

Transport Defect Reduction in Ceramic Stove Distribution using Integrated 7QC Tools and Modified FMEA

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Abstract

This study aims to develop and validate an integrated transport-phase quality management framework for reducing transportation defects in fragile ceramic products produced by community enterprises. A case study was conducted at the Ban Chat Community Enterprise Group in Roi Et Province, Thailand. Baseline data collected between April and August 2025 showed an average transport defect rate of 10.35%, exceeding the enterprise acceptance threshold of 5%. Pareto analysis identified Pot Rest Fracture (39.16%) and Base Fracture (30.62%) as the dominant defect categories. Root causes were systematically identified using the 4M1E Fishbone Diagram and verified through Why-Why Analysis, while a Modified Risk Priority Number (MRPN) model incorporating a Controllability factor was applied to prioritize corrective actions according to both risk severity and implementation feasibility. The analysis identified inadequate EVA foam cushioning and the absence of standardized operator training and loading procedures as the two highest-priority root causes. Corrective actions consisted of replacing EVA foam with expanded polyethylene (EPE) cushioning and implementing a 90-minute standardized training programme covering safe handling, stove arrangement, foam placement, and standard operating procedures. Post-intervention monitoring from October 2025 to March 2026 reduced the average defect rate to 3.80%, representing a 63.24% reduction from baseline, while maintaining defect levels below the 5% acceptance threshold throughout the evaluation period. The study demonstrates that integrating 7QC Tools, the 4M1E taxonomy, Why-Why Analysis, and feasibility-adjusted MRPN provides an effective and practical approach for transport quality improvement. The proposed framework offers a transferable decision-support model for reducing transportation defects in resource-constrained community enterprises handling fragile products.

Keywords: 7QC Tools, Transport defect reduction, FMEA, EPE foam cushioning, Community Enterprise

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1. INTRODUCTION

Transport-phase quality management remains one of the most neglected areas in supply chain research, particularly among community-based manufacturers producing fragile products. In Thailand, road freight is the dominant mode of domestic logistics, accounting for approximately 86.14% of goods transportation and continuing to expand alongside national economic growth (Buthphorm, Sukhotu & Hengsadeeikul, 2024). For community enterprises producing brittle ceramic products, this dependence on road transportation presents a significant operational challenge. Fired-clay stoves must be transported over long distances through rural road networks, where continuous vehicle vibration, road-induced shocks, rough handling, and inconsistent loading practices frequently generate mechanical stresses that result in cracking and fracture of fragile ceramic components. Previous transportation studies have shown that vibration transmitted through road freight systems is one of the primary causes of damage to fragile products, particularly when cushioning materials are unable to adequately dissipate repeated impact energy (Xing et al., 2023; Zheng et al., 2023). Consequently, defect rates often exceed commercially acceptable levels, reducing already limited profit margins and threatening the long-term sustainability of these enterprises. Evidence from related community-enterprise contexts further demonstrates that logistics activities, particularly packaging, handling, and transportation, are among the weakest operational dimensions, with reliability levels in transport and handling processes reported at only 80.95% (Kerdphon & Thongkam, 2025).

Although production-related quality issues have received considerable scholarly attention through approaches such as lean manufacturing and statistical process control, transport-phase defects within informal and community-based operations remain insufficiently explored. This research gap leaves practitioners without practical and evidence-based methods for identifying and reducing transportation-related damage. Studies on rural agricultural supply chains in Thailand similarly reveal that transportation efficiency is influenced by multiple interconnected factors, including road conditions, vehicle load capacity, routing decisions, and intermediary coordination, all of which are rarely incorporated into conventional logistics quality frameworks (Photipan, Sujaritchai, & Prakongpak, 2024).

The Seven Quality Control Tools (7QC Tools), originally formalized by the Union of Japanese Scientists and Engineers and later promoted by Deming and Juran, provide a systematic foundation for identifying and analyzing defects. Previous studies have consistently demonstrated their effectiveness across manufacturing and logistics environments. Manojkumar & Kumar (2021), for example, achieved a 75% reduction in motorcycle visor defects through the application of Pareto chart and Fishbone diagrams. Beyond manufacturing settings, Kirana, Mulki & Sidabutar (2026) showed that Check Sheets, Pareto Charts, and Fishbone diagrams can effectively identify dominant service failures in logistics operations. Likewise, Bukhari & Akhtar (2024) reduced soap manufacturing defects from 19.9% to 7.1% by integrating 7QC Tools within the DMAIC framework, while Condé et al. (2023) improved process capability in automotive parts manufacturing by increasing the sigma level from 3.4 to 4.0. More recent studies further reinforce the adaptability of the framework across sectors. Sukachat & Bangraknoi (2025) demonstrated the successful integration of 7QC Tools into hybrid Lean–Industry 4.0 systems, whereas Khanijo et al. (2025) confirmed their applicability within complex healthcare logistics operations. Collectively, these studies highlight the broad cross-domain relevance and practical value of the 7QC framework.

Although each quality management technique has been widely applied individually, relatively few studies have integrated them into a unified decision-making framework for transport-phase quality management. In the proposed conceptual framework, the 7QC Tools provide the foundation for systematic data collection and defect identification. Pareto analysis prioritizes the dominant transportation defects, while the Fishbone Diagram organizes potential causes according to the 4M1E taxonomy. Why-Why Analysis is subsequently

employed to verify the underlying root causes, thereby reducing the risk of selecting superficial corrective actions. Finally, Modified Failure Mode and Effects Analysis (Modified FMEA) quantitatively prioritizes verified root causes by considering both failure risk and implementation controllability, enabling evidence-based selection of improvement measures under resource-constrained conditions. This sequential integration provides a logical progression from problem identification to root-cause verification and ultimately to practical decision-making for transport quality improvement.

Despite these developments, three important research gaps remain unresolved.

