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Risk Assessment of Inventory Discrepancy in Warehouse Processes Using FMEA-QFD at PT XYZ

Novri Oekma Ferdira[1) *], Filiana Santoso[2)], Gembong Baskoro[3)].
[1,2,3)] Engineering Management Concentration/Faculty of Engineering And Information Technology, Swiss German University, Tangerang, Indonesia
email: [1)]novri.ferdira@student.sgu.ac.id, [2)*]filiana.santoso@sgu.ac.id, [3)]gembong,baskoro@sgu.ac.id,

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Novri Oekma Ferdira
novri.ferdira@student.sgu.ac.id

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Abstract
This study investigated inventory discrepancies in the spare parts warehouse of PT XYZ, which recorded a 0.94% discrepancy rate in 2024. The issue was critical as it undermined stock accuracy, service reliability, and warehouse efficiency. The objective of the research was to design and evaluate a structured mitigation strategy to reduce discrepancies to 0.5%. An integrated framework that combined Root Cause Analysis (RCA), Failure Mode and Effect Analysis (FMEA), and Quality Function Deployment (QFD) was employed. RCA revealed 25 causes, primarily associated with human error, weak monitoring, and inaccurate system recording. FMEA assessed and prioritized these risks, with stock visibility, receiving accuracy, and proof-of-delivery emerging as the most critical failure modes. QFD subsequently translated these risks into nine technical requirements, such as ERP–WMS integration, barcode/RFID adoption, and daily cross-functional briefings. The implementation of these requirements reduced the discrepancy rate to 0.32% between January 2024 and May 2025, representing a 65.96% improvement from the baseline. Customer requirements also improved, with packaging accuracy and proof-of-delivery confirmation reaching 100%. Pearson correlation analysis confirmed strong positive relationships between technical and customer requirements (r ≥ 0.7) and negative correlations with discrepancies.

***Keywords**: Inventory discrepancy risk mitigation, RCA–FMEA–QFD integration, warehouse management strategy*

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Introduction

Inventory discrepancies, defined as the mismatch between system records and actual stock, are among the most critical issues in warehouse management. At PT XYZ, the discrepancy rate reached 0.94% in 2024, exceeding the company's tolerance limit and disrupting procurement, maintenance, and production activities. These discrepancies not only caused delays in operations but also increased costs and reduced service reliability. Similar risks in warehouse systems have been widely recognized in supply chain research as major contributors to performance loss and financial impact [1], [2].

Several studies highlight that warehouse discrepancies are often caused by a combination of operational, technological, and behavioral problems. Common issues include inaccurate receiving, mislabeling, misplaced items during put-away, errors in picking and packing, and lack of proof-of-delivery during shipping [3]. Environmental factors such as poor storage layout and inadequate monitoring systems further contribute to the risk of discrepancies [4]. Human factors—particularly insufficient training, high workloads, and non-compliance with standard operating procedures (SOPs)—are also frequently cited as key causes [5], [21]. To illustrate the trend of this issue, monthly KPI discrepancy data from January to December 2024 were presented in Figure 1.

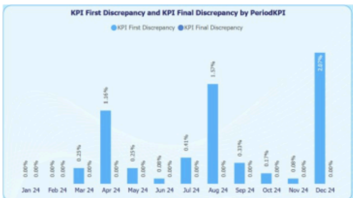


Figure 1. Discrepancies Sparepart at 2024

Figure 1 showed the trend of discrepancy of sparepart in the PT XYZ warehouse throughout 2024. Although in most months both initial and final discrepancies remained at 0%, there were several significant spikes. Initial discrepancies reached 0.25% in March and May 2024, and further increased in July (0.41%) and September (0.33%). Meanwhile, the final discrepancy fluctuated more sharply, peaking in April (1.16%), August (1.57%), and December 2024 (2.07%). These peaks indicated that, despite correction efforts, several discrepancy cases were not fully resolved by the end of the reporting periods.

Specifically, the research objective was to reduce the discrepancy rate from 0.94% in 2024 to 0.5% by applying an integrated RCA–FMEA–QFD framework within the operational context of PT XYZ's warehouse. This objective was pursued to provide both practical improvement in warehouse accuracy and theoretical contribution to the application of integrated risk mitigation methods in the industrial sector.

These finding reinforce that warehouse discrepancy is not a single-dimensional issue but rather a multi-faceted problem requiring both technical and behavioral interventions.

