

Original Research Article

Integrated Risk Management: Banking and Chemical Safety

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ABSTRACT

This study conducted a comparative conceptual analysis of risk management approaches in banking and chemical processing industries, concentrating on credit risk management and process safety risk management, respectively. The research investigated underlying frameworks, including Basel II/III and IFRS 9 in banking, and HAZOP, LOPA, and Quantitative Risk Assessment (QRA) in chemical safety, revealing significant similarities in risk identification, assessment, mitigation, and monitoring. Parallels in quantitative tools were identified between credit risk indicators (Probability of Default, Loss Given Default, and Exposure at Default) and safety metrics (frequency, consequence analysis, risk matrices). The study examined artificial intelligence applications in predictive modeling for both credit defaults and process safety incidents, uncovering methodological overlap that enhances foresight and decision-making. Human and organisational influences on risk perception and control were investigated. Results produced a conceptual Integrated Risk Management Framework demonstrating the viability of applying unified risk principles across highly regulated but diverse industrial contexts. The framework integrates three pillars: predictive intelligence (leveraging advanced analytics, AI, and historical data), quantitative evaluation (systematic measurement of likelihood, severity, and exposure), and human systems management (addressing behavioural biases and fostering risk-aware cultures). This cross-sectoral approach enables knowledge transfer, establishes unified risk language, and promotes AI development synergies. The framework requires empirical validation through case studies and pilot implementations for practical application across financial and industrial sectors.

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Introduction

Numerous risks represent an intrinsic component of all complex systems, particularly in industries where uncertainty and high-impact events can precipitate systemic failure. Risk management has evolved into specialised disciplines within banking and chemical processing sectors, characterised by robust frameworks and regulatory standards [1]. While these sectors appear fundamentally different, one addressing financial solvency and the other physical safety, they share fundamental principles in risk conceptualisation, evaluation, and management. This paper studies the comparison of credit risk management in banking with process safety risk management in chemical plants, examining structural parallels, methodological intersections, and integration prospects. Credit risk, defined as the probability of borrower or counterparty failing to meet contractual obligations, critically influences financial institutions' stability [2]. Following major financial crises, global banking authorities established frameworks, including Basel II and Basel III, to identify, quantify, and mitigate credit risk [3]. These frameworks emphasise internal models computing Probability of Default (PD), Loss Given Default (LGD), and Exposure at Default (EAD), serving as foundations for capital adequacy assessments and credit provisioning [4,5]. The International Financial Reporting Standard (IFRS 9) mandates expected credit loss models, reinforcing predictive, forward-looking risk approaches [6]. The chemical sector primarily addresses process safety, managing risks of inadvertent hazardous material releases causing fatalities, environmental damage, and property destruction [7]. Hazard and Operability Studies (HAZOP), Layers of Protection Analysis (LOPA), and Quantitative Risk Assessment (QRA) represent widely employed techniques for systematically identifying and mitigating potential failure scenarios [8,9]. These methods rely significantly on quantitative evaluation, including frequency estimation, consequence modelling, and risk matrix scoring, to prioritise risks and justify safeguards. Despite different

contexts, both domains follow similar risk management lifecycles: identification, evaluation, mitigation, and monitoring [10,11]. Banks utilise credit scoring models based on historical financial behaviour, while chemical industries employ fault tree analysis or Bayesian networks to forecast failure scenario risks. Both increasingly leverage data analytics and artificial intelligence, improving forecast accuracy and operationalising real-time monitoring [12,13]. Table 1 presents a comprehensive comparison of regulatory and methodological frameworks employed in both sectors. Human and organisational factors significantly impact risk outcomes in both industries. Behavioural biases, misaligned incentives, and governance issues contribute to poor credit decisions in banking [14]. In process safety, inadequate safety culture, operator errors, and poor communication represent fundamental causes of major industrial accidents [15,16]. Understanding these socio-technical linkages proves essential for developing robust risk management systems. This study aims to develop a conceptual Integrated Risk Management Framework based on shared principles and transferable practices. By bridging financial and industrial risk management, the proposed framework potentially promotes cross-sectoral learning, enhances resilience, and supports holistic governance models.

