Drajat Indrajaya: Conceptualization, methodology, software, formal analysis, writing original draft, and project administration. Parwadi Moengin: Methodology, validation, supervision, and writing-review and editing. Dadang Surjasa: Investigation, resources, data curation, and writing-review and editing. Sally Cahyati: Formal analysis, validation, visualization, and writing-review and editing. Etanto Heiliano Wijayanto: Software, data curation, and visualization.

Funding: This research received no external funding.

Acknowledgment: The researcher would like to thank the Dissertation Advisory Team of the Industrial Engineering Study Program, Trisakti University Doctoral Program, who have supported and assisted in writing this research paper.

Conflicts of Interest: The authors declare no conflict of interest.

Declaration of AI-Tool Usage: AI-assisted tools were used to support manuscript proofreading, verify the consistency of variables and mathematical notation, and check reference formatting. All outputs were reviewed and verified by the authors, who take full responsibility for the accuracy and integrity of the final manuscript.

References

Almanasreh, E., Moles, R. J., & Chen, T. F. (2022). A practical approach to the assessment and quantification of content validity. In *Contemporary Research Methods in Pharmacy and Health Services* (pp. 583–599). https://doi.org/10.1016/B978-0-323-91888-6.00013-2

Alsarayreh, R., Buraik, O., Hijazin, A., & Alshdaifat, S. M. (2025). The impact of business intelligence on strategic ambidexterity: The mediating role of knowledge sharing. In *Electronic Journal of e-Learning (EJEL)*. https://doi.org/10.34190/ejbrm.23.1.3719

Antunes, R., & Gonzalez, V. (2015). A Production Model for Construction: A Theoretical Framework. *Buildings*, *5*(1), 209–228. https://doi.org/10.3390/buildings5010209

Awang Ali, Q. S., Hanafiah, M. H., & Mogindol, S. H. (2023). Systematic literature review of Business Continuity Management (BCM) practices: Integrating organisational resilience and performance in Small and medium enterprises (SMEs) BCM framework. *International Journal of Disaster Risk Reduction*, *99*, 104135. https://doi.org/10.1016/j.ijdrr.2023.104135

Ayu, W. D., Nugroho, N., & Just'at, I. (2024). The Influence of Knowledge and Leadership on Clinical Risk Management with Patient Safety Culture as an Intervening Variable at PMI Hospital. *Jurnal Mahasiswa Ilmu Kesehatan*. https://jurnal.stikes-ibnusina.ac.id/index.php/jumkes/article/view/1859

Bromiley, P., McShane, M., Nair, A., & Rustambekov, E. (2015). Enterprise Risk Management: Review, Critique, and Research Directions. *Long Range Planning*, *48*(4), 265–276. https://doi.org/10.1016/j.lrp.2014.07.005

Chien, K.-F., Wu, Z.-H., & Huang, S.-C. (2014). Identifying and assessing critical risk factors for BIM projects: Empirical study. *Automation in Construction*, *45*, 1–15. https://doi.org/10.1016/j.autcon.2014.04.012

Chigbu, B. I., & Makapela, S. L. (2025). Data-driven leadership in higher education: advancing sustainable development goals and inclusive transformation. In *Sustainability*. https://doi.org/10.3390/su17073116

Davies, A., & Mackenzie, I. (2014). Project complexity and systems integration: Constructing the London 2012 Olympics and Paralympics Games. *International Journal of Project Management*, *32*(5), 773–790. https://doi.org/10.1016/j.ijproman.2013.10.004

Dong, S., Ahmed, M., & Chatpattananan, V. (2025). Analysis of Key Factors of Cost Overrun in Construction Projects Based on Structural Equation Modeling. *Sustainability*, *17*(5), 2119. https://doi.org/10.3390/su17052119

Francisco de Oliveira, G., & Rabechini Jr, R. (2019). Stakeholder management influence on trust in a project: A quantitative study. *International Journal of Project Management*, *37*(1), 131–144. https://doi.org/10.1016/j.ijproman.2018.11.001