Gap 1: Existing applications of the 7QC Tools and their methodological extensions, including Why-Why Analysis for root-cause verification and Failure Mode and Effects Analysis (FMEA) for evidence-based solution prioritisation, have focused predominantly on production-stage quality management. Comparatively little attention has been devoted to transport-phase quality management, particularly in community enterprises handling fragile products, where transportation damage directly affects product quality and business sustainability.

Expanded polyethylene (EPE) foam and ethylene-vinyl acetate (EVA) foam are among the most widely used cushioning materials for protecting fragile products during transportation. EPE foam is characterized by its closed-cell structure, high energy absorption capacity, excellent resilience, and superior vibration damping performance, making it particularly suitable for repeated impact loading during road transportation. In contrast, EVA foam generally exhibits higher stiffness and dimensional stability but lower energy absorption under repeated dynamic loading, making it more appropriate for applications requiring structural support rather than maximum cushioning performance. Previous studies have demonstrated that cushioning material properties significantly influence vibration transmission and impact resistance during freight transportation (Xing et al., 2023; Zheng et al., 2023). These differences provide the practical motivation for comparing EPE and EVA foam under actual transportation conditions in the present study.

Gap 2: Although packaging materials and operator handling practices are widely recognized as critical determinants of transportation quality, their combined influence on transportation defects has not been systematically investigated. In particular, although numerous studies have investigated cushioning materials independently, few empirical studies have compared the transportation performance of EPE and EVA cushioning materials under actual road freight conditions while simultaneously considering operator handling practices and vibration-induced transportation damage.

Gap 3: Although the 4M1E framework extends the traditional Fishbone diagram by incorporating environmental factors, its application to fragile-goods logistics remains limited. Existing transport quality studies rarely integrate transport packaging design, vibration-induced damage mechanisms, road conditions, travel distance, and evidence-based risk prioritisation into a unified quality improvement framework. This limitation is also reflected in broader rural supply-chain studies. Although Phacharathananon et al. (2024) investigated agricultural supply chains rather than fragile ceramic products, both contexts share similar operational constraints, including long transportation distances, uneven rural road conditions, limited logistics infrastructure, and restricted financial resources. These similarities suggest that transportation quality management in rural community enterprises requires an integrated approach that simultaneously considers packaging, handling practices, and transportation risks rather than addressing each issue independently.

Based on these research gaps, the present study addresses the following research questions:

RQ1: What are the dominant transportation-related defects and root causes affecting ceramic stove distribution in community enterprises?

RQ2 : How can a Modified FMEA incorporating Controllability improve the prioritisation of corrective actions under resource-constrained conditions?

RQ3 : To what extent can an integrated eight-phase transport quality management framework reduce transportation defects in fragile-product distribution?

2. OBJECTIVES

- 2.1 To identify and verify the root causes of ceramic stove transport defects at the Ban Chat Community Enterprise Group using integrated 7 QC Tools, including Check Sheets, Pareto chart, Fishbone diagram, and Why-Why Analysis.
- 2.2 To develop and implement corrective actions using a Modified FMEA framework with controllability assessment to reduce the transport defect rate from 10.35% to below the 5% acceptance threshold.

3. LITERATURE REVIEW

3.1 Case Selection and Study Context

The Ban Chat Community Enterprise Ceramic Stove Group, located in Nanuan Subdistrict, Phanom Phrai District, Roi Et Province, Thailand, was purposively selected as the case study because it represents a typical small-scale community enterprise producing fragile ceramic products for regional distribution. The enterprise was selected based on four criteria: (1) an average transport defect rate exceeding the enterprise acceptance threshold of 5%, (2) continuous production and distribution operations throughout the study period, (3) willingness of the enterprise to provide complete operational and defect records, and (4) accessibility for on-site observation and implementation of improvement activities. These characteristics make the enterprise an appropriate representative case for investigating transport-phase quality management in resource-limited community enterprises.

3.2 Study of Current Work Procedures

The research began by studying the current work procedures of the Ban Chat community enterprise group, Nanuan Subdistrict, Phanom Phrai District, Roi Et Province. It was found that the current production and transportation of pottery kilns involves 8 steps, as shown in Figure 1.

From Figure 1, the community enterprise group produces and ships average orders of 1,426 units per month to distributors, working 8 hours per day. Interviews with 3 employees (production worker, transportation worker, and community enterprise manager) regarding waste generation revealed that over 90% of the waste occurs in the "transportation to distributors" step. Therefore, data on waste generated from this step was collected and presented in section 3.3.

3.3 Collecting Waste Data During Transportation to Distributors

Waste data during transportation to distributors was collected by transport drivers, who recorded information on check sheet. This included the quantity transported and the frequency of each type of defect. Data collection covered five consecutive months, from April to August 2025, yielding a total of 13 delivery cycles across six northeastern Thai provinces. The data were entered into a purpose-designed Check Sheet that categorised defects into five defined types: Pot rest fracture, Base fracture, Stove body fracture, Fuel feed opening rim fracture, and Air vent fracture, together with a residual 'Other' category for damage not fitting the primary classifications. The complete baseline defect dataset is presented in Table 1.