Materials and Methods

Research design

This study employed comparative conceptual research methodology, analysing and synthesising existing methodologies from two distinct domains: credit risk management in banking and process safety risk management in the chemical industry. The methodology utilised desk research relying on secondary data sources, including academic papers, regulatory documents, industry standards, and technical manuals.

Conceptual framework development

A key methodological technique involved developing a conceptually integrated risk management framework. The study applied risk theory, systems thinking, and comparative analysis to map similar components across both domains. Credit risk and process safety risk models were compared using key risk dimensions: identification, assessment, mitigation, and monitoring. This structure enabled direct comparisons of methodological constructs, terminology, and risk processing cycles.

Literature selection and review process

A systematic search was conducted across major academic databases, including Web of Science, Scopus, and Google Scholar, using key terms related to credit risk management, process safety, Basel frameworks, HAZOP, LOPA, and integrated risk management. Articles published between 2000 and 2024 were prioritised, with foundational texts from earlier periods included where relevant. Selection criteria emphasised peer-reviewed publications, regulatory documents, and industry standards from recognised professional bodies.

Comparative matrix design

A comparative matrix was constructed to juxtapose essential risk management concepts from both domains. Elements included: (1) Risk Measurement Tools (PD, LGD, and EAD versus frequency, consequence, and risk matrices), (2) Predictive Techniques (statistical models, AI, and machine learning), (3) Regulatory Drivers (Basel II/III, and IFRS 9 versus OSHA and CCPS guidelines), and (4) Human and Organizational Risk Influences (safety culture versus compliance culture). Each component was examined for structural similarity, functional equivalence, and cross-sector transferability.

Theoretical foundations

Research was grounded in theoretical models, including the risk triplet model [10], the Swiss Cheese Model of human error [15], and

enterprise risk management concepts. These models established fundamental language and constructs for harmonising terminology across disciplines. Conceptual modelling approaches, including analogical reasoning, systems mapping, and inductive theorising, generated insights and constructed the proposed integrated framework.

Validation strategy

Given the conceptual nature of this study, validation was accomplished through triangulation of authoritative sources and cross-sector consistency assessments. The comparative matrix was evaluated against known risk management practices in both industries, and the proposed framework was assessed for logical coherence and practical applicability.

Results

Regulatory and methodological parallels

Comparative analysis revealed striking parallels between regulatory frameworks and methodologies employed in credit risk management and process safety management. Both Basel III and process safety standards emphasise risk quantification, capital allocation (or resource allocation), stress testing, and continuous monitoring [3,7]. These frameworks require organisations to maintain detailed records, conduct periodic assessments, and implement tiered controls based on risk severity. Cross-sectoral analysis demonstrates that despite domain-specific terminology, underlying risk governance principles exhibit substantial convergence [17,18].

Quantitative risk assessment alignment

A fundamental similarity exists in how both domains quantify risk. In banking, the three pillars of credit risk assessment- Probability of Default (PD), Loss Given Default (LGD), and Exposure at Default (EAD)- find functional equivalents in process safety's frequency analysis, consequence modeling, and exposure assessment. Table 1 illustrates these parallels,

demonstrating that risk assessment logic transcends domain boundaries.

Table 1: Comparative risk metrics between banking and chemical industry [4,5,13].

