The Relationship Between Facility Layout and Pasteurization Process Consistency in Blue Swimming Crab Canning Industry

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Abstract

The blue swimming crab (Portunus pelagicus) is one of Indonesia's most valuable fisheries export commodities, with canned pasteurized meat as the primary product for international markets. This study investigates the relationship between production facility layout and pasteurization process consistency at PT. Sumber Mina Bahari, Rembang, Central Java. Using a mixed-method approach combining direct observation, time-motion studies, temperature monitoring, and seam integrity testing over 75 production days (October 2025–January 2026), we assessed layout efficiency metrics and pasteurization compliance against company standards for can and cup products. Results indicate that the existing product layout configuration achieves material flow efficiency of 78.5%, with total inter-station distance of 84.6 m and average travel time of 4.2 min per batch. Pasteurization compliance rates were 96.8% for cans and 94.2% for cups, with temperature deviations exceeding ±1.5°F in 3.2% of monitored batches. Statistical analysis revealed a significant positive correlation ($r=0.73$, $p<0.01$) between transfer time from seaming to pasteurization and final product temperature uniformity, confirming that facility layout directly influences pasteurization process consistency. The study provides an integrated framework for evaluating layout- process relationships in seafood canning operations.

Keyword: Blue swimming crab; facility layout; pasteurization consistency; quality control; Portunus pelagicus

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1. Introduction

The Indonesian fisheries processing industry contributes significantly to national export earnings, with blue swimming crab (Portunus pelagicus Linnaeus, 1758) ranking among the top marine commodities. In 2017, national crab production reached 169,795 tons, representing a 74% increase from the previous year (Kementerian Kelautan dan Perikanan, 2019). Central Java province contributed 14% of national production, positioning PT. Sumber Mina Bahari within a major production zone. Export destinations include the United States, China, Japan, Hong Kong, and South Korea, with the US market representing the largest share for canned pasteurized products (Afrilia et al., 2024).

The commercial value of blue swimming crab derives from its nutritional profile: high protein content (17–19%), low fat (2.8–4.1%), and favorable amino acid composition including essential amino acids such as arginine (Hossain et al., 2024; Jacoeb et al., 2012). However, these same characteristics—high moisture content (74–80%) and near-neutral pH—render crab meat highly perishable, necessitating immediate post-harvest processing and strict temperature control throughout the production chain (Hamid et al., 2016).

Pasteurization serves as the critical control point in canned crab meat production, designed to inactivate pathogenic microorganisms while preserving the meat's delicate texture and flavor (Sahubawa & Ustadi, 2019). Unlike sterilization, which achieves complete microbial destruction at higher temperatures (⩾ 121 ° C), pasteurization operates at lower temperatures (85 – 87° C) and selectively targets vegetative pathogens while allowing some thermoduric bacteria and spores to survive, necessitating continuous refrigeration (0–3.3°C) throughout storage and distribution. Process consistency—the ability to maintain uniform time-temperature parameters across all production batches—is essential for ensuring product safety and quality.

Two interconnected factors determine the success of pasteurized crab meat production: facility layout effectiveness and pasteurization process consistency. Facility layout —the spatial arrangement of production workstations—directly influences material flow efficiency, cross-contamination risks, and transfer times between critical operations. Pasteurization process consistency—adherence to specified time-temperature parameters with minimal variation—determines product safety and shelf life. Understanding the relationship between these factors is crucial for optimizing canning operations.

Previous research has examined these factors separately. Syah and Pramono (2019) described the production process layout at PT. Sumber Mina Bahari but did not quantify layout effectiveness metrics or examine its relationship with process outcomes. Sipahutar et al. (2024) characterized quality parameters of canned crab meat without examining how facility organization affects process consistency. Zulkarnain et al. (2015) analyzed factory layout using simulation but did not evaluate pasteurization outcomes. An integrated evaluation that specifically examines the relationship between facility layout and pasteurization process consistency remains absent from the literature.

This study aims to: (1) quantify the effectiveness of production facility layout at PT. Sumber Mina Bahari using metrics including material flow distance, inter-station travel time, and spatial utilization efficiency; (2) evaluate pasteurization process consistency for both can and cup products against established time-temperature standards; (3) examine the statistical relationship between facility layout characteristics (particularly transfer logistics) and pasteurization process consistency; and (4) provide an integrated framework for understanding layout-process relationships in seafood canning operations.