Hanay, U., Ince, H., & Isik, G. (2024). Identifying Key Factors of Reputational Risk in Finance Sector Using a Linguistic Fuzzy Modeling Approach. *Systems*, *12*(10), 440. https://doi.org/10.3390/systems12100440

Huang, R., & Wang, Z. (2025). Internal Control and Risk Management in Accounting Information System. *International Journal of Information Systems in the Service Sector*, *16*(1), 1–17. https://doi.org/10.4018/IJISSS.392475

Hwang, B., & Tan, J. S. (2012). Green building project management: obstacles and solutions for sustainable development. *Sustainable Development*, *20*(5), 335–349. https://doi.org/10.1002/sd.492

Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International Journal of Production Research*, *58*(10), 2904–2915. https://doi.org/10.1080/00207543.2020.1750727

Jian, F., Liu, Q., Feng, C., Hu, Q., Yu, Q., & Guo, Q. (2025). Critical Factors Affecting Construction Labor Productivity: A Systematic Review and Meta-Analysis. *Buildings*, *15*(14), 2463. https://doi.org/10.3390/buildings15142463

Kabirifar, K., & Mojtahedi, M. (2019). The impact of Engineering, Procurement and Construction (EPC) Phases on Project Performance: A Case of Large-scale Residential Construction Project. *Buildings*, *9*(1), 15. https://doi.org/10.3390/buildings9010015

Khatib, B. Al, Poh, Y. S., & El-Shafie, A. (2020). Delay Factors Management and Ranking for Reconstruction and Rehabilitation Projects Based on the Relative Importance Index (RII). *Sustainability*, *12*(15), 6171. https://doi.org/10.3390/su12156171

Khoa, V. D., & Chinda, T. (2023). Assessment of Construction Competitiveness through Knowledge Management Process Implementation. *Sustainability*, *15*(22), 15897. https://doi.org/10.3390/su152215897

Love, P. E. D., Matthews, J., Sing, M. C. P., Porter, S. R., & Fang, W. (2022). State of Science: Why Does Rework Occur in Construction? What Are Its Consequences? And What Can be Done to Mitigate Its Occurrence? *Engineering*, *18*, 246–258. https://doi.org/10.1016/j.eng.2022.05.010

Marle, F., & Vidal, L.-A. (2016). *Managing Complex, High Risk Projects*. Springer London. https://doi.org/10.1007/978-1-4471-6787-7

Mochamad Agung Wibowo, & Marah Ali Ammar. (2025). Lean construction and sustainability: A review of research trends and implications for the United Nations SDGs. *E3S Web of Conferences*, *605*, 03048. https://doi.org/10.1051/e3sconf/202560503048

Moon, D., & Krahel, J. P. (2020). Continuous Risk Monitoring and Assessment: New Component of Continuous Assurance. *Journal of Emerging Technologies in Accounting*, *17*(2), 173–200. https://doi.org/10.2308/JETA-18-01-09-1

Nurhidayat, A. E., Fitriana, R., Suhardini, D., & Nugrahanti, A. (2024). The causal loop diagram model of traceability system rental equipment in oil and gas supporting companies. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, *22*(5), 1104. https://doi.org/10.12928/telkomnika.v22i5.26084

O'Sullivan, S. L. (2010). International human resource management challenges in Canadian development INGOs. *European Management Journal*, *28*(6), 421–440. https://doi.org/10.1016/j.emj.2010.06.006

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121–139. https://doi.org/10.1016/j.compind.2016.09.006

Oktafiansyah, T., & Patriadi, A. (2025). Analysis of Project Delay Impacts on Time and Cost In Elevator Work For A 10-Story Office Building Construction Project. *Devotion: Journal of Research & Community Service*. https://doi.org/10.59188/devotion.v6i3.25437

Pinho, H. de. (2015). *Participant Guidelines. System Tools for Complex Health Systems: A Guide to Creating Causal Loop Diagrams [Internet]*. New York City: Mailman School. Columbia University.

