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Quality Control of Corrugated Carton Boxes Using Statistical Process Control to Minimize Defects at PT Bahana Buana Box

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Abstract

Corrugated carton manufacturing requires consistent sheet alignment, bonding, and dimensional conformity, yet defects in the corrugating process can increase material waste. This study assessed defect frequency, production stability, and potential corrective priorities at PT Bahana Buana Box. A descriptive quantitative observational design examined production and quality-assurance records from 30 production observations collected on 2–5 June 2026. Check sheets, a histogram, Pareto analysis, a p-control chart, and cause-and-effect diagrams were used. Among 57,760 corrugated sheets produced, 835 were rejected, representing a rejection rate of 1.45%. Misalignment was the largest category (388 sheets; 46.47%), followed by surface cracking (135), splice marks (127), delamination (105), and sheet buckling (80). The three leading categories accounted for 77.84% of recorded rejects. Under the originally reported constant control limits, 15 observations fell outside the specified boundaries, including 11 above the upper limit and four below the lower limit. Because production-run sizes differed, these classifications require independent verification using observation-specific limits. Potential contributing factors involved personnel, machinery, materials, operating methods, and environmental conditions. Recommended actions included operator inspection, preventive maintenance, material verification, standardized machine settings, and adhesive and environmental monitoring. The proposed measures were not implemented or evaluated; subsequent production monitoring is required to assess their effectiveness.

Keywords: *Control Chart, Corrugated Sheet, Defect Analysis, Quality Control, Statistical Process Control.*

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INTRODUCTION

The expansion of manufacturing, logistics, electronic commerce, and consumer goods distribution has increased the operational importance of corrugated carton boxes as protective and transport packaging. Product conformity in this industry depends on dimensional accuracy, flute consistency, adhesive bonding, printing precision, and mechanical resistance throughout successive manufacturing operations. The growing emphasis on zero-defect manufacturing has also strengthened the role of systematic quality monitoring in controlling production losses and maintaining reliable industrial performance (Fragapane et al., 2023). Mechanical quality remains a critical consideration because the edge crush resistance of corrugated board contributes to the structural performance of finished packaging under compressive loading (Garbowski et al., 2023). Technological developments in automated damage classification have further demonstrated the relevance of identifying physical deterioration and irregularities in corrugated boxes through systematic inspection procedures (Holland et al., 2024). However, the presence of inspection equipment and established product specifications does not necessarily prevent recurring defects when variations originate from interactions among materials, machinery, operating procedures, and production conditions. Effective quality control consequently requires a process-oriented assessment capable of identifying dominant nonconformities, evaluating production stability, and establishing corrective priorities based on measurable manufacturing evidence.

Existing research on carton packaging quality has developed several complementary approaches for detecting production irregularities, identifying their contributing factors, and supporting operational improvements. The application of New Seven Tools to carton-box manufacturing has illustrated the relevance of structured quality analysis for organizing production problems and

identifying areas requiring corrective attention (Amartya & Mahbubah, 2022). Conventional quality-control instruments have also been applied to cardboard-box production, providing a practical analytical framework for classifying defects and examining manufacturing conditions (Pratanca & Wasesa, 2024). A broader process-improvement perspective integrates total productive maintenance with Lean Six Sigma and the DMAIC methodology, connecting equipment reliability, operational performance, and quality improvement within cardboard-box manufacturing (Mares Castro & Ramírez Pérez, 2024). Statistical and computational approaches have extended packaging quality analysis through the combination of Six Sigma principles and data-mining techniques, indicating opportunities for more systematic identification of defect patterns (Ramadhani et al., 2023). These approaches collectively demonstrate that manufacturing quality depends not only on detecting defective products but also on selecting analytical techniques that connect defect characteristics, process variation, equipment conditions, and improvement decisions.