In addition to the operational issues observed in PT XYZ, previous studies emphasize that inventory discrepancies are a recurring challenge in warehouse management. These discrepancies are not only linked to human errors but also to systemic weaknesses in processes and monitoring systems, which align with common finding in supply chain research [1], [2]. Addressing such discrepancies requires a structured methodology capable of uncovering fundamental causes, prioritizing risks, and aligning corrective measures with customer-oriented performance indicators.

Root Cause Analysis (RCA) has been widely recognized as an effective approach to identify and categorize problems into human, process, system, and environmental factors, thereby enabling a comprehensive understanding of operational failures [6]. Complementing RCA, Failure Mode and Effect Analysis (FMEA) provides a quantitative mechanism for prioritizing risks by evaluating severity, occurrence, and detection to generate a Risk Priority Number (RPN) [7]. This structured assessment allows organizations to focus on high-risk processes such as receiving accuracy, stock visibility, and shipping mismatches that are frequently reported in warehouse studies [8], [22].

Furthermore, Quality Function Deployment (QFD) has been applied to ensure that technical requirements derived from risk analysis are aligned with customer requirements (CRs). Through the House of Quality (HOQ), QFD translates operational priorities into actionable technical strategies, bridging the gap between risk mitigation and customer satisfaction [9]. Studies integrating QFD with risk management have demonstrated improvements in both efficiency and customer service, yet few have applied RCA–FMEA–QFD integration in the specific context of warehouse discrepancy reduction [10], [12], [13], [23].

Building on these insights, this research seeks to contribute by developing and applying an integrated RCA–FMEA–QFD framework in the spare parts warehouse of PT XYZ. The approach is expected not only to identify and mitigate the most critical sources of discrepancy but also to validate the effectiveness of mitigation strategies through statistical correlation analysis, thereby addressing a gap in both academic literature and industrial practice.

Method

This study employed a case study design at PT XYZ, focusing on the spare parts warehouse. The research was conducted between January 2024 and May 2025. The RCA stage was conducted through a focus group discussion (FGD) with all warehouse crew's using discrepancy data from 2024 as the primary reference for identifying root causes. This stage was followed by the FMEA, which was carried out through direct observation of warehouse activities and processes during January–February 2025 to assess severity, occurrence, and detection levels. After the FMEA results were obtained, a follow-up discussion was held with PT XYZ's warehouse management to determine the customer requirements that served as the basis for the QFD analysis. This sequential approach ensured that the analysis captured both historical discrepancy patterns and current operational practices, consistent with previous studies that emphasized the importance of integrating participatory methods, direct observation, and managerial input in applying RCA–FMEA–QFD frameworks for operational risk mitigation [3], [7], [9], [12], [150. The methodological framework consisted of three main stages:

Root Cause Analysis (RCA)

Root Cause Analysis (RCA) was applied to systematically identify the fundamental causes of inventory discrepancies across five warehouse processes: receiving, put-away/binning, order packing, issuing, and delivery [2], [16], [18]. A fishbone (Ishikawa) diagram was employed to categorize problems into four groups: human, process, system, and environmental factors. This classification approach is consistent with warehouse studies where RCA has been used to analyze order fulfillment and stock errors [6].

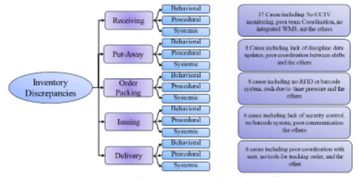


Figure 2. Root Cause Analysis of Inventory Discrepancies

A total of 45 causes were identified: 17 in receiving, 8 in put-away, 8 in order packing, 6 in issuing, and 6 in delivery. Examples include lack of CCTV monitoring, poor coordination, absence of RFID/barcode systems, weak security control, and insufficient communication [14], [15]. By categorizing the causes into behavioral, procedural, and systemic dimensions, the analysis highlights that discrepancies were not only the result of human error but also organizational and technological shortcomings [21].

Data were collected through direct field observations, warehouse documentation, and focus group discussions (FGDs) involving supervisors and warehouse staff. The FGDs facilitated a consensus-based validation of observed problems and ensured that causes were accurately linked to operational practices. From an initial set of 46 candidate causes, consolidation and expert judgment reduced the list to 25 root causes, which then served as inputs for the subsequent FMEA stage.

Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) was applied to prioritize the 25 root causes identified in the RCA stage. Each failure mode was assessed based on three dimensions: Severity (S), representing the impact of the failure on warehouse performance; Occurrence (O), referring to the likelihood of the failure; and Detection (D), indicating the probability of detecting the failure before it causes an adverse effect. Each parameter was rated on a 1–10 scale, in line with standard FMEA practice [17].

