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Development of a Quality Control Framework for Leather Craft MSME Products in Yogyakarta using Integrated BWM-FMEA-GRA

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ABSTRACT

Leather craft MSMEs have substantial economic potential but often struggle to maintain consistent product quality because production relies on manual craft, artisan experience, and limited formal process controls. At the leather craft MSME specializing in leather bags examined in this study, product defects and customer complaints led to rework, material waste, and potential reputational loss. This study develops a case-based quality failure risk prioritization framework that integrates the Best-Worst Method (BWM), Failure Mode and Effects Analysis (FMEA), and Grey Relational Analysis (GRA). Although FMEA, BWM, and GRA have each been applied separately in prior quality-risk studies, their integration remains limited in the leather craft MSME context. Failure risks were identified through observation and interviews, weighted by severity, occurrence, and detection using BWM, rated using FMEA, and prioritized using GRA. The analysis identified 35 failure risks across 13 production stages. Detection received the highest criterion weight, followed by severity and occurrence. GRA ranked 12 highest-priority risks across nine stages, led by inappropriate pattern-making and peeled or scratched product components. For the priority failure risk occurring at the raw material stage, moldy leather was further examined in accordance with SNI 06-0335-1989 (Indonesian National Standard for Cow Leather for Bags and Suitcases – Quality Requirements and Test Methods). The test results revealed nonconformity in moisture content, total ash content, and thickness. These findings indicate that the integrated BWM-FMEA-GRA framework provides a systematic basis for prioritizing quality failure risks and formulating targeted, appropriate quality control recommendations that address the resource constraints of leather craft MSMEs.

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1. Introduction

The craft industry is a creative economy sector dominated by micro, small, and medium-sized enterprises (MSMEs). It relies on manual skill, local resources, and the creation of products with aesthetic and symbolic value (Gambicorti, 2026; Katongole, 2026). Craft products are also characterized by embodied expertise, in which quality is shaped by artisans' tacit knowledge and by consumers' perception of uniqueness and authenticity (Gambicorti, 2026; Kroezen et al., 2021).

Leather products are among the craft subsectors with high economic, aesthetic, and cultural value. In Indonesia, leather products represent a strategic commodity with strong domestic and export potential. Indonesian Ministry of Industry (2025) reported that Indonesia's leather product exports reached USD 4.6 billion in 2024, an 8% increase from the previous year. In the Special Region of Yogyakarta, leather products accounted for 10.46% of total regional exports and ranked among the four largest export commodities in 2024 (DIY, 2025).

Despite this potential, leather craft MSMEs face persistent challenges in maintaining consistent product quality. These challenges arise because production activities depend heavily on manual craft, artisan experience, and methods that are not fully standardized (Katongole, 2026). Compared with large-scale manufacturers, traditional MSMEs have limited resources, workforce capacity, and operational infrastructure to implement formal quality control systems (Susanto et al., 2025). Consequently, quality control is often limited to visual inspection, artisan judgment, and corrective action after defects are found. This condition indicates a practical gap: quality control approaches for craft MSMEs must be compatible with manual production characteristics, operational capacity, and resource constraints. Previous studies have proposed several quality controls approaches for similar problems. Failure Mode and Effects Analysis (FMEA) is widely used to identify and evaluate potential failures based on severity, occurrence, and detection. FMEA has been applied in SME and industrial quality contexts, including batik production Susanto et al. (2025), short shelf-life food Sutanto et al. (2025), bakery Fithri et al. (2021), railway components Andy et al. (2024), milk-cheese supply chains Aleksic et al. (2022), and sustainability-oriented failure analysis (Von et al., 2022).

Traditional FMEA has a methodological limitation because the Risk Priority Number (RPN) assumes equal importance among severity, occurrence, and detection and may yield identical RPN values across different risk profiles (Liu et al., 2013). This limitation has encouraged the integration of FMEA with Multi-Criteria Decision-Making (MCDM) methods. Prior studies have combined FMEA with weighting, uncertainty-handling, and ranking techniques, including AHP, M-CRITIC, ABAC, Z-BWM, Z-WASPAS, ANP, and fuzzy-based approaches, to improve risk analysis and failure-mode prioritization (Ervural & Ayaz, 2023; Liou et al., 2022; Padwekar et al., 2026; Rahmatin et al., 2018; Sriwardany et al., 2025). Among these weighting techniques, the Best-Worst Method (BWM) developed by Rezaei (2015) requires fewer pairwise comparisons than AHP, thereby reducing the comparison burden for respondents, and produces consistent criterion weights without additional structural specifications, such as fuzzy membership functions or a full network of criterion interdependencies.

