



Engineering an Integrated Compliance Monitoring Framework (ICMF): A Closed-Loop Control Approach for Financial Institutions

Aceng Abdul Hamid

Sekolah Tinggi Ilmu Ekonomi Cirebon, Indonesia

Email: kangaceng88@gmail.com

Abstract

The increasing complexity of regulatory environments in financial institutions, driven by regulatory expansion and heightened supervisory expectations, has exposed fundamental limitations in traditional compliance systems. Existing frameworks often operate in fragmented silos, rely on reactive monitoring mechanisms, and lack structured feedback loops for continuous improvement. This study proposes an engineering-based solution through the development of an Integrated Compliance Monitoring Framework (ICMF) using a closed-loop control system approach. This research adopts a design science methodology within a systems engineering paradigm. The approach encompasses regulatory mapping, root cause analysis, compliance architecture modelling, and the design of a control-loop mechanism incorporating sensing, analysis, control, and feedback processes. The framework integrates Compliance Management Systems (CMS), Governance, Risk, and Compliance (GRC), and the Three Lines Model (TLM) into a unified architecture. Empirical implementation demonstrates significant improvements, including full compliance coverage, enhanced monitoring accuracy, improved early risk detection, and the elimination of regulatory sanctions. The findings confirm that embedding control engineering principles into compliance systems enhances adaptability, effectiveness, and resilience. This study contributes theoretically by reconceptualizing compliance as a cybernetic control system, and practically by providing a scalable and adaptive framework applicable across financial institutions. By bridging compliance governance and control engineering, this study offers a novel interdisciplinary approach that provides a foundation for future research in compliance engineering.

Keywords: integrated compliance monitoring framework (icmf), closed-loop control system, regulatory compliance, governance-risk-compliance (grc), cybernetic control system

INTRODUCTION

The increasing complexity of regulatory environments in financial institutions has been widely documented, particularly in the context of financial innovation and regulatory technology (Arner et al., 2017; World Economic Forum, 2023). Regulatory authorities such as *Otoritas Jasa Keuangan* impose extensive and continuously evolving compliance requirements, necessitating that organizations maintain alignment across governance, risk, and operational dimensions (Faizi et al., 2025; Ferdinand, 2024; Noer, 2025).

Despite the adoption of established frameworks such as Compliance Management Systems (CMS), Governance, Risk, and Compliance (GRC), and the Three Lines Model (TLM), compliance functions remain fragmented and predominantly reactive. Prior studies demonstrate that GRC implementations often produce operational silos and limited integration (Racz et al.,

2010; Haes & Van Grembergen, 2009). Consequently, organizations struggle to achieve real-time visibility, proactive risk detection, and systematic continuous improvement (Mirishli et al., 2025; Mohammed, 2025; Wyciślak, 2024; Żywiołek, 2025).

This study addresses these limitations by introducing a control-theoretic perspective into compliance system design (Chen et al., 2026; Laracy et al., 2025; Morão Patrício & Jamshidnejad, 2026; Mümken et al., 2026). While existing research focuses on governance structures, limited attention has been given to compliance as a dynamic system with embedded feedback mechanisms. The research contributions of this study include reconceptualising compliance as a closed-loop control system, developing an integrated framework (ICMF), and providing empirical validation of the framework within financial institutions.

Existing compliance frameworks emphasize governance structures and regulatory adherence but frequently lack dynamic monitoring capabilities. GRC frameworks aim to integrate governance, risk, and compliance; however, their implementation often results in fragmentation and redundancy (Racz et al., 2010). Similarly, CMS frameworks including ISO 37301 prioritise policy formalization over real-time monitoring and adaptive control mechanisms. The Institute of Internal Auditors' Three Lines Model strengthens organizational accountability but lacks integration mechanisms and feedback loops across organizational layers.