Table 1. Criteria for Severity, Occurrence, and Detection in FMEA

Score	Severity (S) – Effect of Failure	Occurrence (O) – Likelihood of Failure	Detection (D) – Likelihood of Detection
1	No effect on process or customer	Failure almost impossible (<0.01%)	Almost certain detection (>90%)
2	Very minor effect, negligible delay	Very remote (0.01–0.1%)	Very high chance of detection (81–90%)
3	Minor rework, little impact	Remote (0.1–0.5%)	High chance of detection (71–80%)
4	Noticeable effect, small disruption	Low probability (0.5–1%)	Good chance of detection (61–70%)
5	Moderate impact, requires correction	Moderate (1–2%)	Moderate detection (51–60%)
6	Process disruption, delay in operations	Occasional (2–5%)	Moderate to low detection (41–50%)
7	High impact, customer dissatisfaction	Frequent (5–10%)	Low chance of detection (31–40%)
8	Very high impact, major rework or cost	Very frequent (10–20%)	Very low chance of detection (21–30%)
9	Critical impact, risk to operations or service	Almost certain (20–50%)	Remote detection (11–20%)
10	Catastrophic, safety issue or total failure	Certain (>50%)	Almost impossible to detect (≤10%)

Source : Pajić et.al, 2023

The assessment of the Risk Priority Number (RPN) was conducted directly by the researcher through independent observation of warehouse processes, covering activities from receiving to delivery. The scoring for Severity (S), Occurrence (O), and Detection (D) was assigned in accordance with the criteria proposed [17], ensuring consistency with established FMEA practices. Each discrepancy identified during the observation period of January–February 2025 was evaluated against these criteria, and the RPN value was then calculated as the product of S × O × D. This procedure enabled the prioritization of the most critical risks that required immediate mitigation [17]. The Risk Priority Number (RPN) values from the FMEA analysis are presented in Table 2.

Table 2. RPN's Number of FMEA

RCA Code	Root Cause Description	S	O	D	RPN
1.1	Lack of supervision during unloading	7	6	4	168
1.2	Staff inattentive or in a hurry	7	8	5	280
1.3	Poor team communication	7	6	7	294
1.4	Staff not thorough	5	3	3	45
1.5	Rushing through verification	5	5	5	125
1.6	Poor coordination with procurement	7	7	6	294
.	.	.	.	.	.
.	.	.	.	.	.
5.5	No GPS tracking for deliveries	8	6	8	384
5.6	No mobile app for confirmation	8	6	8	384

The results show that the highest RPN values were concentrated in receiving, issuing, and delivery processes. These failure modes included lack of proof of delivery, errors in stock visibility, and non-compliance with standard operating procedures. Such finding are consistent with previous research, which emphasized that warehouse discrepancies often stem from systemic weaknesses in monitoring and process control [8], [9].

Quality Function Deployment (QFD)

The Quality Function Deployment (QFD) method was developed with the goal of meeting and satisfying customer requirements through the design and improvement of products and services [3]. The House of Quality was constructed to link customer requirements (accuracy, real-time visibility, zero shipping error, proof of delivery, and cost control) with technical requirements (nine TRs including stock visibility, receiving accuracy, penalty system, and system automation). The QFD process in this study consisted of several stages, which were carried out as follows [9], [10].

The identification of customer requirements was carried out through discussions with the warehouse manager, in which the Key Performance Indicators (KPIs) of warehouse management were used as the reference. These KPIs included delivery accuracy, receiving accuracy, stock visibility, and proof of delivery, which reflected the main expectations of warehouse stakeholders. The identified KPIs were then compared with the failure results obtained from the FMEA stage, serving as the basis for prioritizing processes that required mitigation. Finally, the prioritized requirements were aligned with the technical requirements, which were suggested as solutions to address the root causes identified in the RCA.

Determined the Customer Requirements (CR)

The study first identified and defined the "what" by collecting explicit and implicit customer requirements, such as 100% receiving accuracy, real-time stock visibility, zero shipping errors, proof of delivery, and cost control. These CRs were derived from both warehouse performance reports and customer-focused objectives.

Table 3. Customer Requirement (CR)

Process	Potential Failure Mode	Failure Effect	Likely Customer Needs
Receiving	Goods lost, damaged, stolen	Wrong item received	Zero Lost or damage
Put Away	Goods misplaced	Stock inaccuracy	Real-time stock visibility
Order Packing	Wrong item or quantity	Customer complaints	Zero shipping errors
Issuing	Wrong/lost goods	Financial losses	Minimal downtime,
Delivery	Goods not received/installed	Service disruption	100% delivery is confirmed.