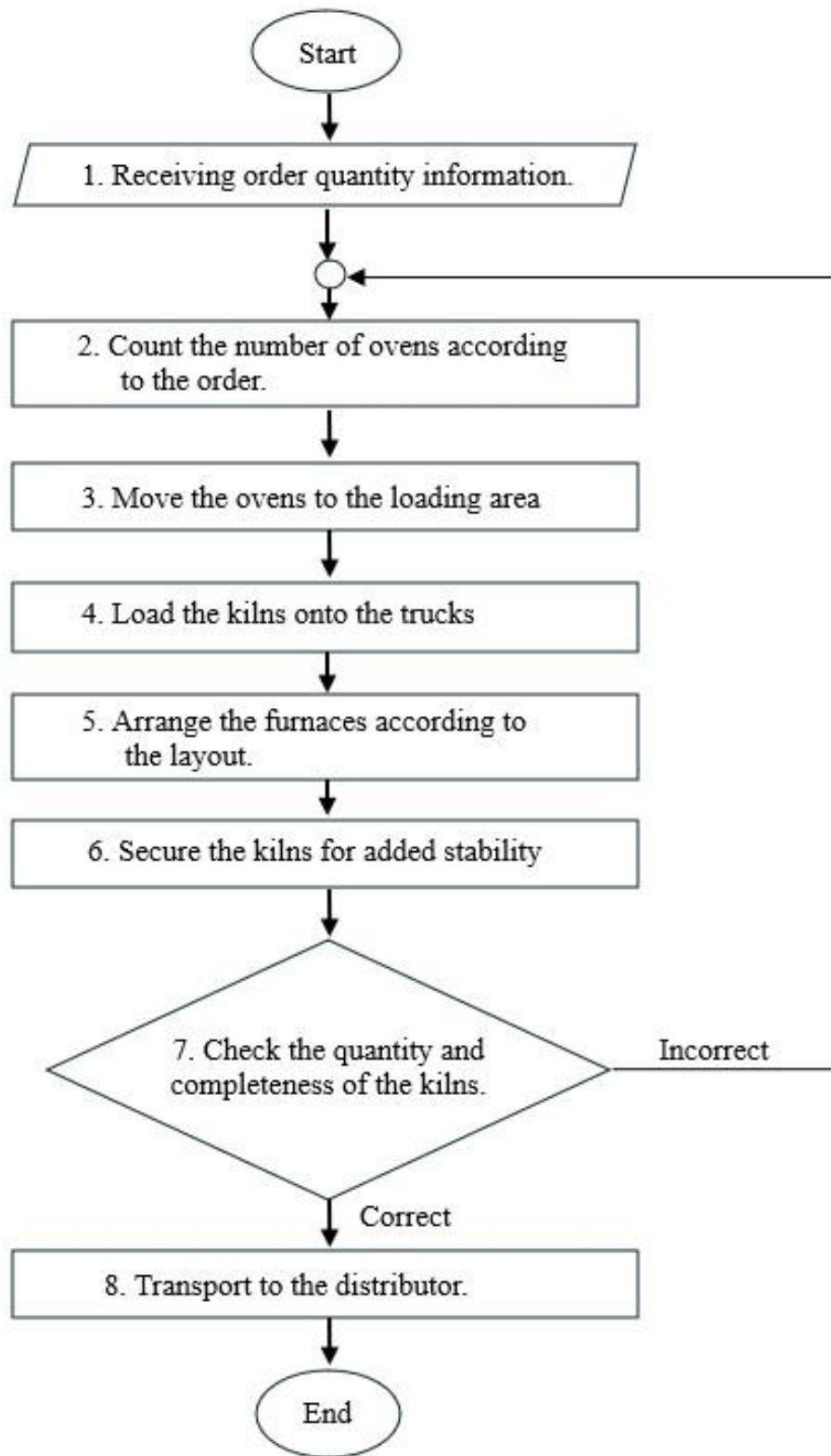
**Figure 1** Current Work Procedures

Table 1 Quantity of defects in the transportation process before improvement (April–August 2025)

Defects Type	Number of defects per month (units)					Total (units)	Average (units/month)	%Average (%)	%Cumulative (%)
	Apr 2025	May 2025	Jun 2025	Jul 2025	Aug 2025				
1. Pot rest fracture	71	66	50	60	42	288	57.80	39.16	39.16
2. Base fracture	50	58	38	45	35	266	45.20	30.62	69.78
3. Stove body fracture	14	14	13	19	9	69	13.80	9.35	79.13
4. Fuel feed opening rim fracture	15	20	5	16	12	68	13.60	9.21	88.35
5. Air vent fracture	17	17	10	14	7	65	13.00	8.81	97.15
6. Other	5	3	4	5	4	21	4.20	2.85	100.00
Total number of defects	172	178	120	159	109	737	147.60	100.00	-
Production volume	1,750	1,470	1,260	1,450	1,200	7,130	1,426	10.35	-
Defect rate (%)	9.83	12.11	9.52	10.97	9.08	10.34	10.35	-	-

Table 1 shows that the defect type with the highest frequency is Pot rest fracture (57.80 units/month; 39.16%), followed by Base fracture (45.20 units/month; 30.62%), Stove body fracture (13.80 units/month; 9.35%), Fuel feed opening rim fracture (13.60 units/month; 9.21%), and Air vent fracture (13.00 units/month; 8.81%), respectively. The overall average defect rate across the five-month baseline period was 10.35%, which is more than twice the enterprise's acceptable threshold of 5%. This data was subsequently analyzed using a Pareto chart, as shown in Figure 2.

As shown in Figure 2, the 70/30 principle was applied to identify the defect categories warranting priority investigation. Under this principle, defect types whose cumulative percentage reaches or exceeds 70% of the total are designated as Priority-A problems requiring immediate corrective action. The analysis indicates that Pot rest fracture and Base fracture jointly account for 69.78% of all transport defects, falling at the 70% threshold, and are therefore identified as the two Priority-A defect categories. The remaining four categories (Stove body fracture, Fuel feed opening rim fracture, Air vent fracture, and Other) collectively represent 30.22% of defects and are classified as Priority-B. Accordingly, the root-cause analysis in Section 3.4 focuses exclusively on the two Priority-A defect types, each investigated independently using a Fishbone diagram combined with Why-Why Analysis.

