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Digital Transformation Risk Management in Subsidized LPG Distribution: An Integrated FMEA and ISO 31000 Approach at the Agent Level

Yulia Suryadi*, Arif Imam Suroso, Asep Taryana
Institut Pertanian Bogor, Indonesia

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**Correspondence Address:*
yuliasuryadi@apps.ipb.ac.ids

Abstract:
This study aims to examine the distribution process of 3 kg subsidized liquefied petroleum gas (LPG), identify operational failure modes, and formulate risk response strategies. This assessment is necessary because digitization through the Pertamina Merchant Application (MAP), while intended to improve targeting accuracy and accountability, does not eliminate subsidy misallocation or weaknesses in digital controls. A qualitative instrumental case study used interviews, observations, and document analysis; triangulation and member checking supported credibility. The analysis combined ISO 31000:2018 with Failure Mode and Effects Analysis (FMEA) to prioritize operational risks. The study mapped six distribution stages, used MAP mainly for depot-level consumer transactions, and identified 11 failure modes. Four risks received the highest priorities: diversion of LPG to unauthorized parties (RPN 432), consumers' failure to provide their National Identification Number (NIK) (378), retailers exceeding allocated quotas (294), and potential manipulation of MAP data (280). The findings indicate that digitization shifts risk exposure from logistics control toward data integrity, downstream actors' behavior, and transactions beyond system monitoring. Agents and stakeholders should strengthen data validation, physical and digital supervision, inter-actor coordination, and risk escalation procedures. Further research should validate these findings using MAP transaction data from more agents and regions.

INTRODUCTION

Three-kilogram subsidized liquefied petroleum gas (LPG) is an important public energy policy instrument intended to protect eligible households and micro-enterprises from the full cost of cooking fuel (Hambali et al., 2024; Daipon et al., 2025; Nasution et al., 2026). Its effectiveness therefore has implications beyond commercial distribution: inaccurate targeting can divert public resources, weaken equitable access, and reduce the fiscal value of subsidies. Digitalization through the Targeted LPG Subsidy mechanism and Merchant Apps Pangkalan (MAP) seeks to improve traceability by linking transactions to National Identification Numbers (NIK). By December 2025, the system had registered 73.7 million NIKs across households, micro-enterprises, and other eligible groups. This scale demonstrates the importance of reliable digital records and accountable

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distribution practices. Accordingly, evaluating how digital controls operate throughout the supply chain is important to protect beneficiaries and ensure that public expenditure achieves its intended social purpose (Ganesh et al., 2024; Baharmand et al., 2025; Hari et al., 2026).

Nevertheless, a digital registration system does not, by itself, guarantee accurate targeting or effective oversight. The State Audit Agency (BPK), in its 2025 IHPS I report, found that consumer eligibility criteria for 3 kg LPG had not been adequately established and that distribution supervision remained suboptimal. During 2024, 1,107,182,088 cylinders, equivalent to 3,321,546,264 kg, were distributed to consumers outside the DTKS, involving subsidies of approximately Rp33.84 trillion. BPK considered this condition insufficient to support the subsidy's objectives and recommended stronger coordination and recipient-database updates. These findings indicate that public accountability depends not only on recording transactions but also on the quality of eligibility rules, data governance, and enforcement. Therefore, examining operational controls is essential to assess whether digitalization translates into equitable distribution and responsible subsidy management overall (Saha et al. 2024; Ma et al., 2025; Wijaya et al., 2026).

The problem is that subsidized LPG distribution involves multiple actors whose responsibilities, information, and control capabilities are not necessarily aligned. Agents connect upstream suppliers with downstream distribution centers, implement regulatory requirements, and record transactions through MAP. As a result, they occupy a critical position where physical product flows, information, and accountability intersect. From a supply chain governance perspective, digitalization can reshape coordination mechanisms, monitoring practices, and relationships across multi-tier networks (Balogun et al., 2024; Shirkoohi & Mohiuddin, 2025; Wang et al., 2026; Macchion, 2026). A sociotechnical systems perspective further suggests that outcomes emerge from interactions among technology, people, procedures, organizations, and institutional conditions. Thus, failures may persist outside the application or arise through human–technology interactions. Assessing MAP solely through its recording functions would overlook these interdependencies and provide an incomplete account of distribution risk and control effectiveness.