Risk dimension	Banking (credit risk)	Chemical industry (process safety)
Likelihood	Probability of default (PD)	Failure frequency (events/year)
severity	Loss given default (LGD)	Consequence magnitude (fatalities and damage)
exposure	Financial exposure to loss sources (credit, market, and operational); measured as potential loss magnitude in monetary terms and probability of default	Concentration and duration of contact between personnel/environment and chemical hazards; measured in dose-response relationships and exposure limits (ppm, mg/m ³)
Risk score	Expected loss (EL = PD × LGD × EAD)	Risk = frequency × consequence

This quantitative alignment suggests that risk assessment logic transcends domain boundaries. Both fields employ probabilistic thinking, consequence-based prioritisation, and risk matrices to guide decision-making. The mathematical structure of risk calculation remains conceptually identical, differing primarily in units and context rather than fundamental methodology.

AI and predictive modelling convergence

Both industries are experiencing convergence in their adoption of artificial intelligence and machine learning for predictive risk modelling. In credit risk management, neural networks and ensemble methods are being deployed to predict defaults with greater accuracy than traditional statistical models [12]. Similarly, in process safety, AI applications are being used for anomaly detection, predictive maintenance, and early warning systems. Machine learning algorithms analyse sensor data in real-time to identify deviations that may precede equipment failures or safety incidents [17]. The methodological overlap extends to feature engineering, where both domains extract indicators from historical data: credit bureaus and financial statements in banking; process parameters and maintenance records in chemical plants. Transfer learning and ensemble techniques show promise in both contexts, suggesting that advances in one field could accelerate progress in the other. Figure 1 illustrates the convergence of AI methodologies

between both sectors, demonstrating shared algorithmic approaches and data processing techniques.

Human and organisational factors

Table 2 summarises the parallels in human and organisational risk factors across both domains, demonstrating that the majority of failures in both industries result from behavioural and organisational dynamics rather than purely technical factors. Biases and over-reliance on prior credit ratings frequently cloud banking risk judgments, just as operators in chemical plants may bypass safeguards due to routine normalisation [15,16]. Organisational learning, feedback loops, and non-punitive event reporting are crucial for developing a proactive risk culture in both fields. Figure 2 illustrates the parallel human and organisational factors affecting risk outcomes across both sectors, highlighting the interconnected nature of cultural, procedural, and systemic influences.

Conceptual integrated risk management framework

Based on the comparative analysis, a conceptual Integrated Risk Management Framework was developed as presented in Figure 3. The framework aligns risk stages across both industries and incorporates three unifying pillars:

Leveraging advanced analytics, artificial intelligence, and historical data to forecast risk events before materialisation.

Predictive intelligence

Table 2: Human and organisational risk factors in banking and chemical industry [14-16]

Factor Category	Banking	Chemical Industry
Culture	Risk appetite and compliance culture	Safety culture and reporting climate
Decision Errors	Cognitive bias and overconfidence in scoring	Operator error and procedural violations
Oversight Failures	Weak internal controls, fraud risk	Inadequate supervision and audit fatigue
Learning from Failure	Post-default analysis and portfolio adjustments	Root cause analysis and corrective action plans

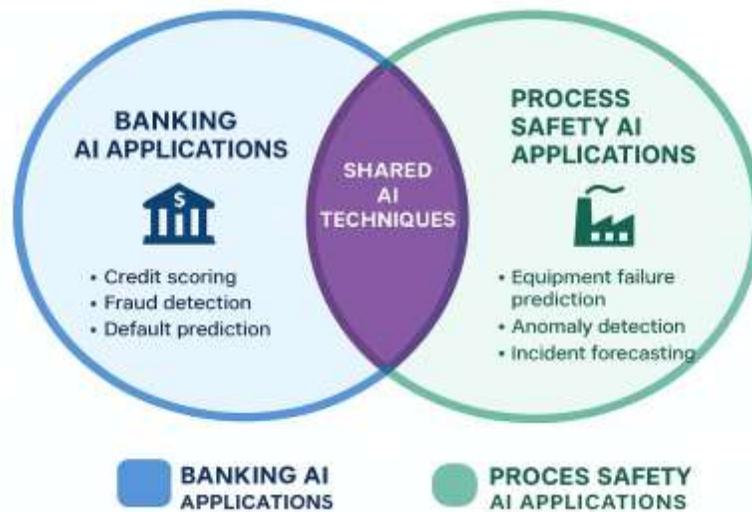


Figure 1: Convergence of artificial intelligence methodologies in cross-sectoral risk prediction (Source: Conceptual framework developed from Sirignano *et al.* [12] and Venkatasubramanian [17]).