Despite these methodological developments, the relationship between defect classification, statistical process stability, and operational causes requires examination within the characteristics of individual corrugating operations. Research applying Statistical Process Control to carton-box production provides a relevant basis for evaluating manufacturing quality through statistical monitoring, although findings from one production environment cannot automatically establish the stability of another (Rahmawati & Shalshabilla, 2025). Statistical quality-control applications in carton packaging further demonstrate the relevance of quantitative defect assessment, while the interpretation of manufacturing performance remains dependent on the observed process and available production records (Whardana et al., 2024). The practical interpretation of control charts also requires attention to statistical assumptions, sampling arrangements, and the distinction between expected process variation and signals of unusual operating conditions (Zwetsloot et al., 2024). Research on zero-defect manufacturing emphasizes production performance and systematic defect prevention, but broad manufacturing assessments do not independently identify the operational causes of nonconformities at a particular corrugating facility (Fragapane et al., 2023). The resulting research gap is therefore not the absence of quality-control techniques, but the need for plant-specific evidence connecting the distribution of corrugated-sheet defects, the statistical stability of production runs, and the factors potentially responsible for recurring nonconformities. Addressing this gap requires an integrated assessment in which defect-frequency analysis, statistical control-chart interpretation, and cause-and-effect examination are applied to the same observed manufacturing process rather than treated as separate diagnostic activities.

PT Bahana Buana Box provides an industrial setting for examining these quality-control requirements through its production of corrugated carton packaging for manufacturing, food and beverage, consumer-goods, and logistics customers. Established in 1994 and commencing formal operations in February 1997, the company operates within Intan Group and the SCG Packaging network at Semarang–Demak Road, kilometre 16, Batu Village, Karangtengah District, Demak Regency, Central Java, Indonesia. Its manufacturing facilities occupy approximately 32,882 m² of land, including 30,714 m² of buildings, and comprise two corrugators with an annual capacity of 66,000 tonnes, seven printing machines with a capacity of 47,600 tonnes, and two die-cutting machines with a capacity of 9,500 tonnes, supported by approximately 363 employees. The production of B-flute, C-flute, and E-flute packaging requires consistency in corrugated-sheet formation and mechanical characteristics, making material integrity and resistance to deformation relevant dimensions of product conformity (Garbowski et al., 2023). Physical damage classification is equally relevant to quality inspection because visible deformation and structural irregularities can indicate packaging conditions that require further examination before products proceed to subsequent manufacturing stages (Holland et al., 2024). Evidence from cardboard-box manufacturing also establishes a connection between production improvement and equipment maintenance, reinforcing the practical need to examine defect occurrence alongside the operating conditions of machinery and associated production activities (Mares Castro & Ramírez Pérez, 2024).

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Figure 1. PT Bahana Buana Box Manufacturing Facility