BWM has been widely applied in MCDM research across various decision-making domains Peykani et al. (2026), including urban resilience and regeneration, transportation modes, sustainable supply chain, and water management (Duleba et al., 2021; Hosseini et al., 2024; Ma et al., 2021; Moktadir et al., 2021). Grey Relational Analysis (GRA) can rank alternatives under limited information and uncertainty (Javed et al., 2022; Minguito & Banluta, 2023; Usgaonkar & Gaonkar, 2025). However, the use of an integrated framework that applies BWM and GRA together with FMEA in an artisanal manufacturing setting remains limited. This study addresses that gap by developing a BWM-FMEA-GRA for prioritizing quality failure risks in leather bag production. The integration is suitable for leather craft MSMEs because it can accommodate artisan-based production characteristics, limited availability of experts, and the lack of formal historical defect records. FMEA systematically identifies potential failure modes, BWM derives consistent criterion weights with fewer pairwise comparisons, and GRA prioritizes risk under limited and uncertain data conditions (Javed et al., 2022; Liu et al., 2013; Minguito & Banluta, 2023; Rezaei, 2015).

This study was conducted at a leather craft MSME in Yogyakarta. Preliminary observation identified customer complaints and 26 defects among 385 products manufactured in August 2025. These problems led to rework, raw material replacement, and potential reputational damage. Therefore, this study aims to prioritize quality failure risks in leather bag production using an integrated BWM-FMEA-GRA approach. The contribution of this study lies in the development of a

quality failure risk prioritization framework for leather bag production at MSME that integrates BWM-based risk-criteria weighting, FMEA-based failure-mode assessment, and GRA-based risk ranking as a basis for formulating systematic quality control recommendations. The remainder of this paper is organized as follows. Section 2 describes the research object, data, and the BWM-FMEA-GRA procedure. Section 3 presents the results of the criterion weighting, FMEA assessment, GRA prioritization, and the raw-material quality test results, along with proposed improvement recommendations. Section 4 concludes the study and outlines its limitations and directions for future research.

2. Method

2.1. Research Object, Population, and Sample

This study was conducted at a leather craft MSME in Yogyakarta from August to November 2025. The study adopted a case-based approach in which the framework was developed and applied within the specific production context of the studied MSME. The research object was the leather bag product line, which contributed more than 75% of the company's sales revenue. The detailed profile of the MSME is presented in Table 1.

Table 1. Profile of the MSME

Characteristics	MSME (leather bag production line)
Size (Total number of employees)	21
Location	Yogyakarta, Indonesia
Year of establishment	2015
Production system	Make-to-stock and make-to-order
Monthly production volume	100 – 600 pcs

The study covered production activities, potential product defects, and quality control practices. Purposive sampling was used because the study required respondents with direct knowledge of quality management and leather technology. The sample consisted of seven expert respondents for BWM and five internal production respondents for FMEA. The detailed sample structure is presented in Table 2.

Table 2. Respondent Criteria and Sample Size for BWM and FMEA

Method	Sample type	Criteria	Sample size
BWM	Expert respondents	Minimum 3 years of experience in quality management and/or leather process and product technology: academics in quality management, leather technology, and leather products (3 persons); an industrial consultant (1 person); leather product MSME practitioners/owners (3 persons).	7 persons
FMEA	Expert respondents	Directly involved in the leather bag production process at the MSME for at least 3 years: MSME owner, leather artisan, finishing staff, and assembling staff.	5 persons

In addition to the risk-prioritization analysis, failure risk at the raw material stage was further examined through diagnostic quality testing in accordance with SNI 06-0335-1989 (Indonesian National Standard for Cow Leather for Bags and Suitcases – Quality Requirements and Test Methods). One mold-contaminated cowhide sheet was selected as a test specimen based on the frequency of observed raw-material defects. The testing was conducted to verify a selected raw material failure mode and was not intended to represent all incoming leather lots.

2.2. Research Data and Instruments

Primary data consisted of production-process information, identified failure modes, expert judgments, and quality characteristics of a defective raw material. These data were collected through

direct observation, semi-structured interviews, focus group discussions, questionnaire-based expert assessments using BWM and FMEA instruments, and quality testing of defective raw material. The BWM instrument was used to obtain pairwise comparison judgments of the relative importance of severity, occurrence, and detection criteria on a 1–9 scale, while the FMEA instrument was used to evaluate ratings for each identified failure mode based on criteria adapted from (Ghoushchi, 2023; Ilbahar, 2022; Weeden, 2015). Secondary data consisted of production records and relevant literature. Quality testing of a defective raw material was conducted on moldy leather, which was identified as a priority failure risk. The testing was conducted in accordance with SNI 06-0335-1989. All testing procedures followed the methods specified in the standard.