Previous studies have examined related policy, technological, and operational dimensions, but their analytical emphases differ. Qudrat-Ullah (2024) and Gould et al. (2024) discuss LPG policy and fiscal risks, while Gintings and Suryanti (2024) examine the digitalization of LPG record-keeping. Muharam et al. (2025) address LPG policy and fiscal risks, highlighting broader governance concerns rather than agent-level operational failure. Dewantara et al. (2022) and Oliveira et al. (2025) investigate distribution risk management through ISO 31000, whereas Nasution et al. (2026) apply the same standard to risks associated with distribution facilities. These contributions provide relevant foundations at the policy-implementation interface. However, the available literature does not jointly explain how MAP-mediated transactions interact with physical distribution activities, agent practices, and control responsibilities in subsidized LPG distribution.

This limitation matters because digitized processes may alter rather than reduce exposure to failure. Risks can remain in physical handling, occur beyond the application's monitoring boundaries, or emerge from interactions between system design and user behavior. The literature therefore leaves an analytical gap concerning how failure modes are distributed across the agent-level process and how they should be prioritized within an integrated risk framework. Supply chain governance helps explain relationships and

accountability among actors (Balogun et al., 2024; Muharam et al., 2025), while the sociotechnical perspective highlights interactions among technical and organizational elements. ISO 31000:2018 provides a structured basis for risk assessment and treatment, and FMEA supports identifying and prioritizing failure modes. Combining these perspectives can connect process-level evidence with practical control decisions.

Table 1. Comparison of Previous Studies

Research	Focus and methods	Research limitations
Qudrat-Ullah (2024)	LPG policy and fiscal risks	Does not specifically examine operational risks at the agent level.
Muharam et al. (2025)	LPG policy and fiscal risks	Has not examined operational risks and control mechanisms at the agent level.
Gintings & Suryanti (2024)	Digitalization of LPG record-keeping	Has not integrated operational and behavioral risks arising from digital implementation.
Dewantara et al. (2022)	Distribution risk management using ISO 31000	Does not address subsidized LPG distribution in the context of digitalization.
Nasution et al. (2026)	Distribution facility risk assessment using ISO 31000	Does not specifically address agent-level subsidized LPG distribution and MAP-related risks.
This study	Integration of BPM, FMEA, and ISO 31000:2018 at the agent level	Single-case study; FMEA assessment relies on informant judgments and is subject to RPN limitations.

Source: Processed by the authors based on previous studies (2026).

The novelty of this study lies not in applying FMEA or ISO 31000:2018 separately, but in integrating Business Process Management (BPM), FMEA, and ISO 31000:2018 to examine how digitalization reshapes subsidized LPG distribution risks at the agent level. It distinguishes agent-controlled failures, risks beyond digital-system boundaries, and technology–behavior interactions in operational distribution practice. The study addresses three questions: how distribution processes are structured following MAP implementation; which failure modes arise and warrant priority attention; and what risk responses are appropriate. It argues that effective governance requires controls matched to each risk's location and ownership, combining digital validation with physical supervision and coordination among actors. Accordingly, the study aims to map business processes, identify and prioritize failure modes through FMEA, and formulate risk management strategies guided by ISO 31000:2018.