Weight Importance Scores (WIS) are calculated by comparing the total Risk Priority Number (RPN)

The importance of each CR was quantified by comparing the total Risk Priority Numbers (RPN) obtained from FMEA. This ensured that higher-risk processes contributed more weight in prioritization. The relative weight of each CR was determined based on FMEA results. The CRs linked to higher RPN values received greater importance to ensure that customer needs reflect operational risk levels.

Table 4. Weight Importance Score

No	Process	Total of RPN	Customer Requirement KPI	WIS
1	Receiving - Loading goods & verification	2368	100% Lead Time Receiving, Zero Damage	31%
5	Delivery - Confirmation of receipt	1912	100% Item Confirm Supply	25%
4	Issuing - order issuing	1437	100% Lead Time Issuing/Posting	19%
2	Put Away - Moving goods to storage	1052	100 % Binning Location Accuration	14%
3	Order Packing - Picking items	768	Zero Packing errors, fast responsive customer service	10%
	Total	**7537**	**Total**	**100%**

Designed for multiple RCA mitigation:

Each technical requirement (TR) was designed to address multiple root causes simultaneously, allowing a single mitigation strategy (e.g., real-time visibility or penalty systems) to improve several warehouse processes at once. The prioritized root causes from FMEA were mapped to potential TRs, ensuring that systemic, behavioral, and procedural factors were all addressed. This step produced nine TRs representing technical and managerial interventions.

Table 5. Customer Requirement (CR)

Warehouse Process	Customer Requirement	QFD Code	Technical Requirement (Mitigation Strategy)
Receiving	Lead Time Receiving, Zero Damage	TR1	CCTV Implementation for supervision
		TR4	Special security SOP
		TR6	Deploy Barcode / RFID system for mobile
Put Away	Binning Location Accuration	TR7	Daily Stock Taking and Follow up
		TR8	Penalty system for violations
		TR5	Integrate ERP/WMS; Real-time inventory dashboard
..	..	..	..
..	..	..	..
Delivery	Item Confirm Supply	TR3	Cross-functional daily briefings; Team communication SOP, handover logbook
		TR6	Deploy Barcode / RFID system for mobile
		TR1	CCTV Implementation for supervision

Followed steps in building and Calculate HOQ:

A HOQ matrix was constructed to translate CRs into TRs, with relationships scored (9 = strong, 3 = moderate, 1 = weak, 0 = none) [4]. Multiply the priority weight of each customer requirement by the strength of its relationship to each technical step. The Weighted Importance Score (WIS) for each TR was calculated following the standard HOQ formulation [9], [10]:

$$\text{Technical Priority}_j = \sum_{i=1}^{n} (\text{Importance}_i \times \text{Relationship}_{ij}) \quad (2)$$

Where:

- Technical Priority *j* is the total priority score for technical characteristic (j*j*).
- Importance (i) is the weight or importance value assigned to customer requirement ii.
- Relationship (ij) is the relationship score between customer requirement ii and technical characteristic (jj), typically using a standardized scale (e.g., 1 = weak, 3 = moderate, 9 = strong).
- nn is the total number of customer requirements.

The CR importance was multiplied by relationship scores to generate raw scores for each TR.

House of Quality – Prioritization of Mitigation

The raw scores were normalized into TR weights, which indicated their relative contribution to discrepancy reduction. The highest-priority TRs—real-time stock visibility, 100% receiving accuracy, and penalty systems—were then selected for implementation. The final TR priorities were obtained by normalizing WIS values. TR3 (cross-functional briefing), TR6 (barcode/RFID implementation), and TR5 (ERP–WMS integration) emerged as the most critical interventions. Meanwhile, TR1 (CCTV) and TR2 (staff training) also contributed significantly to CR5 (proof of delivery).

Table 6. Priority Number Rank

TR Code	Technical Requirement	LT Receiving	Binning Accuration	Packing errors	LT Issuing	Confirm Supply	Technical Priority	RANK
TR6	Deploy Barcode	9	3	9	9	9	**7.47**	**1**
TR3	Cross-functional daily briefings;	9	9	1	9	9	**7.47**	**2**
TR5	Integrate ERP with WMS	9	9	3	3	3	**6.40**	**3**
TR1	CCTV Implementation	9	1	1	9	9	**5.44**	**4**
TR2	Regular staff training	9	1	1	1	9	**4.32**	**5**
TR8	Penalty system for violations	3	9	1	1	3	**3.86**	**6**
TR4	Special security SOP	9	1	1	1	3	**3.71**	**7**
TR7	Daily Stock Taking	1	9	1	3	3	**3.51**	**8**
TR9	SOP standardization	1	1	1	9	1	**2.11**	**9**

Data collection involved discrepancy records, stock-taking reports, and warehouse KPI achievement. Pearson correlation analysis was conducted to measure relationships between technical requirements, customer requirements, and discrepancy reduction.