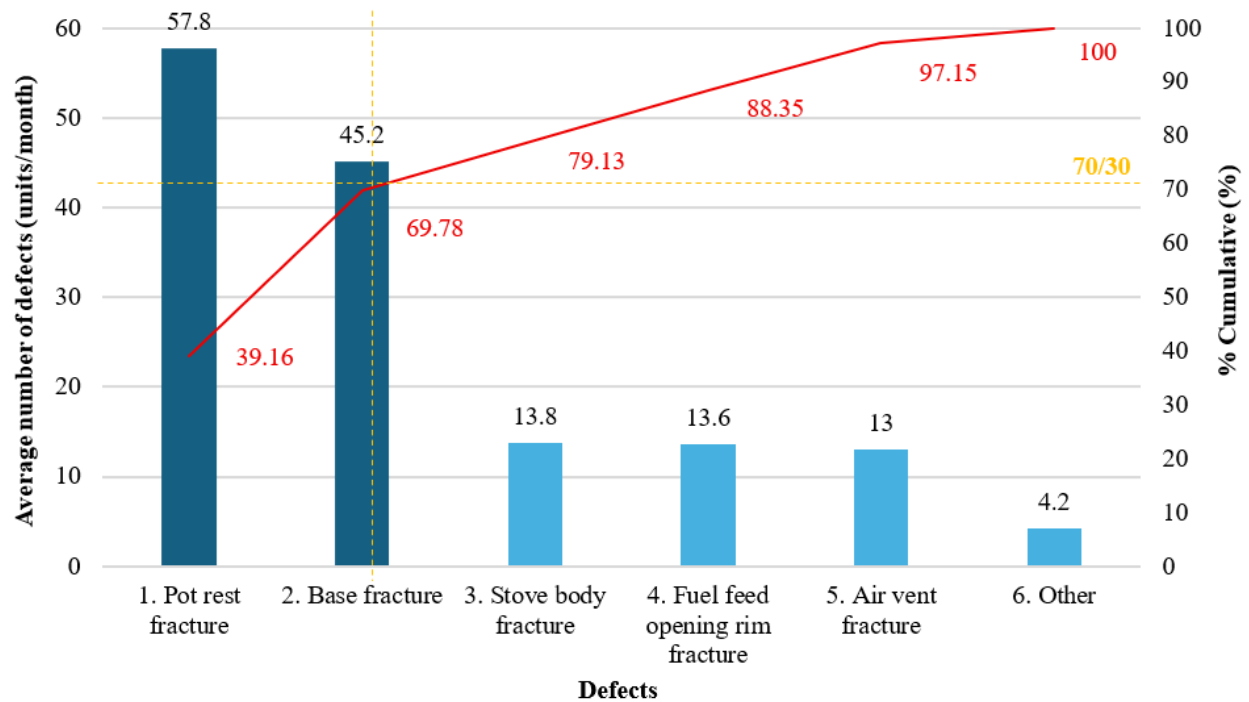


Figure 2 Pareto chart of transport-phase defect categories

3.4 Data Analysis

Having identified Pot rest fracture and Base fracture as the two Priority-A defect categories, In Section 3.4 to diagnose their root causes using Fishbone diagrams structured around the 4M1E framework (Man, Machine, Material, Method, and Environment) in Figure 3 and 4.