RESEARCH METHODS

This study uses a qualitative instrumental case study design (Bhangu et al., 2023; Lim, 2025; Tisdell et al., 2025) to understand the risk configuration in the distribution of 3-kg subsidized LPG after implementing the Pertamina Merchant Application (MAP). The case was selected at PT XYZ, an official 3-kg LPG agent in Bogor City that receives direct supplies from Pertamina's SPBE with a volume of more than 40,000 cylinders per month and serves more than 25 distribution points across six subdistricts. These characteristics make PT XYZ a relevant instrumental case because they allow observation of the interrelationships among the physical flow of LPG, digital record-keeping, the activities of downstream actors, and oversight mechanisms. The research was conducted from April to July 2026.

Table 2. Profiles of Key Informants and Reasons for Selection

Position	No.	Focus of Information	Selection Criteria
Director	1	Strategic policy, relations with Pertamina, risk management guidance	Highest-ranking official; strategic decision-maker
Operations Manager	1	Daily distribution flow, fleet, coordination between depots	Direct manager of daily distribution
MAP operator	1–2	Digital record-keeping, data entry issues, NIK data reconciliation	Access to transaction logs & reconciliation
Fleet driver	2	Field conditions, route obstacles, cylinder handoffs	Empirical knowledge of physical risks
Base Manager	3–5	Demand patterns, MAP/NIK recording, digital compliance	Final distribution points; most vulnerable
Pertamina Supervisor	1	Supervision standards, agent compliance, non-compliance findings	External regulator's perspective

Source: Research data (2026)

The researchers selected informants through purposive sampling (Ahmad & Wilkins, 2025; Bouncken & Schmitt, 2026) based on their direct involvement in and knowledge of the distribution process, MAP operations, and transaction monitoring. The study obtained primary data through in-depth, semi-structured interviews, limited participatory observation, and field notes. Secondary data were derived from internal documents, MAP transaction logs, Schedule Agreements, delivery notes, reconciliations, and relevant regulations. The study involved five informants, coded I1–I5 to protect their identities. Data collection followed the principle of saturation, meaning it was halted when additional interviews yielded no new themes, substantive information, or failure modes. Specify the number of interviews planned and completed based on the original research records so the saturation process can be reported transparently.

Interview, observation, and document data were transcribed, coded, and categorized by distribution stage, actors, control activities, operational disruptions, MAP usage, and potential failures. The findings were then mapped to the business process to identify failure modes at each stage.

Table 3. FMEA rating scale in the context of PT XYZ's LPG distribution

Value	Severity Level (S)	Frequency (O)	Detection (D)
1–2	Not significant	Very rare	Very easily detected
3–4	Minor impact; minor disruption	Rare; a few times a year	Easy to detect; effective control
5–6	Partially disrupts distribution	Fairly often; several times a month	Occasionally detected; additional testing required
7–8	Significant disruption; audit risk	Frequent; almost every week	Difficult to detect; weak control
9–10	Critical; large-scale misuse of subsidy funds	Very frequently; almost every day	Cannot be detected by current oversight mechanisms

Source: Adapted from Stamatis (2003)

Each failure mode is assessed using FMEA based on Severity (S), Occurrence (O), and Detection (D) on a 1–10 scale. The RPN is calculated as RPN = S × O × D. The S, O, and D ratings are determined by the researcher's synthesis of triangulated interview, observation, and document findings, then verified through member checking. Thus, the scores represent a qualitative, evidence-based assessment rather than scores derived

from a single informant. Severity indicates the impact of a failure, Occurrence indicates the frequency of occurrence, while Detection indicates the control system's ability to detect failures. Risks with an RPN ≥200 are categorized as high, 100–199 as moderate, and <100 as low. Failure modes with a Severity ≥8 also receive special attention. Response strategies are then formulated based on the ISO 31000:2018 framework.

Data reliability was ensured through source triangulation, method triangulation, and member checking (Ahmed, 2024; Dahal 2025). Source triangulation involved comparing information from informants with different roles, while method triangulation involved comparing interview, observation, and document results. The researcher used discrepancies between sources to prompt further investigation. Member checking involved presenting a summary of the findings to key informants to verify the research interpretations. Ethically, the study obtained permission from PT XYZ management. The company's identity has been disguised, and informants have been coded I1–I5 to maintain confidentiality.