2.3. Research Procedure and Analysis

The study was conducted through five stages illustrated in Fig. 1 and detailed as follows.

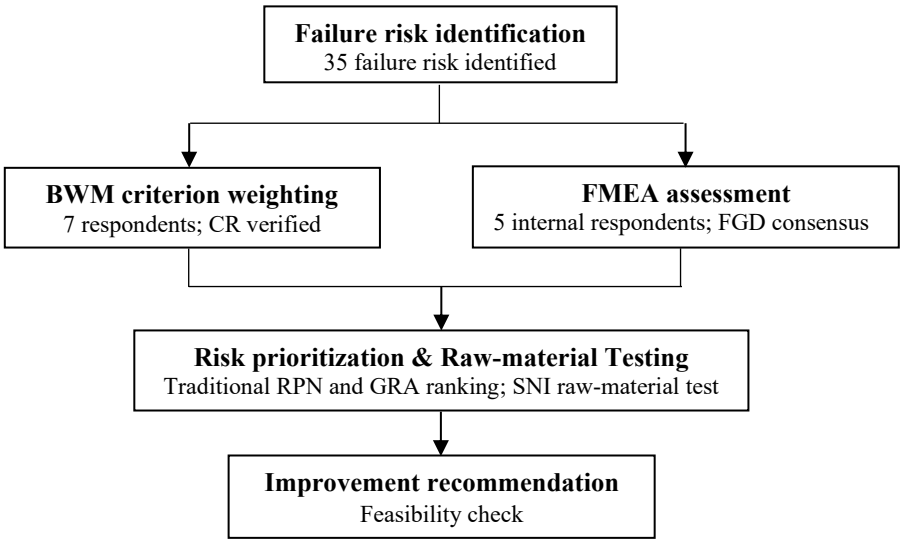


Fig. 1. Research procedure flowchart

Failure risk identification in the production process. Direct observation and interviews were conducted to identify all leather bag production processes and the failure risks occurring at each stage. Weighting FMEA criteria using BWM. The severity, occurrence, and detection criteria were weighted using BWM through pairwise comparisons by expert respondents. The criteria weights were obtained by minimizing the maximum deviation (ξ) between comparison vectors and weight ratios. The consistency of expert judgments was verified using the Consistency Ratio ($CR = \xi^*/CI^*$) based on Rezaei (2015) and the input-based consistency threshold proposed by (Govindbhai & Tathod, 2024). The respondent weights were aggregated using the normalized geometric mean. Assessment of failure risks using FMEA. The assessment of 35 failure risks was conducted through a structured focus group discussions by production staff using the Govindbhai & Tathod (2024) scale. Initial ratings were proposed by the staff specific to each stage and reviewed collectively (Weeden, 2015).

Minor discrepancies were resolved via consensus discussions grounded in historical defect data and operational experience. This open collaboration between the MSME owner and production staff facilitated direct communication, ensuring floor-level realities were accurately integrated. Prioritization of failure risks using GRA. GRA was applied to the severity, occurrence, and detection ratings of the 35 failure risks. The calculation followed the method of (Minguito & Banluta, 2023). Smaller-the-better normalization was used in Eq. (1) because higher ratings indicated worse risk conditions and greater distance from the ideal reference.

$$x_i^*(k) = \frac{\max x_i^{(0)}(k) - x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (1)$$

The Grey Relational Coefficient (GRC) was calculated using a distinguishing coefficient ($\xi = 0.5$), as shown in Eq. (2).

$$\xi_i(k) = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{0i}(k) + \xi \Delta_{\max}} \quad (2)$$

The Grey Relational Grade (GRG) was then calculated using the BWM criterion weights as shown in Eq. (3).

$$\gamma_i = \sum_{k=1}^{n} (w(k)\, \xi_i(k)) \quad (3)$$

Lower GRG values were interpreted greater distance from the ideal reference condition; therefore, failure risks with lower GRG values were given higher priority for improvement. When identical severity, occurrence, and detection profiles were found, tied GRG ranks were retained to avoid artificial rank separation.

Analysis of priority failure risks. Priority failure risks were analyzed based on the lowest GRG values and the tied high-priority profiles. For the moldy leather failure risk at the raw material receiving and storage stage, quality testing was performed on a mold-contaminated cow leather sample in accordance with SNI 06-0335-1989. The test result was used as diagnostic evidence to confirm the presence of quality nonconformity in the identified raw material failure risk.