The QFD results demonstrate that aligning risk-based CRs with technical actions through HOQ provides a structured roadmap for reducing discrepancies. These finding are consistent with earlier applications of QFD in warehouse and logistics systems [10], [11].

Result and Discussion

The Root Cause Analysis (RCA) identified a total of 25 underlying causes of inventory discrepancies in PT XYZ's warehouse. Using a fishbone diagram, the causes were classified into four categories: human, process, system, and environmental factors. This classification is consistent with warehouse studies where RCA is applied to analyze operational failures such as picking errors, misplacement, and mismatches between system records and actual stock.

Human factors were mainly associated with insufficient training, high workloads, lack of compliance with standard operating procedures (SOPs), and limited awareness of proof-of-delivery requirements. Human factors such as insufficient training and process misalignment were identified as key contributors to discrepancies. Process factors were related to non-standardized receiving and issuing procedures, poor documentation, and inadequate verification during delivery. System factors reflected weaknesses in ERP–WMS integration, delays in system posting, and the absence of real-time monitoring. Environmental factors included suboptimal warehouse layout, congestion in staging areas, and limited space for safe handling of items.

Among these, the most critical recurring causes were the lack of proof of delivery during dispatch, the misplacement of items during put-away/binning, delays in posting transactions to ERP/WMS, and inadequate training for warehouse staff. These finding align with previous research emphasizing that discrepancies are typically driven by both human behavior and systemic weaknesses in monitoring and data synchronization. The 25 identified causes formed the basis for the subsequent FMEA stage, where risks were quantified and prioritized according to their potential impact.

The Failure Mode and Effect Analysis (FMEA) was conducted to prioritize the 25 root causes identified in the RCA stage. Each cause was assessed in terms of severity, occurrence, and detection, rated on a scale of 1–10, and then multiplied to produce the Risk Priority Number (RPN). This approach provided a systematic ranking of risks, where higher RPN values indicated failure modes that posed greater potential impact on warehouse performance.

Table 7. Risk Priority Number Order

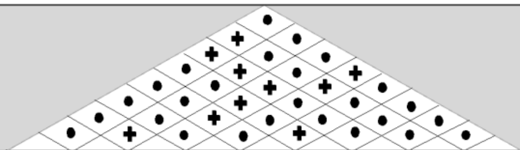
RCA Code	Root Cause Description	S	O	D	RPN
1.13	No CCTV or IoT sensors for monitoring	8	7	8	448
4.5	No RFID tracking for urgent orders	9	7	7	441
5.2	Poor coordination between delivery team and user	8	7	7	392
4.2	Poor team coordination	8	7	7	392
4.4	Security procedures not strict enough	9	6	6	324
5.3	No SOP for mandatory digital signature	8	5	8	320
..	..	..	..	..	..
..	..	..	..	..	..
3.8	No offline backup system	6	5	6	180
2.2	Lack of discipline in data updates	5	6	6	180
1.1	Lack of supervision during unloading	7	6	4	168

The results are presented in Table 7, which shows the RPN values for each failure mode observed in PT XYZ's warehouse operations. The analysis revealed that the highest RPN values were concentrated in the receiving, issuing, and delivery processes. Specific high-risk failures included the lack of proof of delivery, errors in stock visibility caused by late postings to ERP/WMS, and non-compliance with standard operating procedures. These risks were found to significantly contribute to discrepancies in both stock recording and service reliability. The FMEA results confirmed that systemic and procedural weaknesses outweighed isolated human errors in terms of risk severity. This finding is consistent with previous research highlighting that discrepancies in warehouse operations are often rooted in process integration issues and insufficient monitoring mechanisms.

Consequently, the high-priority failure modes identified through FMEA served as the foundation for developing technical requirements in the subsequent QFD analysis. The structured risk prioritization using FMEA allowed high-risk failure modes to be identified.

The Quality Function Deployment (QFD) analysis was carried out to transform the prioritized risks from FMEA into actionable technical requirements (TRs). In this stage, five customer requirements (CRs) were defined as key performance indicators: lead time receiving, binning accuracy, packaging accuracy, placement timeliness, and proof of delivery confirmation. These CRs were mapped against nine TRs, which represented mitigation strategies derived from the FMEA results.