RESULTS AND DISCUSSION

Results

The mapping results show that the distribution process for subsidized LPG at PT XYZ consists of six stages: scheduling and redeeming supplies, loading at the LPG filling station, delivery, handover at the distribution point, recording transactions via MAP, and reconciliation and reporting. Physically, LPG moves from the agent's SPBE to the distribution depot and then to the consumer. At the same time, digital control via MAP primarily occurs during transactions between the distribution depot and the consumer.

Table 4. Mapping of the Subsidized LPG Distribution Process and the Role of MAP

Stage	Main Activities	Control
1	Scheduling and Redemption of Supply	Schedule Agreement and verification of payment
2	Loading at the SPBE	Delivery Order and physical inspection
3	Delivery	Shipping documents and fleet monitoring
4	Handover	Matching of full and empty cylinders
5	Consumer Transactions	MAP, NIK, consumer category, and CAPTCHA
6	Reconciliation and reporting	MAP monitoring and periodic reconciliation

Source: Processed research data (2026)

In the early stages, controls relied more heavily on physical and administrative procedures. In contrast, in the fifth stage, controls shifted to digital record-keeping via MAP. This indicates that implementing MAP did not replace all previous control mechanisms; instead, it added a digital control layer to the downstream distribution chain. Agents then play a crucial role in monitoring record-keeping compliance and transaction accuracy at the distribution center level.

Based on process mapping and the results of interviews, observations, and document reviews, we identified 11 failure modes. The FMEA assessment used Severity, Occurrence, and Detection to calculate an RPN value. Risks with an RPN ≥200 were designated as high priority, while risks with a severity of 8 still received special monitoring even though their RPN values were lower.

Table 5. Risk Identification and Prioritization

Code	Failure Mode	RPN	Category
FM11	Transfer of LPG to refillers/unauthorized parties	432	High
FM5	Consumer did not present NIK	378	High

FM7	Retail sales exceeded the quota	294	High
FM9	MAP data manipulation loophole	280	High
FM6	Repeated NIK input errors	168	Medium
FM8	MAP disruption/maintenance	150	Medium
FM4	Tube Mismatch During Handover	120	Medium
FM3	Fleet delivery delays	105	Medium
FM10	Discrepancies between physical distribution and MAP	96	Low*
FM2	Damaged tubes passed inspection	75	Low
FM1	Delay in refueling at SPBE	48	Low

Source: Processed research data (2026)

**FM10 remains under special monitoring due to its severity level of 8.*

The four risks with the highest RPNs show a fairly clear pattern. FM11 has the highest RPN (432) because LPG transfers can occur after the product reaches the distribution depot, and subsequent transactions take place outside the scope of the MAP. FM5 has a high occurrence value because consumers are still found to be conducting transactions without presenting identification. Meanwhile, FM7 and FM9 indicate that risks also arise from compliance with quota regulations and data integrity within the digital system. The highest-scoring risks do not all stem from physical disruptions to distribution. Some are actually related to actor behavior, administrative compliance, and the integrity of digital information.

Risk Classification Based on Control Configuration

To further examine the implications of the identified failure modes, we classified the 11 risks into three categories based on their operational characteristics, position in the distribution process, and control configuration. This classification distinguishes conventional operational risks that agents can manage through physical procedures (C-1), conventional risks outside agents' primary control (K-2), and risks associated with the digital configuration and implementation of MAP (K-3). This distinction clarifies how each risk can be addressed through existing operational procedures, requires coordination with other stakeholders, or calls for improvements in digital system controls. Accordingly, the classification provides an analytical basis for understanding how risk exposure shifts following digitalization and for determining appropriate control responsibilities across the distribution chain. Table 6 presents the detailed classification of each failure mode.