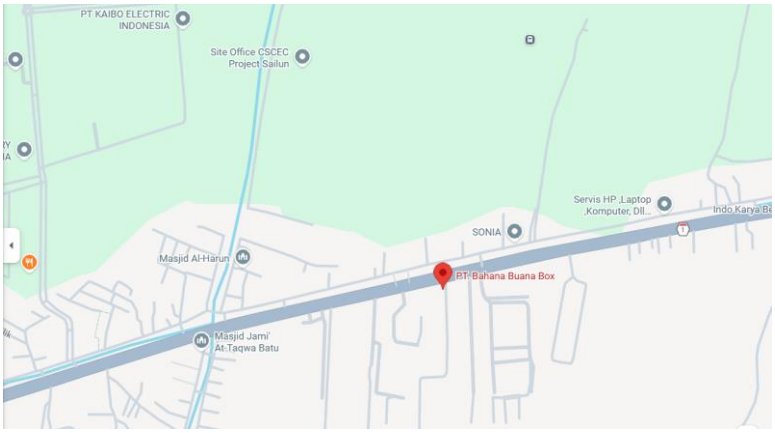


Figure 2. Location of PT Bahana Buana Box

Manufacturing activities at PT Bahana Buana Box begin with customer specifications and production planning, followed by corrugating, flexographic printing, converting, quality inspection, storage, and product distribution. The company's line-and-staff organizational structure assigns strategic responsibilities to senior management, operational coordination to departmental managers and supervisors, and production support to quality assurance, maintenance, logistics, and administrative personnel. During corrugating, the formation and bonding of kraft liner and medium paper require coordinated control of flute formation, sheet alignment, tension, and adhesive application, while quality-assurance procedures determine whether finished sheets satisfy established requirements. Preliminary production records for 2–5 June 2026 documented 57,760 manufactured sheets and 835 rejected sheets, including 388 sheets classified as misaligned, establishing a measurable basis for investigating defect concentration and process variation. The application of Statistical Process Control to carton-box production provides methodological support for examining such manufacturing records through systematic statistical evaluation rather than relying exclusively on final-product inspection (Rahmawati & Shalshabilla, 2025). Previous applications of quality-control tools in cardboard-box manufacturing also support structured defect categorization and the examination of potential operational causes, although these analytical procedures must be adapted to the characteristics of the observed production system (Pratanca & Wasesa, 2024). The proposed contribution is the integration of defect-category analysis, production-run observations, a p-control-chart assessment, and five-factor cause-and-effect analysis within one corrugating operation, with control-chart interpretation informed by the practical statistical considerations identified by Zwetsloot et al. (2024).



Figure 3. Organizational Structure of PT Bahana Buana Box

The present research aims to evaluate quality control in the corrugating process at PT Bahana Buana Box using Statistical Process Control to identify production defects and formulate targeted recommendations for minimizing nonconforming corrugated carton sheets. The investigation focuses on production records collected during 2–5 June 2026, examining manufacturing output, rejected-sheet quantities, defect frequencies, and the distribution of recorded nonconformity categories. Defect classification and frequency analysis are employed to establish the predominant quality problems and determine which categories warrant priority in subsequent operational evaluation. A p-control chart is used to assess variation in the proportion of nonconforming sheets across observed production runs and identify statistical indications of process instability. Cause-and-effect analysis is subsequently applied to organize potential contributing factors into five operational categories and develop corrective recommendations consistent with the identified defect characteristics and manufacturing conditions. The scientific contribution lies in a plant-specific integration of defect prioritization, statistical process-stability assessment, and operational cause analysis, while the practical contribution consists of evidence-based recommendations for quality improvement without claiming that the effectiveness of the proposed interventions has been experimentally established.

RESEARCH METHODS

A descriptive quantitative observational design was employed to examine quality control in the corrugating production area of PT Bahana Buana Box, using manufacturing observations and quality-assurance records collected from 2 to 5 June 2026 without experimental treatment, operator-level intervention, or pre–post evaluation. The dataset comprised 30 production observations involving 57,760 corrugated sheets and 835 recorded rejects, with individual sheets serving as the unit of defect measurement and production observations serving as the analytical units for statistical process monitoring. Production and quality-assurance records provided manufacturing dates, production volumes, rejected-sheet quantities, defect classifications, and shift and work-order information where available, while the analysis retained the original factory classifications and numerical records without introducing additional measurements. Defects were classified into five categories: liner/flute misalignment (Tidak Senter), surface cracking (Kemratak), splice marks (Sambungan), sheet buckling or folding (Ngelobot), and delamination (Ngelupas), with a structured check sheet used to consolidate their frequencies across production observations in accordance with established carton-box quality assessment practices (Amartya & Mahbubah, 2022). Recorded defects were subsequently organized into frequency distributions and presented through histograms, while Pareto analysis was employed to determine the relative contribution of each defect category to total production waste and establish quality-improvement priorities using established quality-control tools (Pratanca & Wasesa, 2024). This analytical procedure distinguished descriptive defect identification from statistical process evaluation, allowing the observed distribution of nonconformities to be examined alongside production stability through an SPC framework applicable to carton-box manufacturing (Rahmawati & Shalshabilla, 2025).