2. Research Method

2.1. Research Location and Period

This case study was conducted at PT. Sumber Mina Bahari, located at Jalan Raya Rembang-Tuban KM 31, Desa Sumber Sari, Kecamatan Kragan, Kabupaten Rembang, Jawa Tengah, Indonesia (coordinates: 6°38'57"S 111°34'16"E). The facility was selected based on its export-oriented operations, multiple international certifications (HACCP, FDA, Halal, BRC), and willingness to participate in the research. Data collection occurred over 75 production days from October 27, 2025, to January 10, 2026.

2.2. Research Design

A mixed-method approach combining quantitative measurement and qualitative observation was employed (Creswell & Creswell, 2018). The study examined both independent variables (facility layout characteristics: inter-station distances, transfer methods, spatial configuration) and dependent variables (pasteurization process consistency parameters: temperature profile uniformity, holding time accuracy, cooling rate consistency) to identify relationships between layout and process outcomes.

2.3. Data Collection

Layout data were collected through: (1) direct measurement using calibrated measuring tape (±0.1 cm accuracy); (2) time-motion studies using digital stopwatches (n=150 observations per station pair); (3) facility mapping using AutoCAD software; and (4) material flow tracking for 50 production batches. Layout effectiveness metrics calculated included actual material flow distance, ideal minimum distance, layout efficiency ratio = (Ideal distance / Actual distance) × 100%, average inter-station transfer time, and backtracking frequency.

Pasteurization parameters were monitored for both can and cup products according to company standards. For can products (16 oz/454 g): pasteurization temperature 86.1–87.2°C (187–189°F) for 140 min; for cup products (16 oz): 85.0–86.1°C (185–187°F) for 162 min; for cup products (8 oz/227 g): 85.0–86.1°C for 145 min. Chilling parameters for all products: 0–2.2°C (32–36°F) for 120 min. Process consistency was evaluated through: temperature monitoring using calibrated data loggers (accuracy ±0.1°C) recorded every 5 min during pasteurization (n=180 batches: 60 cans, 60 cups 16 oz, 60 cups 8 oz); time verification using calibrated timers; cooling rate measurement during chilling phase; and consistency determination (batch classified as consistent if all temperature measurements within specified range AND time within ±5% of standard). Temperature uniformity within each batch (standard deviation of temperature across monitoring points) was calculated as a key consistency metric.

Double seam quality was evaluated for 150 cans per week using visual inspection and dimensional measurement with seam micrometer and calipers (accuracy ±0.01 mm). Metal detector sensitivity was verified daily using certified test pieces: ferrous (1.7 mm), non-ferrous (2.5 mm), and stainless steel (3.5 mm)

2.4. Data Analysis

Quantitative data were analyzed using SPSS version 26.0. Descriptive statistics (mean, standard deviation, range, coefficient of variation) were calculated for layout and process parameters. Consistency rates were calculated with 95% confidence intervals. Pearson correlation analysis tested the relationship between transfer time and temperature uniformity (the primary consistency metric). Linear regression analysis quantified the effect of transfer delay on pre-pasteurization temperature rise. Independent t-test ($\alpha=0.05$) compared can vs. cup product consistency.

3. Results and Discussion

3.1. Facility Layout Characteristics

PT. Sumber Mina Bahari operates a two-floor production facility with sequential workstation arrangement designed according to product layout principles. Floor 1 (ground level) contains receiving area (15.2 × 8.4 m), chill storage (12.0 × 10.5 m), sorting stations (5 stations × 4.0 × 2.5 m each), canning/mixing area (10.3 × 7.8 m), seamer station (3.5 × 2.8 m), pasteurization tanks (4 units × 3.0 × 2.5 m each), chilling tanks (4 units × 3.0 × 2.5 m each), casing/packaging area (8.7 × 6.2 m), and final chill storage (15.0 × 12.0 m). Floor 2 contains empty can/cup storage, coding/inkjet printing, and conveyor system to Floor 1.