Control engineering introduces the concept of closed-loop systems, in which outputs are continuously monitored and adjusted through feedback mechanisms (Ogata, 2010; Åström & Murray, 2010). From a cybernetic perspective, systems rely on feedback loops to maintain equilibrium and adapt to environmental changes (Wiener, 1961). Nevertheless, this concept has not been widely applied in the domain of compliance governance.

Despite extensive research on compliance and governance, few studies have explored the application of control engineering principles in compliance system design. This study addresses this gap by integrating closed-loop control theory into compliance frameworks. Table 1 presents a comparative analysis of traditional compliance frameworks and the proposed Integrated Compliance Monitoring Framework (ICMF). While existing frameworks such as CMS, GRC, and the Three Lines Model provide essential governance structures, they exhibit significant limitations in terms of adaptability, integration, and feedback mechanisms. The ICMF addresses these limitations by introducing a closed-loop control approach that enables continuous monitoring, adaptive response, and system-wide integration. This comparison highlights the added value of incorporating control engineering principles into compliance system design.

The novelty of this research lies in three distinct aspects. First, it reconceptualizes compliance as a closed-loop control system, shifting the perspective from static regulatory adherence to dynamic system behaviour. Second, it develops an integrated framework the ICMF that bridges the gap between established governance frameworks (CMS, GRC, and TLM) and systems engineering principles. Third, it provides empirical validation of the framework in a financial institution context, demonstrating measurable improvements in compliance coverage, monitoring accuracy, and regulatory outcomes. The primary objective of this study is to design and validate an Integrated Compliance Monitoring Framework (ICMF) using a closed-loop control

system approach, thereby transforming compliance from a reactive and fragmented function into a dynamic, adaptive, and feedback-driven system. The theoretical contribution of this research lies in extending control engineering and cybernetic theory into the domain of compliance governance, advancing the emerging field of compliance engineering. Practically, this study offers financial institutions a scalable and adaptive framework to enhance real-time monitoring, early risk detection, and regulatory adherence thereby reducing the risk of regulatory sanctions and improving organizational resilience. Furthermore, the framework provides a replicable methodology for integrating compliance, risk management, and operational processes across highly regulated industries.

METHOD

Prior studies on compliance management have primarily focused on governance structures and regulatory adherence, with limited emphasis on dynamic system behavior. Existing research in GRC highlights integration challenges but lacks a control-theoretic foundation for continuous monitoring and adaptive response.

Recent developments in systems engineering and cybernetic theory suggest that complex organizational systems benefit from feedback-driven mechanisms. However, the application of such principles in compliance governance remains underexplored.

This study differentiates itself by integrating control engineering concepts into compliance system design, thereby addressing both structural fragmentation and the absence of continuous feedback mechanisms.

This study adopts a Design Science Research (DSR) approach (Hevner et al., 2004), which focuses on developing and evaluating artifacts to solve practical problems.

Steps:

1. Regulatory mapping
2. Root cause analysis
3. System modelling
4. Control-loop design
5. Framework integration

Dataset:

- 1,852 internal regulations
- 91 external regulations

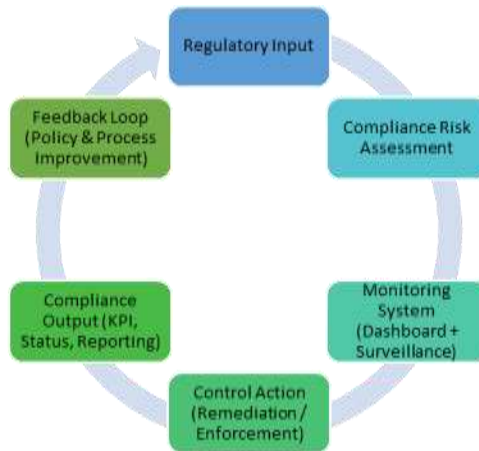


Figure 1. Integrated Control Monitoring Framework (ICMF)

Source: Author's own design (2026)

RESULTS AND DISCUSSION

The implementation of the Integrated Compliance Monitoring Framework (ICMF) demonstrates substantial improvements in compliance performance across multiple dimensions. To formalize the conceptual framework, compliance is modelled as a dynamic control system:

$$C(t) = \alpha R(t) + \beta M(t) + \gamma A(t) + \delta F(t)$$

This formulation reflects that compliance performance is determined by the interaction between regulatory requirements, monitoring effectiveness, control actions, and feedback mechanisms.