3. Results and Discussion

3.1. Identification of Failure Risks in Leather Bag Production

The leather bag production process consists of the following steps: raw-material receiving and storage, order receiving, pattern making, leather cutting, lining cutting, leather skiving, logo embossing, lining attachment, panel assembly, sewing, accessory attachment, finishing, and packaging/storage/delivery. The production flow and quality-control checkpoints are shown in Appendix A, Fig. A1. Existing quality-control checkpoints relied primarily on visual inspections, including raw-material, embossing, finishing, and rework re-inspections. Identification produced 35 potential failure risks as detailed in Appendix A, Table A4 for further analysis.

3.2. Weighting FMEA Criteria using BWM

The FMEA criteria were weighted using BWM for severity, occurrence, and detection. The optimization was solved using the Microsoft Excel solver template provided by (Rezaei, 2016). The resulting weights were aggregated using a normalized geometric mean. The BWM results are presented in Table 3. Table 3 shows that detection obtained the highest weight (0.448), followed by severity (0.360) and occurrence (0.192). This result indicates that respondents consider the ability to identify quality failures before products reach the customer to be the most important risk-assessment criterion in the observed leather craft MSME.

The finding highlights the importance of early defect detection in minimizing quality failures throughout the production process. Disaggregating the individual weights by respondent occupation shows that three of the four practitioner-facing respondents (MSME owners RB1, RB2 and industrial consultant RB3) weighted detection highest, while the fourth (owner RB7) weighted severity highest. The three academic respondents (RB4, RB5, RB6), by contrast, each prioritized a different criterion, with no consistent pattern within this group. This pattern is a descriptive observation rather than a statistically robust subgroup difference (Chang, 2021; Filz, 2021).

Table 3. BWM Weighting Results for FMEA Criteria

Respondent	Occupation	B (Best)	O (Other)	W (Worst)	Comparison			Weighted Criteria		
					B-W	B-O	O-W	WS	WO	WD
RB1	MSME owner	Detection	Severity	Occurrence	7	3	3	0.236	0.091	0.673
RB2	MSME owner	Detection	Severity	Occurrence	9	7	2	0.125	0.097	0.778
RB3	Industrial consultant	Detection	Severity	Occurrence	2	2	1	0.250	0.250	0.500
RB4	Academic	Severity	Detection	Occurrence	9	5	3	0.758	0.077	0.165
RB5	Academic	Occurrence	Severity	Detection	9	6	2	0.135	0.781	0.083
RB6	Academic	Detection	Severity	Occurrence	7	5	2	0.157	0.100	0.743
RB7	MSME owner	Severity	Detection	Occurrence	9	5	2	0.762	0.083	0.155
Normalized Geometric Mean								**0.360**	**0.192**	**0.448**

Notes: B-W = Best-Worst; B-O = Best-Other; O-W = Other-Worst; WS = Weighted Severity; WO = Weighted Occurrence; WD = Weighted Detection.

3.3. Assessment of FMEA Criteria for Failure Risks

The identified qualitative failure risks were translated into severity, occurrence, and detection scores through FMEA assessment for subsequent risk prioritization using traditional RPN and GRA. The FMEA rating scales are presented in Appendix A, Table A1, Table A2 and Table A3. The 35 failure risks were then prioritized using the GRA method. The severity, occurrence, and detection scores were normalized using the smaller-the-better approach because higher scores represent worse risk conditions. The final Grey Relational Grade was calculated using the BWM-derived criterion weights, where lower GRG values indicated higher risk priority. Sensitivity analysis across $\xi = 0.1$–0.9 identified the same twelve highest-priority failure risks as the baseline ($\xi = 0.5$), with unchanged ordering. Spearman's ρ across all 35 failure modes ranged from 0.992 to 1.000, confirming the robustness of the priority ranking to variations in ξ. Traditional RPN was also calculated as a comparative indicator, and the complete results are presented in Appendix A, Table A4.

Comparatively, traditional RPN differentiated the 35 failure risks into only 9 distinct values (largest tie group = 13). In contrast, applying BWM-derived weights within the GRA framework improved this resolution to 17 distinct GRG values (largest tie group = 7). This empirical finding confirms the RPN tied-rank limitation documented by (Rahmatin et al., 2018). While their study resolved this issue using RPN fuzzification, the proposed framework achieves comparable tie-resolution without requiring fuzzy membership functions. Furthermore, compared to recent weighted-RPN models such as Sriwardany et al. (2025), the integrated approach enhances risk discrimination. Nevertheless, these improved GRA results remains a decision-support aid complementing managerial judgment.