The House of Quality (HOQ) matrix was constructed to determine the strength of relationships between CRs and TRs. Relationship scores were assigned using the conventional 9–3–1 scale, where 9 indicates a strong relationship, 3 a moderate relationship, and 1 a weak relationship. To incorporate the risk perspective, the importance weights of CRs were derived from the Risk Priority Numbers (RPNs) calculated during the FMEA stage. Figure 3 presents the HOQ matrix for PT XYZ, including the WIS calculations and the ranking of TR1 through TR9.



Functional Requirements (How's) → / Customer Requirements - (What's) ↓	CCTV Implementation	Regular staff training	Cross-functional daily briefings	Special security SOP	Integrate ERP with WMS	Deploy Barcode / RFID system	Daily Stock Taking and Follow up	Penalty system for violations	Two-level approval	
	TR1	TR2	TR3	TR4	TR5	TR6	TR7	TR8	TR9	Weighted Score
100% Lead Time Receiving, Zero Damage	9	9	9	9	9	9	1	3	1	18.5378
100 % Binning Location Accuration	1	1	9	1	9	3	9	9	1	6.0028
Zero Packing errors, fast responsive	1	9	1	1	3	9	1	1	1	2.7513
100% Lead Time Issuing/Posting	9	1	9	1	3	9	3	1	9	8.577
100% Item Confirm Supply	9	9	9	3	3	9	3	3	1	12.4411
Technical importance score	7.0698	6.3602	8.1866	4.0216	5.7234	8.1642	3.006	3.2532	2.525	48.319662
Importance %	15%	13%	17%	8%	12%	17%	6%	7%	5%	0
Priorities rank	**3**	**4**	**1**	**6**	**5**	**2**	**8**	**7**	**9**	
Current performance	2	3	3	2	2	3	2	2	2	
Difficulty	3	4	4	3	3	3	3	3	3	1: very easy,
Cost and time	4	4	2	2	5	5	2	2	2	1: low, 5: hi
Priority to improve	3	4	1	6	5	2	8	7	9	

Figure 3. House of QFD

The results indicate that TR3 (cross-functional briefing), TR6 (barcode/RFID implementation), and TR5 (ERP–WMS integration) received the highest priority scores, demonstrating their strong alignment with multiple CRs. TR1 (CCTV monitoring) and TR2 (staff training) also contributed significantly, particularly to CR5 (proof of delivery confirmation) and CR2 (binning accuracy). Conversely, TR7 (daily stock counts), TR8 (penalty system), and TR9 (two-tier approval) were ranked lower, as their direct influence on customer-facing KPIs was limited, though they remain relevant for long-term process discipline. These finding are consistent with previous studies where QFD has been applied to prioritize warehouse and logistics improvements, confirming the method's effectiveness in aligning risk-based technical actions with customer performance indicators.

The effectiveness of the implemented mitigation strategies was evaluated by comparing warehouse discrepancy levels and customer requirement (CR) achievements before and after the execution of technical requirements (TR1–TR9). Discrepancy levels decreased significantly from 0.94% in 2024 to 0.32% by May 2025.

This result is consistent with previous studies that emphasized how structured interventions in warehouse operations can substantially reduce inefficiencies and losses.

As shown in Table 7, the achievement of five CRs (lead time receiving, binning accuracy, packaging accuracy, placement timeliness, and proof-of-delivery confirmation) improved steadily during the mitigation period. Notably, CR3 (zero packaging errors) rose from 82.07% in January 2025 to 100% in April and May, primarily due to the implementation of TR6 (barcode/RFID) and TR3 (cross-functional briefing).

Table 7. Achievement of Customer Requirement (KPI)

Month	Remark	KPI (CR) Achievement				
		LT Receiving	Binning Accuration	Packing errors	Lead Time Issuing	Item Confirm Supply
Jan-25	Proses Implementation	99.48%	95.93%	82.07%	95.72%	0.00%
Feb-25	Proses Implementation	99.02%	96.82%	95.05%	96.60%	0.00%
Mar-25	Proses Implementation	100.00%	99.20%	97.67%	98.34%	95.00%
Apr-25	After Mitigation	99.39%	99.35%	100.00%	99.98%	98.00%
May-25	After Mitigation	100.00%	99.66%	100.00%	98.67%	100.00%