Table 6. Risk Classification Based on Control Configuration

Category	Characteristics	Failure Mode
C-1	Conventional risks controlled through physical procedures	FM1, FM2, FM3, FM4, FM10
K-2	Conventional risks outside primary control	FM11
K-3	Risks related to post-MAP digital configuration	FM5, FM6, FM7, FM8, FM9

Source: Processed research data (2026)

Category K-1 primarily relates to activities that can be directly inspected, such as cylinder condition, delivery, and quantity accuracy. K-2 is represented by FM11, which refers to transfer risks after LPG has reached the downstream stage that the MAP does not fully cover. Meanwhile, K-3 relates to transaction processes, consumer identity, quotas, system disruptions, and data integrity. This classification does not imply that all K-3 risks are new due to digitalization. This category is used to highlight risks related to process configurations after MAP is implemented. The research findings reveal distinct characteristics among risks in the flow of goods, information, and finance. Risks in the

flow of goods tend to be verifiable through physical inspections, such as cylinder checks, quantity verification, and shipping documents.

In contrast, risks in the flow of information are harder to identify because they involve input accuracy, identity validity, and the potential for data manipulation. are RPN values reflect these findings. Physical risks, such as delays in refilling SPBE units and cylinder damage, have relatively low RPN values. In contrast, record-keeping and behavior risks in the downstream stage have higher RPN values. This pattern indicates that after MAP is implemented, control focuses not only on LPG movement but also on the quality of the information representing those transactions.

The four high-priority risks require differentiated responses based on their causes and control boundaries. FM11 and FM7 require mitigation and prevention, while FM5 and FM9 primarily require mitigation through improved verification and digital controls. Table 7 presents are corresponding response strategies.

Table 7. Risk Priority Assessment and Response Strategies

Risk	RPN	Response Strategy
FM11 – Transfer to Unauthorized Parties	432	Mitigation and Prevention
FM5 – Consumers Do Not Carry Their NIK	378	Mitigation
FM7 – Retail sales exceed the quota	294	Mitigation and Prevention
FM9 – MAP data manipulation loophole	280	Mitigation

Source: Processed research data (2026)

For FM11, the agency's internal oversight is insufficient because the risk lies in downstream activities outside the MAP system. FM5 requires strengthening compliance and consumer verification, while FM7 requires oversight of retail distribution and quota compliance. FM9 primarily requires strengthening the validation and oversight of MAP data integrity. Moderate-risk issues are addressed through operational mitigation, while low-risk issues are acceptable as long as oversight is maintained. FM10 is an exception because it still requires special monitoring even though the RPN is below the priority threshold.

Further analysis shows that the root causes of risk stem from four main groups, namely behavior, procedures/policies, systems/technology, and the environment. This pattern indicates that the distribution of risk cannot be explained solely by technological weaknesses. Some risks arise from interactions among rules, user behavior, system characteristics, and operational conditions. For physical risks, the agent’s scope of control is relatively clearer because it can be managed through inspections and operational procedures. Conversely, for digital risks and risks occurring after a transaction, the agent’s scope of control becomes more limited. This is particularly evident in FM11, which requires cross-stakeholder coordination because risky activities occur outside the system’s boundaries. Based on their nature and scope of control, risks can be managed at three levels. Operational risks include delivery delays, handover discrepancies, and system disruptions. Tactical risks include NIK compliance, input errors, retailer quotas, data manipulation, and distribution discrepancies.

Meanwhile, FM11 requires strategic escalation because it involves activities and actors beyond the agency’s direct control. This classification indicates that PT XYZ cannot resolve all risks through internal actions. Some risks require coordination with the base, system operators, or regulatory authorities, especially when the risk source lies beyond the agency’s jurisdiction.