3.4. Priority Failure Risks

Based on the GRA ranking in Appendix A, Table A4, 12 failure risks were identified as the highest priorities and summarized in Table 4. As detailed in Table 4, the 12 priority failure risks span nine distinct production stages, indicating that quality risks within artisanal set craft MSMEs emerge from systemic process vulnerabilities rather than isolated errors. The top-ranked risks, specifically inappropriate pattern making (FM8) and peeled or scratched components (FM32), illustrate how a heavy reliance on manual craftsmanship, unstandardized methods, and artisans' tacit knowledge precipitates significant quality deviations (Katongole, 2026; Kroezen et al., 2021). Dimensional inaccuracies during early-stage pattern making trigger a cascading propagation of errors throughout subsequent operations, manifesting as misaligned lining cutting (FM12) and excessive leather skiving (FM15). This defect trajectory aligns with the findings of Susanto et al. (2025), who observed that the absence of initial process standardization and rigorous pattern controls severely compromises overall product conformity. Furthermore, because these operational inaccuracies systematically propagate to downstream manufacturing stages, the prevention of visual and structural defects becomes paramount, as the market value of craft products is fundamentally contingent upon their aesthetic integrity and perceived authenticity (Filz, 2021; Gambicorti, 2026; Shafiee, 2021).

Table 4. Failure risk ranking based on GRA calculation

Code	Failure risk	Production process stage	Rank
FM8	Inappropriate pattern	Pattern making	1
FM32	Peeled/scratched component	Finishing	1
FM17	Overheated embossing	Logo embossing	3
FM15	Excessive skiving	Leather skiving	4
FM12	Size is not synchronized with the leather	Lining cutting	5
FM4	Moldy leather	Raw material receiving and storage	6
FM10	Leather stained by pen marks	Leather cutting	6
FM22	Excessive adhesive	Panel assembly	6
FM28	Incorrect attachment position	Accessory attachment	6
FM30	Unstitched component	Finishing	6
FM31	Stained component	Finishing	6
FM33	Cracked stitch edge	Finishing	6

The emergence of moldy leather (FM4) as a priority risk underscores a critical vulnerability in incoming material management, where latent defects often evade initial visual screening. As summarized in Table 5, the diagnostic assessment revealed significant nonconformities in three parameters. The elevated moisture content creates an environment highly conducive to fungal proliferation during storage under uncontrolled ambient conditions. The excessive total ash content indicates high levels of residual inorganic tanning salts, while the sub-standard thickness compromises the structural integrity and dimensional stability required for load-bearing bag components. These empirical findings confirm that receiving-stage quality assurance cannot rely solely on subjective visual inspection, making measurable parameter checks vital for preventing latent material failures from disrupting downstream production.

Table 5. Quality test results of the moldy leather sample based on SNI 06-0335-1989

Parameter	Value	SNI 06-0335-1989
Moisture content (%)	18.46	Max. 18
Total ash content (%)	5.16	Max. 2
Thickness (mm)	1.32	1.5 – 3.5

The remaining priority risks which are predominantly clustered at intermediate and finishing stages further illustrate the operational vulnerabilities of manual assembly. Spanning early, intermediate, and final production phases, these collective failure risks corroborate the findings of Sutanto et al. (2025), confirming that quality control in resource-constrained MSMEs cannot rely on reactive, end-of-line sorting. Instead, it necessitates a shift toward integrated preventive controls across entire artisanal production workflow. The proposed improvement recommendations were formulated using a modified Countermeasures Matrix, derived from the 12 priority failure risks obtained through GRA. Dominant causes were classified using the Ishikawa 4M+1E framework, referring to the cause categorization approach applied by (Vierci-Codas et al., 2025). The implementation priority was determined by multiplying the average technical and economic feasibility scores assessed by five internal respondents for the studied MSME. Scores of 6.34–9.00 were categorized as high priority, 3.00–6.33 as medium priority, and 1.00–2.99 as low priority. The detailed feasibility assessment results are presented in Appendix A, Table A5. Two recommendations were classified as high priority.

First, keeping sharp objects away from the finished-product area for the Environment component of FM32 (peeled or scratched component) was considered highly feasible due to its low implementation cost and potential to reduce rework. Second, replacing the sewing machine presser foot with a Teflon type and adjusting machine pressure for the Machine component of FM32 was recommended to prevent surface damage caused by direct machine-leather contact during sewing. The remaining recommendations were classified as medium priority. For FM17 (overheated embossing), applying temperature and time setting parameter labels and conducting scrap testing were proposed to strengthen process parameter control, as different leather articles respond differently to

heat and pressure. For FM4 (moldy leather), storage-environment monitoring was rated more urgent than administrative material-flow control. For FM8 (inappropriate pattern), standardizing pattern dimensions and documenting artisans' tacit knowledge were recommended to transform individual expertise into organizational knowledge. Recommendations addressing the Method-component failures (FM8, FM15, FM28, FM31, FM33) consistently emphasized work standardization, while the Man-component failures (FM12, FM30) highlighted operator self-inspection and accuracy. No recommendation was classified as low priority, indicating that all proposed actions are feasible within MSME resource constraints. Overall, the proposed recommendations suggest that quality improvement efforts at leather craft MSMEs should prioritize preventive control mechanisms over corrective inspections to maintain product quality consistency and minimize defect risk across production stages.