Statistical Process Control was implemented using a p-control chart to evaluate variation in rejected-sheet proportions across the 30 recorded production observations, with the individual

proportion calculated as $p_i = d_i/n_i$ and the overall centre line expressed as $\bar{p} = \Sigma d_i/\Sigma n_i$, where d_i represents rejected sheets and n_i represents inspected sheets in observation i (Zwetsloot et al., 2024). The nominal three-standard-deviation control limits were defined as $UCL_i = \bar{p} + 3\sqrt{[\bar{p}(1 - \bar{p})/n_i]}$ and $LCL_i = \bar{p} - 3\sqrt{[\bar{p}(1 - \bar{p})/n_i]}$, with negative lower limits replaced by zero to maintain the valid range of defect proportions. Although these formulas accommodate differences in observation sizes, the original calculation table and control chart applied constant comparison values of CL = 0.0145, UCL = 0.0226, and LCL = 0.0063 across all observations, which were retained when interpreting the submitted analytical results rather than replaced with recalculated observation-specific limits. Production observations were assessed against these reported reference boundaries to identify deviations requiring operational examination, while interpretations were restricted to statistical indications of process instability rather than claims of experimentally established causal relationships. Potential contributors to the identified defects were examined through a cause-and-effect diagram structured around five operational dimensions—people, machines, materials, methods, and environment—using recorded defect characteristics and manufacturing observations to organize possible sources of quality variation (Whardana et al., 2024). Corrective recommendations were formulated for operator monitoring, machine adjustment and preventive maintenance, raw-material inspection, adhesive application, and workplace temperature and humidity control, reflecting maintenance-oriented and systematic improvement practices in cardboard-box manufacturing while recognizing that the observational design did not establish the effectiveness of the proposed interventions (Mares Castro & Ramírez Pérez, 2024).

RESULTS AND DISCUSSION

Production Output and Defect Characteristics

Production records from the corrugating area of PT Bahana Buana Box cover 30 observations collected between 2 and 5 June 2026. The observed operation produced 57,760 corrugated sheets, of which 835 were classified as rejected products. This corresponds to approximately 1.45% of the recorded output, calculated from the aggregate number of rejected sheets and the aggregate production volume. Production volume and reject counts varied across dates and individual runs, making a single total insufficient to describe the distribution of quality losses. Research on reject monitoring in packaging production similarly treats recorded nonconformities as the basis for identifying quality-control priorities (Ali & Hariono, 2025). The analysis therefore considers daily output, individual production observations, and defect categories as complementary descriptions of the same manufacturing record.

On 2 June 2026, the production area recorded 18,220 sheets and 360 rejects, establishing the largest daily reject count in the four-day record. Output increased to 27,877 sheets on 3 June, whereas the number of rejected sheets decreased to 275. The following day recorded 4,491 produced sheets and 90 rejects, reflecting a substantially smaller production volume. On 5 June, output reached 7,172 sheets and the recorded reject count was 110. These daily differences indicate that absolute reject counts cannot be interpreted independently of the amount manufactured during each observation period. Previous analysis of carton-product quality has likewise employed production and nonconformity records to structure the evaluation of manufacturing performance (Prasetyo & Andesta, 2025). Table 1 reproduces the 30 recorded observations and their five defect-category counts without changing the reported figures.

Table 1. Corrugated Sheet Production and Defects, 2–5 June 2026

Date	Produced	Misalign.	Cracking	Splices	Buckling	Delamin.	Rejected
2 Jun 2026	1,340	10	10	5	0	0	25
2 Jun 2026	840	8	0	12	0	0	20
2 Jun 2026	1,000	40	40	0	20	0	100
2 Jun 2026	320	10	0	0	0	0	10
2 Jun 2026	2,500	20	25	0	0	0	45
2 Jun 2026	2,220	10	0	15	0	0	25
2 Jun 2026	2,000	10	0	0	15	0	25
2 Jun 2026	1,000	15	0	0	15	0	30
2 Jun 2026	4,000	15	0	0	0	15	30