Based on the three research objectives, the results show that, first, the distribution process for subsidized LPG at PT XYZ consists of six stages, with the MAP primarily used in transactions between distribution centers and consumers. Second, are study identifies 11 failure modes, including four high-priority risks: diversion of LPG to unauthorized parties, consumers not presenting their National Identification Number (NIK), retailers selling beyond their quota, and vulnerabilities to MAP data manipulation. Third, response strategies must match the nature of the risks and the scope of control, ranging from operational mitigation to cross-organizational escalation. The research results show that implementing MAP creates a control configuration that combines physical and digital mechanisms. Digital controls strengthen recording and monitoring of downstream transactions but do not automatically eliminate risks occurring outside the system's boundaries. These findings provide a basis for further discussion of how digital transformation is changing the location, nature, and mechanisms of risk control in the distribution of subsidized LPG.

Discussion

Digital Transformation Is Changing the Focus and Nature of Risks in LPG Distribution

The research findings show that implementing the Pertamina Merchant Application (MAP) has altered the risk control framework for distributing subsidized LPG. Before the transition to digital transactions, controls primarily relied on physical inspections, shipping documents, cylinder count verification, and reconciliation. After MAP was implemented for distributor-to-consumer transactions, controls were expanded to include consumer identity verification, transaction recording, recipient categories, and data integrity. These changes are reflected in the four risks with the highest RPN scores: the diversion of LPG to unauthorized parties (FM11; RPN 432), consumers failing to present their National Identification Number (NIK) (FM5; RPN 378), retailers selling beyond their quota (FM7; RPN 294), and vulnerabilities to MAP data manipulation (FM9; RPN 280). These findings indicate that digitization does not eliminate distribution risks but shifts the locus of risk from controlling the movement of goods to the interconnections between goods, information, and the behavior of downstream actors. These findings align with González et al. (2025) and Simbolon (2024), who, through a systematic review of 156 articles, demonstrated that digitization can simultaneously strengthen, simplify, and weaken governance mechanisms within supply chains. Digitalization enhances control capabilities among actors, but reduced human interaction can also diminish the social mechanisms that serve as safeguards against opportunism and coordination problems. In the case of PT XYZ, these findings take on a more specific empirical form. MAP strengthens record-keeping at transaction points covered by the system, but compliance still depends on consumers, depots, retailers, operators, and other actors outside the system. Thus, this study shows that digitalization's effectiveness cannot be assessed solely by the system's existence or its ability to record transactions. Still, it depends on how well its coverage aligns with the entire process it is meant to control.

The sociotechnical systems perspective further explains this pattern. Risks in LPG distribution do not lie solely in MAP technology or human error, but arise from the interaction between digital systems, users, procedures, distribution rules, and the operational environment. Rey et al. (2024) and Satrio et al. (2024) demonstrate that the sociotechnical perspective allows supply chain risks to be understood as the result of repeated interactions between social and technical elements, rather than as the

consequence of a single component in isolation. In this study, FM5 highlights the system's dependence on consumer behavior; FM7 demonstrates the relationship between quota rules and sales practices; while FM9 shows that the existence of digital mechanisms does not automatically guarantee data integrity. Thus, the empirical findings show that digitalization creates sociotechnical control configurations: the success of digital controls depends on how technology interacts with surrounding behaviors and rules. These findings also clarify the study's contribution to the context of subsidized energy distribution. Previous research has largely addressed digitalization in the context of improving transparency, traceability, or supply chain governance.

In contrast, this study shows that in subsidized LPG distribution, digitalization can shift points of vulnerability without changing the overall scope of control. Therefore, the change occurring is not merely a shift from a manual system to a digital one, but rather a change in the risk structure: directly observable physical risks remain. In contrast, information and behavioral risks become increasingly significant as transactions are represented through digital data.