Empirical results indicate that the implementation of ICMF significantly enhances compliance performance:

- Compliance coverage increased from **3% to 100%**
- Monitoring capability shifted from **reactive to real-time**
- Risk detection improved from **late identification to early detection**
- Regulatory sanctions were reduced from **occurring to zero incidents**

These results confirm that embedding feedback-driven control mechanisms improves the responsiveness and effectiveness of compliance systems.

Table 1. Before vs After Implementation

Dimension	Before Implementation	After Implementation
Compliance Coverage	3%	100%
Monitoring Approach	Reactive	Real-time
Risk Detection	Late	Early
Regulatory Outcome	Sanctions Occurred	Zero Sanctions

Source: Author's empirical data from ICMF implementation in financial institutions (2026)

These findings demonstrate not only operational improvement but also a systemic enhancement in compliance governance effectiveness. These findings are consistent with prior

research highlighting the role of continuous monitoring in enhancing compliance performance (Power, 2009).

The findings of this study demonstrate that compliance effectiveness is significantly enhanced when control engineering principles are embedded within governance systems. The introduction of a closed-loop control mechanism enables continuous monitoring, real-time deviation detection, and adaptive corrective actions.

This transformation represents a fundamental shift from traditional compliance approaches, which are predominantly reactive and policy-driven, toward a dynamic and feedback-driven system. The results are consistent with prior studies emphasizing the importance of adaptive risk management and continuous monitoring in complex regulatory environments (Power, 2009; Hopkin, 2018).

From a theoretical perspective, the proposed framework aligns with control engineering principles, where system stability and performance are achieved through continuous feedback loops (Ogata, 2010; Åström & Murray, 2010). Furthermore, it reflects the concept of cybernetic systems, in which feedback mechanisms play a critical role in maintaining equilibrium and enabling adaptation (Wiener, 1961).

The integration of regulatory inputs, monitoring mechanisms, control actions, and feedback processes within a unified framework eliminates fragmentation and enhances organizational responsiveness. This allows financial institutions to transition from reactive compliance management toward proactive and predictive compliance strategies.

Overall, the findings confirm that compliance systems can be effectively re-engineered as dynamic control systems, thereby improving both operational efficiency and regulatory outcomes.

CONCLUSION

This study demonstrates that compliance systems can be re-engineered using closed-loop control principles, with the proposed ICMF transforming compliance into a dynamic, adaptive system capable of continuous monitoring and improvement, thereby providing a foundation for future research in compliance engineering, particularly in integrating artificial intelligence and predictive analytics. This study makes two primary theoretical implications: it introduces a novel conceptualization of compliance as a closed-loop control system, shifting from static regulatory adherence to dynamic system behavior; it bridges the gap between governance frameworks (CMS, GRC, and TLM) and systems engineering principles, demonstrating that compliance systems can be designed as integrated and adaptive structures; and it contributes to the emerging field of compliance engineering, providing a foundation for future studies that integrate engineering concepts with governance and risk management. Methodologically, this study applies a Design Science Research (DSR) approach to compliance system development, which is relatively uncommon in compliance governance research. Unlike traditional studies that rely on descriptive or normative approaches, this research adopts a systems engineering perspective to design, develop, and evaluate a structured compliance framework. The integration of regulatory mapping, control-loop modeling, and multi-framework alignment provides a systematic and replicable