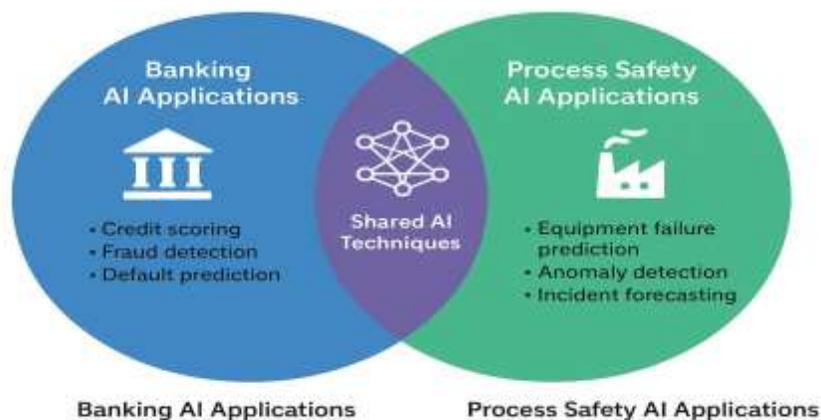


Figure 2: Human and organisational factors impact model: parallel influences on risk outcomes in banking and process safety (Source: Adapted from Reason [15], Le Coze [16], and Kashyap *et al.* [14]).

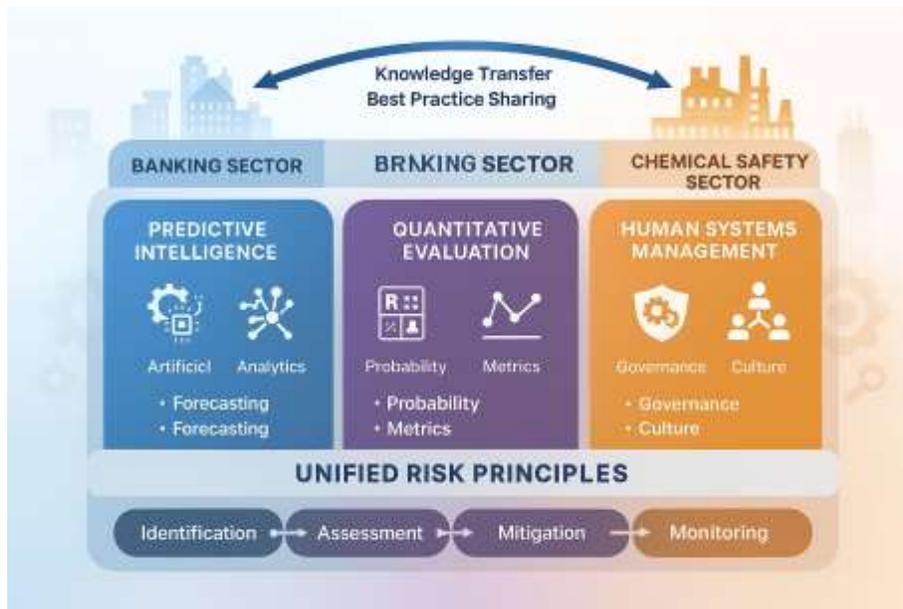


Figure 3: Conceptual integrated risk management framework: three-pillar model for cross-sectoral application (Source: Original framework developed from comparative analysis synthesising Kaplan and Garrick [10], Hopkin [1], and multiple sector-specific sources [3,18]).

Quantitative evaluation

Systematic measurement of likelihood, severity, and exposure using probabilistic models and risk matrices.

Human systems management

Addressing behavioural biases, fostering risk-aware cultures, and implementing robust governance structures.