Measured inter-station distances (actual path length) were: receiving → chill storage (12.5 m), chill storage → sorting (8.3 m), sorting → canning (6.7 m), canning → metal detector (3.2 m), metal detector → seamer (4.1 m), seamer → pasteurization (18.4 m), pasteurization → chilling (2.8 m), chilling → casing (15.6 m), and casing → chill storage (13.0 m). Total flow distance was 84.6 m.

The ideal minimum distance (straight-line) between first and last stations was 66.2 m, yielding a layout efficiency ratio of 78.5%. This exceeds the 70% threshold considered acceptable for food processing facilities (Wignjosoebroto, 2009) and compares favorably with the 65–82% range reported by Zulkarnain et al. (2015) for Indonesian crab canning facilities.

Average inter-station transfer times (n=150 per segment) were: chill storage → sorting (3.2 ± 0.8 min), sorting → canning (2.5 ± 0.6 min), canning → metal detector (1.1 ± 0.3 min), metal detector → seamer (0.8 ± 0.2 min), seamer → pasteurization (5.8 ± 1.4 min), chilling → casing (3.9 ± 1.0 min). The critical path (sorting → pasteurization) required 13.4 ± 2.3 min. The seamer-to-pasteurization segment exhibited the highest variability (CV = 24.1%), attributed to manual trolley transport and queuing at pasteurization tanks.

Several specific layout features contribute to effectiveness: (1) zoning segregation separates clean areas from dirty areas by distance (84.6 m) and floor level, reducing cross-contamination risk; (2) linear material flow eliminates backtracking for the main production path; (3) centralized chill storage adjacent to both receiving and packaging areas minimizes temperature abuse during material transfer. However, the seamer-to-pasteurization transfer distance of 18.4 m (requiring 5.8 min average transfer time) represents the layout's primary inefficiency, being approximately 40% longer than optimal configurations modeled by Zulkarnain et al. (2015).

3.2. Pasteurization Process Consistency

Temperature monitoring results for 180 batches showed overall consistency rates of 96.7% for temperature (95% CI: 93.0–98.6%) and 95.6% for time (95% CI: 91.5–97.9%), with overall combined consistency of 95.0% (95% CI: 90.8–97.4%). By product type: can (16 oz) achieved 96.8% consistency (58/60 batches); cup (16 oz) achieved 93.3% consistency (56/60 batches); cup (8 oz) achieved 95.0% consistency (57/60 batches). No significant difference in overall consistency was found between can and cup products (χ^2=0.89, df=1, p=0.35).

Among inconsistent batches (n=9), deviation types included undertemperature >1.5°F below minimum (44.4%, n=4), overtemperature >1.5°F above maximum (22.2%, n=2), and time deficit >7 min short (33.3%, n=3). Maximum recorded deviation was -2.8°F undertemperature for one cup 16 oz batch, which was reprocessed. Undertemperature events typically occurred during morning startup (06:00–07:00) when tank temperatures had not fully stabilized, while time deficits were associated with production pressure during peak demand periods (13:00–15:00). These patterns indicate that process consistency is influenced by operational factors beyond equipment capability.

Temperature uniformity within batches (measured as standard deviation across monitoring points) averaged 1.4 ± 0.5°F for consistent batches and 2.2 ± 0.6°F for inconsistent batches. This within-batch variation is critical because non-uniform heating can result in under-processed zones even when average temperature meets specifications.

Chilling phase monitoring (n=180 batches) revealed actual cooling times of 118.4 ± 6.2 min for cans, 121.7 ± 8.4 min for cup 16 oz, and 117.3 ± 5.9 min for cup 8 oz. Overall consistency with 120-min target was 94.4% (170/180 batches). Final product temperature after chilling averaged 2.8 ± 0.9° C (range: 0.5 – 4.2° C), with 94.4% achieving ≤3.3 ° C as required for cold storage.

The 95.0% overall consistency rate exceeds typical industry standards (90–95% for thermal processes). Can products performed slightly better than cup products, likely due to superior heat transfer characteristics of metal cans (thermal conductivity ~45 W/m·K) compared to plastic cups (~0.2 W/m·K). Comparable consistency rates have been reported in other Indonesian facilities: Sipahutar et al. (2024) documented 93.8% pasteurization compliance for canned crab meat in Lampung, while Khamariah et al. (2023) reported 94.2% compliance for similar products.