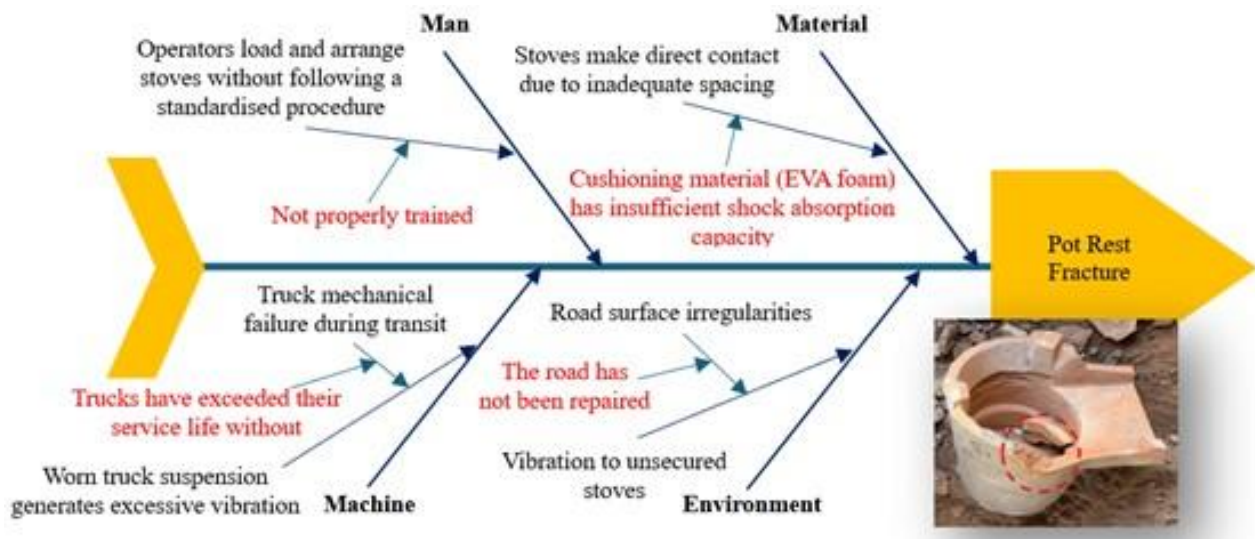


Figure 3 Fishbone diagram for the Pot Rest Fracture problem

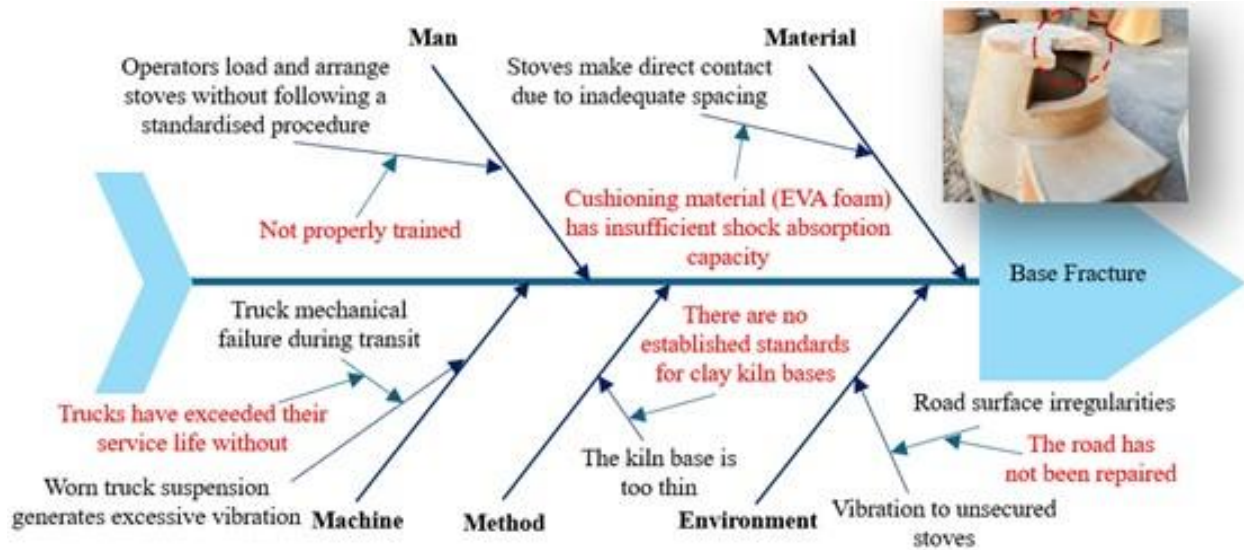


Figure 4 Fishbone diagram for the Base Fracture problem

Figures 3 and 4 illustrate the root causes of defects occurring during transportation to distributors, identified through fishbone diagram analysis of Pot Rest Fracture and Base Fracture defects. The analysis revealed five primary contributing factors. These issues were subsequently examined in greater detail using Why-Why Analysis to identify the underlying causes and determine appropriate corrective actions, as presented in Table 2.

Table 2 Why-Why Analysis of Pot Rest Fracture and Base Fracture Defects

Why level	Question	Answer
Problem 1	Why do operators load and arrange stoves without following a standardised procedure?	Operators have not been properly trained.
Why 1	Why have Operators not been properly trained?	No formal training programme exists for loading and transport procedures.
Why 2	Why does no formal training programme exist?	The enterprise has no documented standard operating procedure (SOP) for stove loading.
Why 3	Why is there no documented SOP?	Knowledge of loading practices has been passed down informally and was never formalized.
Why 4	Why was it never formalised?	The enterprise lacked awareness that informal practices were contributing to transport defects.
True Root Cause: Absence of a documented SOP and structured training programme for stove loading and handling.		
Corrective Action: Develop a written loading SOP and deliver a structured short-course training programme to all operators covering safe lifting, stove arrangement, and cushioning material placement.		
Problem 2	Why do stoves make direct contact and suffer impact damage during transit?	Cushioning material (EVA foam) has insufficient shock absorption capacity.

Why level	Question	Answer
Why 1	Why does EVA foam have insufficient shock absorption capacity?	EVA foam is designed for floor matting, sports footwear, and equipment — not for product-level freight cushioning (Chang et al., 2023).
Why 2	Why was EVA foam selected for stove cushioning?	It was the material available locally at lowest cost; no evaluation of cushioning performance was conducted.
Why 3	Why was no cushioning performance evaluation conducted?	The enterprise had no awareness of alternative materials or their comparative protection properties.
Why 4	Why was there no awareness of alternatives?	No packaging engineering guidance had been provided to the enterprise prior to this study.
True Root Cause: Selection of cushioning material was based solely on cost and local availability without any assessment of shock absorption performance.		
Corrective Action: Replace EVA foam with EPE (Expanded Polyethylene) foam at minimum 10 mm thickness, which is purpose-engineered for product freight protection and offers superior vibration and impact absorption at lower cost per unit (Xing, Sun, & Chen, 2023; Zheng et al., 2023).		
Problem 3	Why does truck mechanical failure occur and worn suspension generate excessive vibration?	Trucks have exceeded their service life without replacement.
Why 1	Why have trucks not been replaced at end of service life?	The enterprise has insufficient capital to purchase replacement vehicles.
Why 2	Why does the enterprise have insufficient capital for vehicle replacement?	Transport defect losses (10.35% defect rate) reduce revenue available for capital reinvestment.
Why 3	Why have defect-related losses not triggered earlier corrective action?	No systematic defect tracking or cost-of-quality monitoring was in place.
Why 4	Why was no defect tracking in place?	The enterprise lacked a formal quality management framework before this study.
True Root Cause: Absence of preventive maintenance scheduling and vehicle replacement planning due to lack of a formal asset management procedure.		
Corrective Action: Establish a preventive maintenance schedule for truck suspension, brakes, and chassis components; set a mileage-based replacement criterion; in the interim, reduce vibration transmission by using EPE foam cushioning as a compensating measure.		
Problem 4	Why do road surface irregularities transmit vibration to unsecured stoves?	Roads on distribution routes have not been repaired or maintained.
Why 1	Why have the roads not been repaired?	Road maintenance is the responsibility of government authorities, outside the enterprise's control.
Why 2	Why has the enterprise not adapted its operations to account for poor road conditions?	No route assessment or route selection protocol exists to identify and avoid the worst road segments.
Why 3	Why is there no route selection protocol?	Drivers follow habitual routes based on familiarity rather than road surface quality.