Sabri, O. K., Dovland, M., & Daae, F. (2025). Understanding Owner–Contractor Conflicts in State Building and Infrastructure Projects: A Case Study of Norway. *Buildings*, *15*(7), 1135. https://doi.org/10.3390/buildings15071135

Samad, N., Mansor, M., Mohd Noor, M. A., & & Jumahat, T. (2023). Measuring the Content Validity of Middle Leadership Competence Model using Content Validity Ratio (CVR) Analysis. *International Journal of Business and Technology Management*. https://doi.org/10.55057/ijbtm.2023.5.4.12

Shahzad, A., Terziovski, M., & Sandhu, M. A. (2026). Benchmarking an integrative project management model to enhance the effectiveness of EPC projects through the adoption of digital technology. *... : An International Journal*. https://doi.org/10.1108/BIJ-12-2023-0912/1275430

Shrotryia, V. K., & Dhanda, U. (2019). Content Validity of Assessment Instrument for Employee Engagement. *Sage Open*, *9*(1). https://doi.org/10.1177/2158244018821751

Smith, C. L., & Brooks, D. J. (2013). Knowledge Management. In *Security Science* (pp. 177–198). Elsevier. https://doi.org/10.1016/B978-0-12-394436-8.00008-4

Soltanizadeh, S., Abdul Rasid, S. Z., Mottaghi Golshan, N., & Wan Ismail, W. K. (2016). Business strategy, enterprise risk management and organizational performance. *Management Research Review*, *39*(9), 1016–1033. https://doi.org/10.1108/MRR-05-2015-0107

Subiyanto, E. (2021). Investigating the logistics costs model: recent update in Indonesia. *Journal of Science and Technology Policy Management*. https://doi.org/10.1108/JSTPM-03-2020-0034

Sultana, S., Paul, N., Tasmin, M., Dutta, A. K., & Khan, S. A. (2024). Analyzing Supply Chain Risks and Resilience Strategies: A Systematic Literature Review. *1st International Conference on Industrial, Manufacturing, and Process Engineering (ICIMP-2024)*, 41. https://doi.org/10.3390/engproc2024076041

Too, E. G., & Weaver, P. (2014). The management of project management: A conceptual framework for project governance. *International Journal of Project Management*, *32*(8), 1382–1394. https://doi.org/10.1016/j.ijproman.2013.07.006

Torabi, S. A., Rezaei Soufi, H., & Sahebjamnia, N. (2014). A new framework for business impact analysis in business continuity management (with a case study). *Safety Science*, *68*, 309–323. https://doi.org/10.1016/j.ssci.2014.04.017

Wang, N., Xu, Z., & Liu, Z. (2023). Innovation in the construction sector: Bibliometric analysis and research agenda. *Journal of Engineering and Technology Management*, *68*, 101747. https://doi.org/10.1016/j.jengtecman.2023.101747

Xia, M., Zhao, L., & Zhao, L. (2022). A Comprehensive Risk-Assessment Method for Prefabricated Buildings Using EPC: A Case Study from China. *Sustainability*, *14*(3), 1910. https://doi.org/10.3390/su14031910

Yang, Y., Huang, Z., Chen, Y., Luo, L., & Li, F. (2026). Strategies for optimizing EPC project cost management via analytic hierarchy process: a case study approach. *Journal of Asian Architecture and Building Engineering*, *25*(4), 3439–3453. https://doi.org/10.1080/13467581.2025.2505793

Yuan, M., Li, Z., Li, X., & Luo, X. (2021). Managing stakeholder-associated risks and their interactions in the life cycle of prefabricated building projects: A social network analysis approach. *Journal of Cleaner Production*, *323*, 129102. https://doi.org/10.1016/j.jclepro.2021.129102

Zhang, Z., Duan, L., & Du, X. (2025). Risk Assessment of Prefabricated Building Projects Based on the G1-CRITIC Method and Cloud Model: A Case Study from China. In *Buildings*. https://doi.org/10.3390/buildings15152787