This cross-sectoral architecture encourages a systems-based approach, enabling financial institutions and industrial operators to share tools, standards, and analytical methodologies. Rather than prescribing a one-size-fits-all methodology, it provides flexible integration of concepts based on shared risk logic. Recent research on sustainability and reliability in supply chain design demonstrates similar cross-functional integration potential [19].

Discussion

Key findings and theoretical contributions

This study conducted a conceptual comparative analysis of credit risk management in the banking industry and process safety risk management in chemical plants, revealing significant methodological and structural similarities between seemingly unrelated businesses. Both domains follow a similar risk lifecycle, including identification, evaluation, mitigation, and monitoring, contextualised by unique operational realities [10,11]. Quantitative methods in banking (PD, LGD, EAD) demonstrate functional equivalence to frequency and consequence modeling in chemical safety, indicating potential for shared risk analytics frameworks [4,13].

The proposed Integrated Risk Management Framework synthesises these concepts, demonstrating how predictive intelligence, quantitative rigour, and human systems thinking combine to form a unified risk governance architecture. This framework aims not to standardise sector-specific methods but rather to enable risk professionals from different industries to share a common vocabulary, utilise transferable tools, and develop systemic resilience. The growing use of artificial intelligence in both industries promotes this convergence by providing

advanced capabilities for early risk detection and decision-making support [12,17]. Similar convergence patterns have been observed in sustainable supply chain design, where reliability and sustainability criteria are increasingly integrated [19,20].

Practical implications

The findings suggest several practical applications for risk managers and policymakers. Cross-sector knowledge transfer enables organisations to learn from risk management innovations in adjacent sectors, accelerating the best practice adoption. Establishing a unified risk language facilitates communication between financial regulators and industrial safety authorities, particularly in critical infrastructure protection. Collaborative research on predictive models could yield algorithms applicable across multiple risk domains, reducing redundant development efforts. The emergence of integrated risk paradigms in supply chain management provides a relevant precedent for cross-sectoral framework development [21]. The framework's three pillars- predictive intelligence, quantitative evaluation, and human systems management- provide actionable guidance for organisations seeking to enhance risk management capabilities. Organisations can implement advanced analytics and AI for early risk detection, adopt systematic quantitative assessment methodologies, and address behavioural and cultural factors influencing risk outcomes. The emphasis on human and organisational factors proves particularly important, as both sectors demonstrate that technical risk management systems alone are insufficient without addressing underlying human factors and organisational culture [14-16]. Enterprise risk management literature increasingly recognises the importance of such holistic approaches [22,23].

Integration with emerging risk paradigms

The proposed framework aligns with emerging trends in enterprise risk management that emphasise interconnectedness and systemic perspectives [22]. Recent developments in

sustainable and reliable supply chain design demonstrate successful integration of multiple risk dimensions, including economic, environmental, and reliability factors [19-21]. These parallels suggest that the integrated approach proposed here reflects broader movements toward holistic risk governance across industrial sectors. The convergence of sustainability and reliability considerations in supply chain network design offers methodological insights applicable to the banking-chemical safety integration examined in this study [24].

Limitations and implementation challenges

While this analysis identifies meaningful conceptual alignments between banking and chemical safety risk management, several fundamental differences and implementation challenges warrant acknowledgement.

Fundamental sectoral differences

(1) Risk nature: Banking risks are primarily financial and probabilistic with potential for rapid contagion, while chemical risks involve physical harm with deterministic safety thresholds and localized impacts; (2) Regulatory frameworks: Banking operates under financial regulations (Basel Accords, Dodd-Frank Act, and MiFID II), while chemical safety follows occupational health and environmental protection standards (OSHA, EPA, and REACH), creating distinct compliance landscapes; (3) Measurement units: Financial metrics (monetary loss, Value-at-Risk, and Expected Shortfall) versus toxicological and engineering metrics (exposure limits, dose-response relationships, and failure frequencies) present fundamental incommensurability; (4) Temporal dynamics: Market risks materialize instantaneously through electronic trading systems, while chemical exposures may manifest delayed chronic health effects over years or decades.