4. Conclusion

This study prioritized quality failure risks in leather bag production at an MSME in Yogyakarta using an integrated BWM-FMEA-GRA approach. It identified 35 failure risks across 13 production stages. Detection obtained the highest BWM weight, followed by severity and occurrence, indicating that failure detectability is a critical criterion in this MSME context. GRA identified 12 priority risks across nine production stages, with the highest risks being inappropriate pattern-making and peeled or scratched product components. Testing of moldy leather showed nonconformity in moisture content, total ash content, and thickness, as per SNI 06-0335-1989. All proposed improvement recommendations were classified as medium to high priority, indicating they are feasible for implementation at the MSME scale. Most priority failure risks were associated with the Method, Man, and Environment components, suggesting that product quality variation remained strongly influenced by dependence on individual artisan skills and insufficient standardization of work processes. Overall, the quality-control system in the leather bag production process should shift from a corrective approach toward a preventive approach.

This study has several limitations. First, the findings are based on a single-case design at one leather craft MSME. Second, the SNI 06-0335-1989 testing was performed on a single raw-material specimen of the moldy-leather failure mode. Third, FMEA ratings were derived from subjective FGD-based consensus judgments, reflecting the limited availability of formal historical defect data typical of MSME settings. Fourth, the same internal staff who identified the failure risks also assessed the feasibility of the corresponding improvement recommendations, potentially biasing feasibility scores toward locally familiar or convenient solutions. Future research could extend this framework by replicating the BWM-FMEA-GRA procedure across multiple leather-craft MSMEs to test its generalizability and to obtain a larger, more balanced expert panel capable of robustly testing the respondent-occupation patterns observed in this study.

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Conflicts of Interest: The authors declare no conflict of interest.

Declaration of AI-Tool Usage: AI-assisted tools were used to support manuscript proofreading, verify the consistency of variables and mathematical notation, and check reference formatting. All outputs were reviewed and verified by the authors, who take full responsibility for the accuracy and integrity of the final manuscript.

Appendix A

The appendix provides the FMEA rating scales for severity (Table A1), occurrence (Table A2), and detection (Table A3), the complete traditional RPN and GRA calculation results for all identified failure risks (Table A4), the feasibility assessment of the proposed improvement recommendations (Table A5), and the process flowchart and quality control checkpoints (Fig. A1).

Table A1. Severity rating scale

Rating	Effect	Description
6	Extreme	The company may stop operating or go out of business.
5	Major	The company may lose a significant market share or provide a major advantage to competitors.
4	Significant	Significant sales losses and/or customer-base decline occur, and the company develops a poor reputation.
3	Moderate	Sales decline and repeat purchases or repeat orders decrease.
2	Minor	Inconvenience and increased costs occur for the organization.
1	None	No effect occurs on the company or business.

Table A2. Occurrence rating scale

Rating	Effect	Failure rate	Description
5	Almost certain	1 in 5	Failure occurs all the time.
4	High	1 in 15	Failure occurs frequently or too often.
3	Medium	1 in 30	Failure occurs more often than desired, but not consistently
2	Low	1 in 50	Failure occurs occasionally.
1	Never	1 in 100	Failure has never occurred.

Table A3. Detection rating scale

Rating	Effect	Description
5	Almost impossible	Failure is not detected; when it occurs, the company treats it as part of normal business conditions.
4	Low	If customers complain, the company responds, but does not change its work practices.
3	Medium	The company recognizes recurring problems and investigates their causes to stop them from recurring.
2	High	Employees are trained to identify potential problems and record them so the company can respond quickly.
1	Almost certain	The company systematically reviews all processes, identifies potentially problematic areas, and establishes controls that trigger warnings when problems occur.