MAP Limits, Failure Interactions, and Agent Accountability

Risk FM11 provides the most significant findings in explaining the limitations of digitization. With an RPN of 432, FM11 is the highest priority risk because LPG transfers can occur after the product reaches the distribution depot level, and subsequent transactions take place outside the scope of the MAP. This means that while the system can improve traceability at the point of recorded transactions, it does not automatically provide traceability regarding LPG usage after those transactions are completed. This situation highlights the limitations of digital systems, which do not fully align with the actual boundaries of the distribution chain. This finding can be interpreted through Perrow's Normal Accident Theory (NAT), which explains that risks in complex systems stem from interactions between components and high interdependencies. In complex systems, failures do not always stem from a single faulty component. Instead, they can arise from interactions among multiple parts, resulting in consequences that are difficult to predict or detect. Contemporary literature applying NAT to complex systems also emphasizes the importance of hidden interactions between components that can elude operators' detection capabilities. In LPG distribution, these components include physical supply, payment, inventory, distribution centers, retailers, consumers, and MAP record-keeping. When any of these activities occurs outside the system's boundaries, digital controls no longer function as a comprehensive oversight mechanism.

The findings of this study also reveal the limitations of applying NAT too simply. The issue at PT XYZ is not merely that the system is too complex or tightly coupled, but that technological boundaries do not align with process boundaries. MAP controls certain parts of the transaction chain, while activities beyond that point continue through social and economic relationships on the ground. Therefore, this study offers a revised perspective on risk in digital systems: complexity stems not only from the sheer number of components but also from process spaces that are not digitally connected yet remain operationally linked. Reason's Organizational Accident Theory perspective helps explain why these issues should not be understood solely as individual errors. FM5, for example, relates to consumers who do not carry their National Identification Numbers (NIK); FM7 relates to retail sales exceeding quotas; and FM9 relates to data manipulation loopholes. While all three do arise at the operational level, the root causes of these risks are also linked to procedures, policies, system design, and oversight mechanisms. The research

findings identify these four sources as groups of root causes: behavior, procedures/policies, systems/technology, and environment. Thus, failures at the front-line level must be analyzed alongside the latent conditions that enable them. These findings also highlight significant governance issues at the agent level. PT XYZ serves as the point of accountability in distribution but does not always possess authority commensurate with its responsibilities. Risks may arise at the distribution center or after LPG is transferred to another party, while administrative and reputational consequences may still fall back on the agent. In the context of a multi-tier supply chain, Bernardini et al. (2023), Khoiro et al. (2025), and Singh et al. (2024) show that digitalization transforms supply chain governance mechanisms and makes managing relationships among actors at various levels increasingly important. They also show that governance mechanisms relying solely on dyadic or contractual relationships have limitations when processes occur within a multi-tier network. This study found an imbalance between points of accountability and points of control. Agents serve as key monitoring points, but some risks lie beyond their capacity to intervene directly. These findings explain why mitigation strategies cannot be placed entirely on agents. Risks such as FM11 require cross-actor escalation and coordination mechanisms, whereas risks such as FM5, FM7, and FM9 still allow for intervention at both the operational and system levels.

Integrating FMEA and ISO 31000 for Risk-Based Control

The use of FMEA in this study shows that risk priority is determined not only by the frequency of occurrence, but by a combination of severity, frequency, and detectability. FM11 received the highest RPN, while several physical risks such as delays in refilling SPBE units and cylinder damage received lower RPNs. This difference indicates that existing physical controls can make risks easier to detect before they escalate into larger problems. In contrast, information and behavioral risks in downstream stages tend to be less detectable. The RPN values in this study cannot be treated as a measure of absolute probability. The Severity, Occurrence, and Detection scores were obtained by triangulating qualitative data and assessments in the context of the PT XYZ case. Therefore, the FMEA in this study is more appropriately positioned as a risk prioritization tool. At the same time, interviews, observations, and documents were used to explain the mechanisms and root causes behind these values. This distinction is important because the classical RPN has limitations, including the possibility that several score combinations may yield the same RPN value and the equal weighting of its three dimensions.