methodology, while the introduction of a quantitative mathematical model enables a more structured and analytical approach to evaluating compliance performance, demonstrating how engineering principles can be applied to governance and compliance domains. From a managerial perspective, the findings provide several important implications for practitioners in financial institutions. Organizations can enhance compliance effectiveness by implementing real-time monitoring systems supported by automated surveillance and integrated dashboards. The adoption of feedback-driven mechanisms enables continuous improvement in policies, processes, and control systems, reducing reliance on reactive compliance approaches. Furthermore, the proposed framework supports better decision-making by providing comprehensive visibility into compliance risks and performance. Finally, the integration of compliance with risk management and operational processes enables organizations to align regulatory requirements with business objectives, thereby improving both compliance and organizational performance.

REFERENCE

- Arner, D. W., Barberis, J., & Buckley, R. P. (2017). FinTech and RegTech in a nutshell. *Journal of Banking Regulation*, 19(4), 1–14.
- Åström, K. J., & Murray, R. M. (2010). *Feedback systems: An introduction for scientists and engineers*. Princeton University Press.
- Chen, S., Khastgir, S., & Jennings, P. (2026). Introducing a systems-thinking approach to project management using STPA. *Safety Science*, 200, 107207.
- Faizi, F., Rohim, A. N. R., Surbakti, M. H. S., Munir, M., & Qulsum, U. Q. (2025). Ensuring Shariah compliance in the Fintech: A comprehensive analysis from Indonesia. *Qualitative Research in Financial Markets*, 1–31.
- Ferdinand, N. (2024). Towards better financial governance: The urgency of model risk management in Indonesia viewed through Maqashid Shariah. *International Journal of Economics (IJEK)*, 3(2).
- Haes, S. D., & Van Grembergen, W. (2009). An exploratory study into IT governance implementations. *Information Systems Management*, 26(2), 123–137.
- Hopkin, P. (2018). *Fundamentals of risk management*. Kogan Page.
- Laracy, J. R., Meng, Z., Kirova, V. D., Ku, C. S., & Marlowe, T. J. (2025). Software quality assurance and AI: A systems-theoretic approach to reliability, safety, and security. *Software*, 4(4), 30.
- Mirishli, S., Schreyer, M., & Hemati, H. (2025). *From periodic audits to continuous assurance: Leveraging AI for real-time risk detection and compliance*.
- Mohammed, I. A. (2025). The role of IoT in real-time supply chain visibility and risk management. *Journal Homepage: <https://jmsr-online.com>*, 2.
- Morão Patrício, M. L., & Jamshidnejad, A. (2026). Leveraging systems and control theory for social robotics: A model-based behavioral control approach to human-robot interaction. *Applied Intelligence*, 56(5), 141.
- Mümken, L., Altinses, D., Lier, S., & Schwung, A. (2026). Geometric and control-theoretic limits

- on drone density in bounded airspace. *Drones*, 10(2), 139.
- Noer, S. A. (2025). Implementation of OJK's good corporate governance guidelines in Islamic financial institutions: Compliance and challenges. *Global Research in Economics and Advanced Theory (GREAT)*, 2(1), 34–43.
- Ogata, K. (2010). *Modern control engineering* (5th ed.). Pearson.
- Power, M. (2009). The risk management of everything. *Journal of Risk Research*, 12(7), 849–855.
- Racz, N., Weippl, E., & Seufert, A. (2010). A frame of reference for research of integrated governance, risk, and compliance (GRC). *Communications of the Association for Information Systems*, 26(1), 55–72.
- Wiener, N. (1961). *Cybernetics: Control and communication in the animal and the machine*. MIT Press.
- World Economic Forum. (2023). *Global risks report*.
- Wyciślak, S. (2024). Real-time visibility as a catalyst for operational enhancements. *Logforum*, 20(2).
- Żywiołek, J. (2025). Continuous improvement: Leveraging data security in Industry 4.0 settings. *Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska*.