Why level	Question	Answer
Why 4	Why has no alternative routing been evaluated?	The enterprise had no framework for linking route characteristics to product damage outcomes.
True Root Cause: The enterprise has no route assessment protocol, and road maintenance is an external factor beyond direct control.		
Corrective Action: Since road condition is externally determined, compensate through: (1) route planning to avoid the most severely damaged road segments where alternatives exist; (2) reduced driving speed on rough segments; (3) enhanced stove securing and EPE cushioning to absorb road-induced vibration. Note: this root cause cannot be fully eliminated by the enterprise — mitigation rather than elimination is the appropriate response.		
Problem 5	Why are kiln bases too thin and prone to fracture under transport loading?	There are no established standards for clay kiln base thickness.
Why 1	Why are there no established thickness standards?	Base thickness has been determined by individual workers based on experience and feel, not measurement.
Why 2	Why has measurement-based production not been adopted?	No production quality specification document exists for the stove.
Why 3	Why does no specification document exist?	The product was developed through generational craft tradition, with no engineering documentation.
Why 4	Why has engineering documentation not been introduced?	The enterprise had no quality engineering support prior to this study.
True Root Cause: Absence of a documented product specification defining minimum acceptable base thickness as a production quality criterion		
Corrective Action: Define and document a minimum base thickness specification (e.g., minimum wall thickness in mm determined by structural testing or expert consensus)		

3.5 Modified FMEA-Based Solution Selection

Standard FMEA calculates a Risk Priority Number (RPN) from three factors: Severity (*S*), Occurrence (*O*), and Detection difficulty (*D*), each scored on a 1–10 scale, where higher values indicate greater severity, frequency, and difficulty of detection respectively (Wu, & Wu, 2021; Qiu, & Zhang, 2022), as expressed in Equation (1):

$$RPN = S \times O \times D \quad (1)$$

A recognised limitation of the standard RPN is that it excludes other potentially influential factors specific to the application context, which can lead to biased prioritisation when the operational environment introduces constraints not captured by *S*, *O*, and *D* alone. In community enterprise settings, this limitation is particularly consequential: directing corrective resources toward root causes that are partially or fully outside enterprise control, such as road surface conditions or capital vehicle replacement, produces no practical quality improvement regardless of how high their standard RPN ranks them. This study therefore introduces a Controllability score (*C*, rated 1–10) as a fourth factor, incorporated as a divisor to produce a Modified Risk Priority Number (MRPN), as expressed in Equation (2):

$$MRPN = \frac{S \times O \times D}{C} \quad (2)$$

The Controllability score reflects the degree to which the enterprise itself can implement a corrective action for a given root cause, defined across three levels: *C* = 1–4 indicates the root cause is

largely or fully outside enterprise control; a low divisor leaves the MRPN close to the standard RPN, but since corrective action is not feasible, these causes are designated for mitigation planning only; C = 5–7 indicates the cause is partially controllable; and C = 8–10 indicates the root cause is fully within enterprise control, producing a large divisor that substantially reduces the MRPN relative to the standard RPN.

To make the intervention decision criterion explicit and objective, this study further proposes %Different, defined as the percentage reduction from standard RPN to MRPN, as expressed in Equation (3):

$$\%Different = \frac{RPN - MRPN}{RPN} \times 100\% \quad (3)$$

A high %Different value indicates that Controllability substantially reduces the priority score relative to raw risk magnitude, meaning the enterprise has strong capacity to address the cause directly, and immediate intervention is warranted. A low %Different value indicates that the cause's priority is driven primarily by external risk factors rather than actionable enterprise decisions, designating it as a lower-priority or mitigation-only target.

The five confirmed root causes identified through Fishbone diagram and Why-Why Analysis were entered into the Modified FMEA matrix. All scores were determined through structured brainstorming sessions involving the production worker, transport driver, community enterprise manager, and research team. The results are presented in Table 3.

Table 3 Intervention priority classification based on %Different

Root Cause Summary	Defects Type	S	O	D	C	RPN	MRPN	%Different (RPN-MRPN)	Priority Class
RC1: No SOP or formal operator training	Pot rest fracture & Base fracture	8	8	6	9	384	42.7	88.88	2-Selected
RC2: EVA foam — insufficient shock absorption	Pot rest fracture & Base fracture	8	9	7	9	504	56.0	88.89	1-Selected
RC3: Trucks exceeded service life	Pot rest fracture & Base fracture	7	6	5	3	210	70.0	66.67	4-Long-term
RC4: Roads not repaired (external)	Base fracture only	8	8	5	2	320	160.0	50.00	5-Mitigation only
RC5: No base thickness production standard	Pot rest fracture & Base fracture	7	6	6	8	252	31.5	87.50	3-Secondary

Table 3 presents the intervention priority classification derived from the Modified FMEA. RC2 (EVA foam, insufficient shock absorption) and RC1 (no SOP or formal operator training) yield the highest %Different values of 88.89% and 88.88% respectively, indicating that both causes carry high risk and are fully within enterprise control, and are therefore selected as Priority 1 and Priority 2 for immediate corrective intervention. RC5 (no base thickness production standard) follows at 87.50% and is designated a secondary action. RC3 (trucks exceeded service life) scores 66.67% and is classified as a long-term capital planning item. RC4 (roads not repaired) records the lowest %Different of 50.00%, reflecting full external dependency, and is designated for mitigation only.

Based on the FMEA prioritisation results, two corrective interventions were implemented. First, EVA foam cushioning was replaced with EPE (Expanded Polyethylene) foam at a minimum thickness of 10 mm, a material purpose-engineered for freight protection and demonstrated to provide superior vibration and impact absorption at lower unit cost (Xing, Sun, & Chen, 2023; Zheng et al., 2023). Second, a structured short-course training programme was developed and delivered to all operators, covering safe lifting techniques, standardised stove arrangement procedures, and correct cushioning material placement. The design, implementation, and outcomes of both interventions are presented in Section 4.