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Table A4. Complete traditional RPN and GRA calculation results for 35 failure risks

Production process stage	Code	Failure risk	Criteria score			RPN	RPN Rank	GRG	GRG Rank
			S	O	D				
Raw material receiving and storage	FM1	Wavy/collapsed leather	2	3	1	6	21	0.710	28
	FM2	Peeled/torn leather	2	2	1	4	28	0.743	29
	FM3	Uneven leather color	1	3	2	6	21	0.666	27
	FM4	Moldy leather	3	2	2	12	6	0.459	6
Order receiving	FM5	Customer requests detail changes	2	2	2	8	19	0.519	19
	FM6	Incomplete specifications	2	3	2	12	6	0.486	14
	FM7	Recording error	2	3	2	12	6	0.486	14
Pattern making	FM8	Inappropriate pattern	3	3	3	27	1	0.352	1
Leather cutting	FM9	Incorrect size	3	1	1	3	31	0.760	31
	FM10	Leather stained by pen marks	3	2	2	12	6	0.459	6
	FM11	Incorrect cutting position	2	1	1	2	32	0.820	32
Lining cutting	FM12	Size is not synchronized with the leather	2	2	3	12	6	0.445	5
	FM13	Incorrect cutting position	2	1	3	6	21	0.521	21
Leather skiving	FM14	Uneven skiving result	2	4	2	16	5	0.468	13
	FM15	Excessive skiving	2	3	3	18	3	0.412	4
Logo embossing	FM16	Unclear embossing	2	3	2	12	6	0.486	14
	FM17	Overheated embossing	3	2	3	18	3	0.385	3
	FM18	Incorrect logo position	2	2	1	4	27	0.743	29
Lining attachment	FM19	Imprecise attachment	2	3	2	12	6	0.486	14
Panel assembly	FM20	Imprecise assembly	2	1	2	4	28	0.596	25
	FM21	Component omitted	3	1	2	6	21	0.536	22
	FM22	Excessive adhesive	3	2	2	12	6	0.459	6
	FM23	Components interchanged	2	1	2	4	28	0.596	25
Sewing	FM24	Skipped/broken stitches	2	3	2	12	6	0.486	14
	FM25	Misaligned edge-binding stitch	1	2	1	2	32	0.923	35
	FM26	Misaligned leather stitches	2	2	2	8	19	0.519	19
	FM27	Incorrect thread type/color	3	1	2	6	21	0.536	22
Accessory attachment	FM28	Incorrect attachment position	3	2	2	12	6	0.459	6
	FM29	Incorrect accessory size/type	3	1	2	6	21	0.536	22
Finishing	FM30	Unstitched component	3	2	2	12	6	0.459	6
	FM31	Stained component	3	2	2	12	6	0.459	6
	FM32	Peeled/scratched component	3	3	3	27	1	0.352	1
	FM33	Cracked stitch edge	3	2	2	12	6	0.459	6
Packaging, storage, and delivery	FM34	Product scratched or deformed during packaging	2	1	1	2	32	0.820	32
	FM35	Mislabeling/miscoding	2	1	1	2	32	0.820	32

Table A5. Feasibility Assessment of Proposed Improvement Recommendations

Code	Failure risk	Production process stage	QC system component	Proposed improvement recommendation	T. score	E. score	Total score	Priority
FM8	Inappropriate pattern	Pattern making	Method	Standardize pattern dimensions for all artisans	1.80	2.80	5.04	Medium
			Man	Document the technical details of artisans' tacit knowledge	2.20	2.40	5.28	Medium
FM32	Peeled/ scratched component	Finishing	Machine	Use a Teflon presser foot; adjust machine pressure to leather characteristics	2.40	2.80	6.72	High
			Environment	Keep sharp objects away from the finished-product area	2.60	2.80	7.28	High
FM17	Overheated embossing	Logo embossing	Machine	Label leather-specific temperature and time-setting parameters; conduct scrap testing before production	2.40	2.60	6.24	Medium
FM15	Excessive skiving	Leather skiving	Method	Set leather-specific minimum thickness limits; use thickness gauge to inspect skiving results	2.00	2.40	4.80	Medium

Table A5. Continued.

Code	Failure risk	Production process stage	QC system component	Proposed improvement recommendation	T. score	E. score	Total score	Priority
FM12	Size not synchronized with leather	Lining cutting	Man	Mark the pattern direction on lining materials; inspect the pattern position and size before cutting	2.20	2.60	5.72	Medium
FM4	Moldy leather	Raw material receiving and storage	Environment	Monitor temperature and humidity of the storage room	2.20	2.40	5.28	Medium
			Method	Record incoming materials and implement a first-in-first-out system	1.80	2.00	3.60	Medium
FM10	Leather stained by pen marks	Leather cutting	Method	Replace pens with erasable markers and limit pen use in the production area	2.20	1.80	3.96	Medium
FM22	Excessive adhesive	Panel assembly	Material	Standardize leather-specific adhesive application and drying time; inspect adhesive application before sewing	2.00	2.00	4.00	Medium
FM28	Incorrect attachment position	Accessory attachment	Method	Mark attachment points and inspect positional symmetry before attachment	2.20	2.00	4.40	Medium
FM30	Unstitched component	Finishing	Man	Artisan self-inspection before process transfer	2.00	2.40	4.80	Medium
FM31	Stained component	Finishing	Environment	Establish a contaminant-free area and finished-product handling procedure	1.80	1.80	3.24	Medium
			Method	Apply cyanoacrylate adhesive in a controlled manner	1.80	2.40	4.32	Medium
FM33	Cracked stitch edge	Finishing	Method	Adjust leather-specific stitch settings; standardize the skiving thickness	1.60	2.80	4.48	Medium