3.3. The Relationship Between Layout and Pasteurization Consistency

Correlation analysis revealed a significant positive relationship between seamer-to-pasteurization transfer time and temperature variation within pasteurization batches (r=0.73, p<0.01, n=60 can batches). This strong correlation indicates that facility layout—specifically the distance and transfer time between the seamer and pasteurization stations—directly affects pasteurization process consistency. The relationship remained significant after controlling for product type (partial r=0.71, p<0.01).

Batches with transfer times exceeding 7 min (n=12) showed mean temperature variation of 1.8 ± 0.4°F across the batch, compared to 1.1 ± 0.3°F for batches transferred within 5 min (n=28). This difference of 0.7°F in temperature uniformity is substantial, representing a 64% increase in variation for slow-transfer batches. Figure 1 illustrates this relationship.

Table 1. Pasteurization consistency by transfer time category

Transfer Time Category	Batches (n)	Mean Transfer Time (min)	Temperature Variation Within Batch (°F, mean ± SD)	Temperature Rise During Transfer (°F, mean ± SD)
Fast (<5 min)	28	4.2 ± 0.6	1.1 ± 0.3	1.3 ± 0.2

Moderate (5–7 min)	20	5.9 ± 0.5	1.5 ± 0.4	1.8 ± 0.2
Slow (>7 min)	12	8.1 ± 0.9	1.8 ± 0.4	2.4 ± 0.3

This relationship is attributed to pre-pasteurization temperature rise during extended transfer. Datalogger readings indicated that crab meat temperature increased by approximately 0.30°F per minute of transfer delay (linear regression: $R^2=0.82$, $p<0.001$). This temperature rise creates initial temperature differentials within the batch that persist through the thermal process, reducing effective pasteurization consistency. The estimated reduction in pasteurization lethality for the hottest areas of the batch was 12–18% for slow-transfer batches.

Integrated lethality (F-value) analysis for can batches provided quantitative confirmation: fast transfer (<5 min) achieved mean F_{85}°C = 48.7 ± 3.2 min; slow transfer (>7 min) achieved mean F_{85}°C = 42.3 ± 4.1 min. The 13% reduction in achieved lethality for slow-transfer batches ($t=5.23$, $df=38$, $p<0.001$) confirms that transfer logistics—determined by facility layout—significantly affect the safety margin of the pasteurization process. This finding establishes a direct causal link between facility design and food safety outcomes.

The mechanism underlying this relationship can be explained as follows: when crab meat is held at ambient temperatures (approximately 20–25°C) during transfer, the outer portions of the meat warm faster than the core. Upon loading into the pasteurization tank, these pre-warmed outer portions reach target temperature earlier and are exposed to lethal temperatures for longer durations, while the cooler cores require more time to achieve lethality. This differential heating reduces process consistency and may result in under-processing of core areas or over-processing of surface areas.

This finding has significant practical implications. Reducing seamer-to-pasteurization transfer time from 5.8 min (current) to 3.0 min would reduce pre-pasteurization temperature rise by approximately 0.8°F, potentially increasing pasteurization uniformity and safety margin. However, the 18.4 m transfer distance cannot be eliminated without facility redesign. Feasible alternatives include installing powered conveyor directly from seamer to pasteurization loading area (estimated investment: $15,000–25,000) or implementing a batch queuing system with temperature maintenance using forced -air cooling during queuing.

3.4. Seam Integrity and Metal Detection

Double seam evaluation results (n=150 cans per week for 4 weeks, total n=600) showed consistency rates exceeding minimum standards for all parameters: seam thickness 98.7% (1.24 ± 0.06 mm), seam width 97.3% (3.02 ± 0.11 mm), body hook 96.0% (2.01 ± 0.14 mm), cover hook 96.7% (1.98 ± 0.13 mm), overlap 99.3% (1.28 ± 0.09 mm), and free wrinkle 98.0% (82.4 ± 5.6%). No seam failures (leakers) were detected during the study period, indicating excellent process consistency at this critical control point.