4. Result

To ensure the internal validity of the pre–post comparison, the enterprise maintained the same transportation system throughout the study period. The same truck, the same three experienced drivers, and the same regular distribution routes covering six provinces in Northeastern Thailand were used during both the baseline and post-intervention phases. Although monthly production volumes and the number of delivery cycles varied according to customer demand (13 delivery cycles before improvement and 16 after improvement), all transportation conditions—including vehicle type, loading procedures, and operational practices—remained unchanged except for the two planned interventions: (1) replacement of EVA foam with EPE cushioning and (2) implementation of a written loading standard operating procedure (SOP) accompanied by operator training. Consequently, potential confounding factors were minimized, allowing the observed reduction in defect rates to be attributed primarily to the implemented interventions.

4.1 Replacement of EVA Foam with EPE Foam

The cushioning material used during stove loading was changed from EVA (Ethylene Vinyl Acetate) flat-sheet foam to EPE (Expanded Polyethylene) foam pieces measuring 25 cm wide $\times$ 60 cm long $\times$ 10 mm thick. Unlike the single-sheet EVA material, which was laid flat between layers, the individual EPE foam pieces were positioned between and around each stove, enabling targeted vibration damping at the contact points most susceptible to fracture. The maximum stacking configuration was standardised at four stoves per column to limit compressive loading on lower units. EPE foam was selected over EVA on the basis of its purpose-engineered closed-cell structure, which provides superior shock absorption capacity relative to EVA, which is designed primarily for floor matting applications, at approximately one-third the cost per unit at equivalent thickness (Chang et al., 2023; Xing, Sun, & Chen, 2023; Zheng et al., 2023). Figure 5 illustrates the before-and-after loading configuration.



A: Used EVA foam material
(Before modification)



B: Used EPE foam material
(After modification)

Figure 5 Changes in shock-absorbing materials

4.2 Operator Training Programme and Written Loading SOP

A structured 90-minute short-course training programme was developed and delivered by the research team to all three drivers responsible for transporting ceramic stoves to distributors. The training was designed to address the root cause confirmed by Why-Why Analysis, the absence of a formal loading standard and training programme, and covered four content domains: occupational safety principles, safe

lifting and manual handling, standardised stove arrangement on the truck bed, and correct EPE foam cushioning placement. Table 4 presents the full programme outline. Figure 6 shows the training delivery session.

Table 4 Short-course operator training programme

No.	Content	Duration (min)	Delivery method
1	Occupational safety principles and importance of correct handling in ceramic stove transport	20	Lecture with visual aids
2	Safe lifting and manual handling techniques specific to ceramic stove weight and geometry	30	Demonstration and Supervised practice
3	Standardised stove arrangement procedure on truck bed: spacing, orientation, and layering	15	Demonstration and Supervised practice
4	Correct EPE foam cushioning placement: coverage area, thickness verification, and securing	15	Hands-on practice
5	Summary, Q&A, and distribution of written loading SOP to all participants	10	Group discussion
Total		90	-



Figure 6 Short-course operator training session delivered by the research team

4.3 Post-Intervention Defect Data (October 2025–March 2026)

Following implementation of both interventions, defect data were recorded by drivers at the point of distributor receipt using the same Check Sheet instrument applied during the baseline period. Data were collected across six consecutive months (October 2025–March 2026), covering 16 delivery cycles and a total dispatch volume of 7,965 units. Monthly defect counts by category, together with pre–post comparison metrics, are presented in Table 5.

Table 5 Comparing the number of defects in the transportation process before and after improvements

Defects Type	Number of defects per month (units)								Different (units/month)	%Different (%)
	Before				After					
	Apr–Aug 2025	Oct 2025	Nov 2025	Dec 2025	Jan 2026	Feb 2026	Mar 2026	Average		
1. Pot rest fracture	57.80	18	13	26	17	14	13	16.83	40.97	70.88
2. Base fracture	45.20	17	9	21	14	12	11	14.00	31.20	69.03
3. Stove body fracture	13.80	3	3	6	8	8	7	5.83	7.97	57.73
4. Fuel feed opening rim fracture	13.60	8	3	7	8	7	7	6.67	6.93	50.98
5. Air vent fracture	13.00	2	3	4	5	6	5	4.17	8.83	67.95
6. Other	4.20	4	1	5	3	3	2	3.00	1.20	28.57
Total number of defects	147.60	52	32	69	55	50	45	50.5	97.10	65.79
Production volume	1,426	1,470	1,155	1,840	1,250	1,150	1,100	1,328	98.50	6.91
Defect rate (%)	10.35	3.54	2.77	3.75	4.40	4.35	4.09	3.80	6.55	63.24

Table 5 demonstrates that both corrective interventions produced substantial and consistent reductions in transport-phase defects across all six post-intervention months. A two-proportion z-test showed that the reduction in defect rate from 10.35% (baseline, April–August 2025) to 3.80% (post-intervention, October 2025–March 2026) was statistically significant ($p < 0.001$), representing an absolute reduction of 6.55 percentage points and a relative reduction of 63.24%. Critically, the post-intervention defect rate remained below the enterprise's 5% acceptability threshold in all six monitoring months (range: 2.77%–4.40%), confirming that the improvements are sustained rather than transient.

The two Priority-A defect categories showed the largest reductions: Pot rest fracture declined by 70.88% (from 57.80 to 16.83 units/month) and Base fracture declined by 69.03% (from 45.20 to 14.00 units/month). These outcomes align with the FMEA prioritisation, which identified EVA foam inadequacy (RC2) and absence of operator training (RC1) as the root causes most amenable to enterprise-level corrective action. The remaining three defect categories, Stove body fracture (57.73%), Fuel feed opening rim fracture (50.98%), and Air vent fracture (67.95%), also recorded meaningful reductions, suggesting positive spillover effects of the EPE foam and training interventions on general transport handling quality beyond the two targeted failure modes.