Notes: T. score = Technical score; E. score = Economic score.

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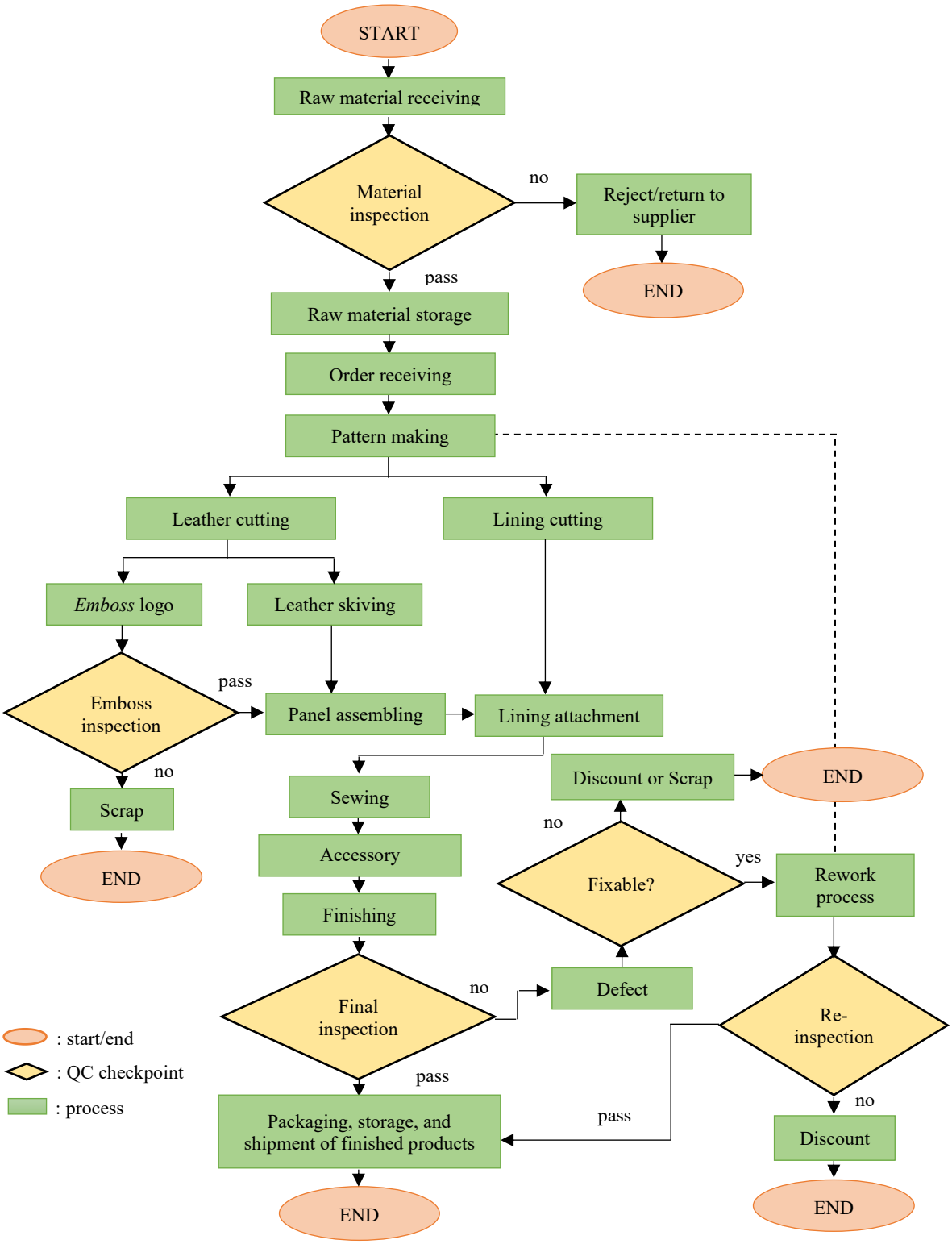


Fig. A1. Process flowchart and quality control checkpoints

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