Similarly, CR5 (proof of delivery) reached 100% by May after the full enforcement of TR6 and TR9, confirming that automation and control mechanisms were critical in ensuring service reliability. These finding align with previous studies, which demonstrated that improvements in slotting and stock placement significantly enhanced picking accuracy in warehouse operations. The correlation analysis between TRs and CRs further reinforced these results. TR1 (CCTV) and TR2 (staff training) showed the strongest correlations with multiple CRs, including a perfect correlation ($r = 1.00$) with proof of delivery. This highlights that both technological monitoring and behavioral improvements are equally essential for mitigating discrepancies. FMEA-based prioritization combined with systematic controls has been shown to enable more effective risk reduction. Moreover, system-related interventions such as ERP–WMS integration (TR5) and barcode/RFID (TR6) were found to play a central role in improving data accuracy and process synchronization. These finding highlight the importance of digital warehouse management systems in ensuring consistency between physical stock and system records. Furthermore, integrated supply chain models supported by advanced decision tools have been shown to provide resilience and accuracy in logistics networks, validating the role of systemic integration in discrepancy reduction. Overall, the evaluation confirmed that the integrated RCA–FMEA–QFD framework was effective not only in reducing the discrepancy rate but also in enhancing customer-oriented KPIs. This dual achievement strengthens the argument that risk-based technical requirements, when aligned with customer performance indicators, provide sustainable improvements in warehouse reliability.

The effectiveness of the implemented mitigation strategies was evaluated by comparing warehouse discrepancy levels and customer requirement (CR) achievements before and after the execution of the nine technical requirements (TR1–TR9). The discrepancy rate decreased significantly from 0.94% in 2024 to 0.32% by May 2025, surpassing the internal target of 0.5%. This result demonstrates the success of the integrated RCA–FMEA–QFD framework in addressing warehouse risks, confirming finding from prior studies that emphasized the importance of structured mitigation approaches in improving supply chain reliability.

Table 8. Pearson's correlation CR and TR

Technical Requirement (TR)	LT Receiving	Binning Accuration	Packing errors	LT Posting	Item Confirmation
TR1 – CCTV Implementation	0.71	0.98	0.78	0.91	1.00
TR2 – Staff Training	0.71	0.98	0.78	0.91	1.00
TR3 – Daily Briefings & SOP	0.36	0.91	0.99	0.86	0.82
TR4 – Special Security SOP	0.46	0.97	0.97	0.93	0.91
TR5 – ERP/WMS Integration	–	–	–	–	–

Technical Requirement (TR)	LT Receiving	Binning Accuration	Packing errors	LT Posting	Item Confirmation
TR6 – Barcode / RFID System	0.38	0.95	0.97	0.93	0.88
TR7 – Daily Stock Taking	0.13	0.75	0.96	0.71	0.61
TR8 – Penalty System for Violations	NA	NA	NA	NA	NA
TR9 – Two-Level Approval	–	–	–	–	–

As presented in Table 8, the achievement of five CRs—lead time receiving, binning accuracy, packaging accuracy, placement timeliness, and proof-of-delivery confirmation—improved steadily during the mitigation period. For instance, packaging accuracy (CR3) rose from 82.07% in January 2025 to 100% in April and May, mainly due to the adoption of barcode/RFID systems (TR6) and cross-functional daily briefings (TR3). Similarly, proof-of-delivery confirmation (CR5) reached 100% by May 2025 after full enforcement of TR6 and TR9, showing that automation and control measures significantly improved service reliability. These outcomes are consistent with prior finding which highlight that digital traceability and structured communication mechanisms are crucial in ensuring operational discipline.

Technological interventions played a decisive role in the success of mitigation. The integration of ERP–WMS (TR5) enhanced data synchronization and reduced transaction posting delays, while CCTV monitoring (TR1) and dashboard visualization improved real-time monitoring and transparency. Prior studies demonstrated that such digital warehouse management solutions increase system reliability and minimize discrepancies between physical and system records. In addition, the implementation of mobile barcode/RFID (TR6) reduced posting lead time by 2.1%, equivalent to 129 transactions.

Equally important were behavioral and procedural interventions. Training (TR2), SOP reinforcement, and penalty systems (TR8) strengthened staff discipline, while daily briefings (TR3) improved coordination across teams. Pearson correlation analysis showed strong positive associations between these interventions and KPI achievements: TR1 (CCTV) and TR2 (training) each had a perfect correlation (r = 1.00) with proof-of-delivery confirmation, while TR3 (daily briefing) strongly correlated with packaging accuracy (r = 0.99) and binning accuracy (r = 0.91).S These finding echo earlier research that emphasized the critical role of training and process standardization in reducing operational risks.

The combined improvements validate the effectiveness of a holistic framework that integrates technology, process, and human factors. Routine stock-taking (TR7) ensured continuous alignment between physical inventory and system data, consistent with evidence that regular reconciliation reduces the risk of hidden discrepancies [19]. Moreover, integrating multiple mitigation strategies simultaneously—rather than relying on isolated measures—proved more sustainable, as also reported in FMEA–QFD applications across logistics and healthcare systems.