Implementation barriers

(1) Organizational culture: Different risk appetites and safety cultures between financial

institutions prioritizing return optimization and industrial facilities emphasizing zero-harm principles; (2) Expertise gaps: There is limited cross-disciplinary knowledge among risk management professionals, with banking risk managers rarely trained in engineering safety principles and process safety engineers unfamiliar with financial risk methodologies; (3) Regulatory constraints: Sector-specific compliance requirements and reporting standards may complicate integrated approaches, potentially creating regulatory uncertainty; (4) Data compatibility: There are challenges in translating chemical safety metrics (parts per million, failure rates) to financial risk frameworks (basis points and default probabilities), requiring development of translation protocols.

Study limitations

(1) This conceptual analysis lacks empirical validation through case studies or pilot implementations in real organizational settings. (2) The comparative approach may oversimplify complex domain-specific practices that have evolved over decades within each sector. (3) There is limited examination of sector-specific edge cases where integration may prove infeasible or counterproductive. (4) The analysis focused primarily on operational risks, while strategic and systemic risks require separate detailed examination. (5) The study relied exclusively on secondary data sources without primary research involving practicing risk management professionals who could provide implementation insights.

Future empirical studies are essential to test integration feasibility, including controlled pilot implementations, comprehensive cost-benefit analyses, and systematic stakeholder feedback collection from both banking and chemical industry practitioners.

This conceptual study presents several limitations requiring future research attention. First, the framework requires empirical validation through case studies and pilot implementations in real-world settings. Second, comparative analysis focused on credit risk and process safety; expanding the framework to other risk domains (operational, cyber, and

environmental) would test generalizability. Third, computational modeling and simulation studies could quantify the benefits of integrated risk management approaches. Fourth, the study relied on secondary data sources; primary research involving risk management practitioners would provide additional insights into practical implementation challenges and opportunities.

Future research directions

Future research should build on this conceptual foundation with empirical validation, computational modeling, and industry-specific case studies. Opportunities exist for investigating the integration of environmental and reputational risks within unified frameworks. Longitudinal studies tracking organisations adopting cross-sectoral risk practices would provide valuable insights into implementation challenges and success factors. Additionally, research could explore sector-specific adaptations of the integrated framework, examining how different industries customise general principles to their unique contexts while maintaining fundamental alignment in risk management philosophy. The successful integration of sustainability and reliability in supply chain network design provides a methodological template for such cross-domain applications [24,25].

Conclusion

This study conducted a conceptual comparative analysis of credit risk management in banking and process safety risk management in chemical plants, revealing significant methodological and structural similarities between seemingly unrelated industries. Investigation of regulatory frameworks, quantitative risk measurements, predictive modelling methodologies, and human-organisational factors established foundations for cross-sector learning and integration. The proposed Integrated Risk Management Framework synthesises shared concepts, demonstrating how predictive intelligence, quantitative evaluation, and human systems management combine to form a unified risk governance architecture. This framework

challenges conventional wisdom that these domains require entirely distinct approaches, suggesting that unified risk principles can enhance resilience across diverse industrial contexts. As organisations face increasingly complex and interrelated risks, the ability to synthesise insights across domains becomes essential for survival and prosperity. The framework provides a conceptual bridge enabling knowledge transfer, establishing unified risk language, and promoting collaborative development of risk management tools and methodologies. While requiring empirical validation and practical adaptation, the integrated approach represents a significant step toward holistic risk governance in interconnected industrial ecosystems. This study demonstrates the importance of interdisciplinary risk thinking in an increasingly dynamic world, revealing that deep structural similarities between credit risk and process safety management challenge the need for entirely distinct approaches across sectors.

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Conflict of Interest

The authors declared that there are no conflicts of interest.

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