Integration with ISO 31000 provides different functions. While FMEA helps identify which risks need to be prioritized, the ISO 31000 approach helps guide how those risks are addressed in accordance with the organization's context and sphere of control. Research findings indicate that FM11 requires mitigation, prevention, and escalation because the risk source lies outside the agent's direct control. FM5 requires stronger compliance and verification; FM7 requires monitoring quota compliance; and FM9 requires stronger data integrity controls. Thus, the risk response does not stop at the RPN ranking but also considers the actor's ability to intervene. These findings show that risk level and scope of control are two dimensions that must be considered together. Risks with a high RPN but still within the agent's control scope can be addressed through operational mitigation and procedural enhancements. Conversely, risks that are also high but fall outside the system's boundaries or an agent's authority require cross-organizational governance mechanisms. This approach expands the application of FMEA

and ISO 31000 in the context of digitized LPG distribution, as priorities are determined not only by risk magnitude but also by the risk's location, the boundaries of the digital system, and the distribution of authority among actors.

From a supply chain governance perspective, these implications are significant because LPG distribution is not a process carried out by a single organization. Nisa et al. (2025) and Alam et al. (2026) demonstrate that the implementation of technology in multi-tier supply chains drives the need for more relational governance mechanisms that do not rely solely on contractual structures. PT XYZ's findings show that this need is even more critical when digital technology covers only part of the process. Digital systems can strengthen oversight at certain points, but their effectiveness still depends on coordination with actors outside the system. This study's main contribution is a conceptual model: digital transformation in subsidized distribution is a process of risk reconfiguration, not merely digitizing controls. This reconfiguration has three characteristics. First, risk shifts partially from physical activities toward information integrity and user behavior. Second, some risks remain outside the digital system, meaning that digitization is not synonymous with comprehensive control. Third, risk management effectiveness depends on aligning the level of risk with the scope of control of the responsible actors. These findings bring together the perspectives of FMEA, ISO 31000, sociotechnical systems, Normal Accident Theory, and supply chain governance within a single empirical context: the distribution of subsidized LPG at the agent level.

CONCLUSION

This study demonstrates that subsidized LPG distribution involves six operational stages, with the Pertamina Merchant Application (MAP) primarily supporting transactions between distribution centers and consumers. The FMEA identified 11 failure modes, four of which were classified as high-priority risks: diversion of LPG to unauthorized parties (RPN 432), consumers' failure to provide their National Identification Number (NIK) (378), retailers exceeding allocated sales quotas (294), and potential manipulation of MAP data (280). These findings show that digital transformation does not eliminate operational risks but reshapes their distribution, shifting risk exposure from physical logistics activities to data integrity, downstream actors' behavior, and transactions beyond the system's monitoring boundaries. Theoretically, this study extends the application of integrated FMEA and ISO 31000:2018 by demonstrating how digital and physical risk exposures can be assessed within a unified risk management framework. Practically, the findings underscore the need for stronger data validation, physical and digital monitoring, clearly defined control responsibilities, and improved coordination among stakeholders to address risks that extend beyond individual agents' authority. Future research should expand the empirical scope to include more agents and geographical areas and incorporate quantitative MAP transaction data to validate FMEA-based risk prioritization. Further methodological development using Fuzzy FMEA may also help address uncertainty in risk assessment and improve prioritization accuracy.

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CONFLICTS OF INTEREST

The author declares no financial, professional, or personal conflicts of interest that could have influenced the conduct of this research, the analysis and interpretation of its findings, or the preparation of this manuscript.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

During the preparation of this manuscript, the authors used AI-assisted tools to refine English usage, correct grammatical errors, and enhance academic clarity and readability. The authors critically reviewed and verified all AI-assisted revisions to ensure they accurately reflected the intended meaning and scholarly content. The authors retain full responsibility for the accuracy, originality, and integrity of the final manuscript.

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