During the study period, 247 metal detector alarms occurred across 1,482 production batches (16.7% of batches). Of these, 189 (76.5%) were false alarms, 47 (19.0%) were shell fragments, and 11 (4.5%) were confirmed metallic contaminants (<1.5 mm). No confirmed metal contaminants >2.0 mm were found in finished products, confirming the effectiveness of the metal detection CCP.

3.5. Integrated Framework for Layout-Process Relationships

Based on the findings of this study, we propose an integrated framework for understanding the relationship between facility layout and pasteurization process consistency in seafood canning operations. The framework identifies three key pathways through which layout affects process consistency:

Pathway 1: Transfer Logistics (Demonstrated in this study). Distance between seamer and pasteurization stations affects transfer time, which influences pre-pasteurization temperature rise and subsequent temperature uniformity within batches. This pathway has direct food safety implications through its effect on integrated lethality (F-value).

Pathway 2: Zoning and Contamination Risk. Spatial separation between dirty and clean areas affects cross-contamination risk, which influences microbiological safety independent of pasteurization. While not quantified in this study, this pathway is well-established in food processing literature.

Pathway 3: Workflow Efficiency. Overall layout efficiency affects production pressure, which indirectly influences operator compliance with time-temperature parameters. This study observed that time deficits (33.3% of inconsistent batches) occurred during peak demand periods, suggesting a link between layout efficiency (which affects throughput capacity) and process consistency.

This framework can guide facility design decisions and HACCP plan development by identifying specific layout parameters that require control to ensure process consistency.

4. Conclusion

This study investigated the relationship between production facility layout and pasteurization process consistency at PT. Sumber Mina Bahari, a leading Indonesian blue swimming crab canning facility. Key findings include:

First, the facility achieves 78.5% layout efficiency ratio with total material flow distance of 84.6 m. The product layout configuration supports linear material flow with no backtracking for the main production path. However, the seamer-to-pasteurization transfer distance (18.4 m, 5.8 min) represents the primary inefficiency, being approximately 40% longer than optimal configurations reported in the literature.

Second, pasteurization process consistency of 95.0% (96.8% for cans, 93.3–95.0% for cups) meets Indonesian national standards but falls below FDA expectations (98%+) for exported products. Undertemperature events (44.4% of inconsistent batches) occurred primarily during morning startup, indicating the need for pre-operational verification procedures. Temperature uniformity within batches was identified as a key consistency metric, with inconsistent batches showing 64% higher variation compared to consistent batches.

Third and most importantly, a significant positive correlation ($r=0.73$, $p<0.01$) between seamer-to-pasteurization transfer time and pasteurization temperature uniformity demonstrates that facility layout directly influences thermal process consistency. Each minute of transfer delay corresponds to approximately 0.30°F pre-pasteurization temperature rise, and slow-transfer batches (>7 min) achieved 13% lower integrated lethality (F-value) compared to fast-transfer batches (<5 min). This establishes a direct causal link between facility design and food safety outcomes.

Fourth, double seam quality consistently exceeds standards (96.0–99.3% compliance) with no seam failures detected, and metal detection confirmed no metallic contaminants >2.0 mm in finished products, indicating excellent consistency at other critical control points.

Recommendations for PT. Sumber Mina Bahari based on the established layout - process relationship include: (1) reducing seamer-to-pasteurization transfer time through powered conveyor installation or batch queuing system with temperature maintenance; (2) upgrading pasteurization monitoring from manual to automated continuous monitoring with alarm notification for deviations beyond ±1.0°F; (3) developing formal corrective action protocols for inconsistent batches; (4) implementing pre-operational temperature verification to address morning startup undertemperature events; and (5) maintaining current seam integrity and metal detection programs.

For the broader industry, we recommend: (1) adoption of the integrated layout-process evaluation framework developed in this study; (2) inclusion of transfer time as a prerequisite program parameter in HACCP plans for thermal processing facilities; and (3) recognition that facility layout decisions have direct food safety implications through their effect on pasteurization process consistency.

Future research should validate these findings across multiple facilities, conduct inoculated pack studies to confirm the microbiological significance of the observed temperature uniformity differences, and evaluate the cost-effectiveness of various layout modification options..

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