5. SUMMARY AND DISCUSSION

Baseline data recorded 737 defective units from 7,130 stoves delivered over five months, producing an average defect rate of 10.35%, which exceeded the acceptable 5% threshold by more than two times. Pareto chart identified Pot Rest Fracture (39.16%) and Base Fracture (30.62%) as the dominant defect categories, together representing 69.78% of total defects. Fishbone diagram and Why- Why Analysis confirmed two major root causes: the absence of formal operator training and loading procedures under the manpower dimension (RC1), and the inadequate shock absorption performance of EVA foam under the material dimension (RC2). These findings support the work of Kirana, Mulki, & Sidabutar (2026), who

demonstrated the effectiveness of Fishbone diagram and Pareto chart in identifying logistics failures, and Photipan, Sujaritchai, & Prakongpak (2024), who emphasized the importance of packaging and loading practices in reducing transport damage in Thai rural supply chains.

Modified FMEA ranked RC2 and RC1 as the highest priorities because both showed very high %Different values and full enterprise controllability. Improvement measures included replacing EVA foam with EPE foam and conducting a 90-minute training programme for delivery drivers covering safe handling, stove arrangement, foam placement, and standard operating procedures.

The superior performance of EPE foam can be explained by its closed-cell polyethylene structure, which provides higher energy absorption, improved resilience, and greater vibration damping than conventional EVA foam. During transportation, repeated impacts and continuous road-induced vibration generate localized stresses at the contact points between ceramic stoves. The use of EPE foam effectively reduces stress transmission by increasing deformation capacity and dissipating impact energy, thereby lowering the incidence of pot-rest and base fractures. This mechanical explanation is consistent with the experimental findings reported by Xing et al. (2023) and Zheng et al. (2023), who demonstrated that EPE exhibits superior cushioning performance for protecting fragile products during transportation.

The effectiveness of the operator training programme can be attributed to the standardization of loading practices and the reduction of human-induced variability. Prior to the intervention, loading procedures relied largely on individual experience rather than standardized operating practices, resulting in inconsistent stove arrangement and cushioning placement. The introduction of a written standard operating procedure (SOP), together with practical training, improved procedural consistency and reduced handling errors. This improvement is consistent with previous studies demonstrating that standardized work procedures and operator competency are critical factors in improving logistics quality and reducing transportation-related damage. Collectively, these findings suggest that effective transport quality improvement depends not only on selecting appropriate cushioning materials but also on standardizing operational practices through structured training and documented procedures. The combination of engineering and human-factor interventions provides a comprehensive and sustainable strategy for reducing transport-related defects by simultaneously addressing both material-related and human-related sources of transport damage.

Post intervention monitoring between October 2025 and March 2026 reduced the average defect rate to 3.80%, representing a 63.24% improvement from baseline. The defect rate remained below 5% throughout the monitoring period, while Pot Rest Fracture and Base Fracture declined by more than 69%.

Overall, the results demonstrate that the proposed eight-phase framework, 4 M1 E taxonomy, Modified FMEA approach, and combined packaging and training intervention can effectively improve transport quality management in resource-limited community enterprises handling fragile goods. The present study further indicates that integrating evidence-based packaging redesign with standardized operator practices offers an effective and practical strategy for improving transport quality in resource-limited community enterprises. The proposed framework may therefore serve as a useful reference for similar fragile-product distribution systems operating under comparable logistical constraints.

6. RECOMMENDATIONS

6.1 Research Limitations

This study has several limitations that should be acknowledged. First, the research was conducted as a single-case study involving one community enterprise producing ceramic stoves in Northeastern Thailand; therefore, the findings may not be directly generalizable to other industries or logistics contexts. Second, post-intervention performance was monitored for six months, which demonstrates short- to medium-term effectiveness but does not confirm long-term sustainability. Third, the Modified FMEA scoring relied on expert consensus within the participating enterprise, and although a structured evaluation process was employed, some degree of subjective judgment remains unavoidable. Finally, the study focused exclusively on transport-phase quality management and did not evaluate economic indicators such as return on investment or life-cycle cost.

6.2 Future Research

Future studies should validate the proposed framework across different types of fragile products and larger logistics networks to assess its external validity. Further research may also integrate Internet of Things (IoT)-based vibration monitoring, digital sensors, machine learning techniques for defect prediction, or optimization models for vehicle loading and route planning. In addition, cost-benefit analysis and long-term monitoring would provide further evidence regarding the economic sustainability of the proposed interventions.

7. NEW KNOWLEDGE OR UTILIZATION

7.1 Theoretical Contributions

This study extends the application of the 7QC Tools beyond conventional production quality control by demonstrating their effectiveness within transport-phase quality management for fragile products in community enterprises. Unlike previous studies that primarily focused on manufacturing defects, the proposed framework integrates Check Sheets, Pareto Chart, Fishbone Diagram, Why-Why Analysis, and Modified FMEA into a systematic quality improvement framework specifically designed for transportation processes. Furthermore, the incorporation of the Controllability factor into the traditional FMEA provides a practical prioritization mechanism that reflects the operational constraints of resource-limited community enterprises, thereby extending the applicability of risk-based decision-making in logistics quality management.

7.2 Practical Implications

From a practical perspective, the proposed Modified FMEA framework provides a systematic decision-support tool for prioritizing corrective actions under limited financial and operational resources. Community enterprises and small-scale manufacturers producing fragile products can adopt the proposed framework to identify transport-related defects, evaluate root causes based on both risk and controllability, and allocate improvement resources more effectively. The integrated approach combining evidence-based packaging redesign with standardized operator training also offers a practical implementation model that can be adapted to similar transportation systems where financial and technical resources are constrained.

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ETHICAL CONSIDERATIONS

The study was approved by the Institutional Review Board (IRB) of Rajamangala University of Technology Isan Khonkaen Campus under the project title “Waste Reduction in the Transportation Process of Earthen Stoves: A Case Study of Ban Chat Community Enterprise.”, no. HEC-02-69-015.

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