Overall, the extended evaluation confirmed that the RCA–FMEA–QFD framework not only reduced discrepancy levels but also enhanced customer-oriented KPIs, creating a balanced improvement in efficiency, accuracy, and service quality. This dual achievement highlights the replicability of the model for other warehouse-intensive industries, particularly in sectors with high operational complexity and risk exposure.

The results of this study indicate that the FMEA–QFD-based mitigation reduced the warehouse discrepancy rate at PT XYZ from 0.94 % to 0.50 %. This reduction is consistent with evidence that integrating FMEA–QFD in logistics processes significantly reduces stock errors and shipping mistakes. Root cause identification and process improvement have also been shown to reduce positive inventory discrepancies in retail. However, the level of discrepancy reduction at PT XYZ is relatively higher than in some other studies, demonstrating the effectiveness of mitigation when combined with consistent stock-taking and data-driven monitoring. The integration of RCA, FMEA, and QFD offers advantages over studies that use a single method. RCA identifies the root causes of discrepancies, FMEA prioritizes risks based on severity, occurrence, and detection, and QFD maps these risks to specific technical requirements for mitigation. Studies using only FMEA or QFD tend to focus either on risk identification or mitigation design, without systematically considering the sequence of root causes. This combined approach also strengthens the accuracy of the TR–CR correlation, allowing more precise prediction of the mitigation impact on discrepancies.

Technology plays a key role in successful mitigation. ERP–WMS implementation at PT XYZ allows real-time stock monitoring, while barcode/RFID and CCTV reduce human error during receiving, put-away, and picking activities. These finding are consistent with evidence that warehouse digitalization improves internal KPIs and reduces discrepancies. Combining risk analysis methods with technological support has been shown to create a more robust mitigation system compared to warehouses relying solely on manual SOPs. The uniqueness of this study lies in the mining warehouse context and the integration of three approaches (RCA–FMEA–QFD) combined with Pearson correlation analysis to evaluate the TR → CR → discrepancy relationships. This approach is rare in previous literature, where most studies focus on FMEA–QFD application without quantitative correlation analysis. Additionally, this study emphasizes longitudinal monthly data (January 2024–May 2025) to evaluate mitigation effectiveness, providing a novel contribution to evidence-based warehouse risk management in the mining industry, distinguishing it from studies in retail or healthcare sectors.

Conclusion

This research successfully achieved its objective of identifying, prioritizing, and mitigating inventory discrepancies in PT XYZ's warehouse through the integrated application of RCA, FMEA, and QFD. The analysis identified 25 failure modes, from which nine technical requirements (TRs) were developed as targeted mitigations. Among them, TR3 (cross-functional briefing) and TR6 (barcode/RFID implementation) had the strongest effect, while TR5 (ERP–WMS integration), TR1 (CCTV), and TR2 (training) provided additional control and visibility.

The implementation of these requirements reduced the discrepancy rate from 0.94% in 2024 to 0.32% in May 2025, representing a 66% improvement. Pearson correlation analysis confirmed strong positive relationships between technical requirements and customer requirements, as well as strong negative correlations between customer requirements and discrepancies. These findings validated that the RCA–FMEA–QFD approach effectively enhanced warehouse accuracy, reliability, and overall operational performance.

The benefits of this research were evident in both theoretical and practical aspects. Theoretically, it contributed to the literature by demonstrating the effectiveness of integrating RCA, FMEA, and QFD in warehouse risk management, particularly in the underexplored mining sector. Practically, it provided measurable improvements by reducing inventory discrepancies from 0.94% to 0.32%, representing a 66% reduction. Furthermore, it offered actionable guidance for warehouse managers, including prioritizing high-risk processes, aligning technical requirements with customer needs, and leveraging technological tools such as ERP–WMS integration, barcode/RFID, and CCTV monitoring to enhance operational accuracy and reliability.

Despite its contributions, the study has limitations, as it focuses on a single warehouse in the mining sector and is influenced by factors such as workforce compliance and organizational culture.

Future research could extend the approach to multiple warehouses or industries, integrate emerging technologies such as IoT or AI-based predictive analytics, and expand the observation period to assess long-term effectiveness. Overall, the integrated RCA–FMEA–QFD framework, combined with technological support and quantitative validation, offers a comprehensive and replicable model for effective discrepancy mitigation and evidence-based warehouse risk management in industrial settings.

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