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2 Jun 2026	3,000	20	0	20	10	0	50
3 Jun 2026	3,150	15	15	0	0	0	30
3 Jun 2026	3,000	10	0	0	0	0	10
3 Jun 2026	2,851	20	0	0	0	25	45
3 Jun 2026	1,240	20	0	30	0	0	50
3 Jun 2026	1,051	20	0	0	0	30	50
3 Jun 2026	210	10	0	0	0	0	10
3 Jun 2026	1,875	10	10	0	0	0	20
3 Jun 2026	3,500	10	0	0	10	0	20
3 Jun 2026	3,500	10	0	10	0	0	20
3 Jun 2026	7,500	10	0	0	10	0	20
4 Jun 2026	746	10	10	10	0	0	30
4 Jun 2026	228	10	0	0	0	0	10
4 Jun 2026	945	10	0	0	0	0	10
4 Jun 2026	2,000	10	0	10	0	0	20
4 Jun 2026	572	10	0	0	0	10	20
5 Jun 2026	1,050	10	10	0	0	0	20
5 Jun 2026	3,000	10	0	15	0	0	25
5 Jun 2026	572	15	0	0	0	0	15
5 Jun 2026	1,000	10	0	0	0	10	20
5 Jun 2026	1,550	0	15	0	0	15	30
TOTAL	**57,760**	**388**	**135**	**127**	**80**	**105**	**835**

The production-run information in Table 1 shows substantial variation in the number of sheets recorded within individual observations. Recorded run volumes ranged from 210 to 7,500 sheets, while rejected-sheet counts ranged from 10 to 100. The observation with 100 rejects occurred on 2 June 2026 in a run of 1,000 sheets, representing a much higher within-run reject proportion than the aggregate production rate. Other observations recorded 10 rejects despite substantially different production volumes, demonstrating why count-based comparisons alone may obscure variation in process performance. Practical guidance on control-chart monitoring distinguishes the observed fraction nonconforming from the raw defect count when subgroup sizes differ (Zwetsloot et al., 2024). The run-level dataset consequently provides the required numerical basis for the separate assessment of process stability presented later in the analysis.

Five categories of nonconforming corrugated sheets were retained from the factory record to preserve the technical distinction between different defect manifestations. Misalignment refers to displacement between the liner and fluted layer, with incorrect machine positioning or lateral paper movement identified as possible contributors. Surface cracking denotes visible fractures in the sheet, potentially associated with excessive roller pressure or unusually dry paper. Splice marks describe visible paper-roll joints, whereas sheet buckling refers to curved or folded material potentially associated with unstable tension or machine temperature. Delamination indicates separation between the liner and fluted layer, with insufficient adhesive application or inadequate bonding pressure identified as possible contributing conditions. Studies of corrugated-board strength show why the structural characteristics of the material must be distinguished from the mere presence of visible surface irregularities (Garbowski et al., 2023). Table 2 retains the original categories, observable descriptions, and indicated causes, with the cause statements treated as operational indications rather than verified causal findings.

Table 2. Recorded Waste Categories, Characteristics, and Indicated Causes

Defect Photograph	Defect and Observable Characteristic	Indicated Cause
	Misalignment — The liner and fluted layer are not aligned.	Imprecise machine settings or lateral movement of paper.
	Surface cracking — Cracks develop on the carton surface.	Excessive roller pressure or excessively dry paper.
	Splice marks — A paper-roll splice remains visible on the sheet.	Poorly aligned joining of paper rolls.
	Sheet buckling — The sheet is curved or folded.	Unstable paper tension or machine temperature.
	Delamination — The liner separates from the fluted layer.	Insufficient adhesive strength or improper roller pressure.

The classification presented in Table 2 separates positional, surface, joining, geometric, and interlayer-bonding nonconformities. This distinction matters because defects with different visible appearances need not arise from the same manufacturing condition. Mechanical analysis of corrugated cardboard establishes that the material can exhibit different responses under applied stresses, supporting attention to the particular form of observed damage rather than a single undifferentiated reject category (Boaca et al., 2024). Research on automated classification of corrugated-box damage also reflects the value of recognizing distinct physical manifestations during quality inspection (Holland et al., 2024). Nevertheless, descriptions such as excessive pressure, paper dryness, and adhesive inconsistency were not independently tested against linked operating measurements in the available records. The indicated causes therefore provide a structured basis for later fishbone analysis without establishing that any single mechanism produced the observed rejected sheets.

The check-sheet summary identifies liner/flute misalignment as the largest defect category, with 388 rejected sheets. Surface cracking accounted for 135 sheets and splice marks for 127, followed by delamination at 105 and sheet buckling at 80. Misalignment thus represented approximately 46.47% of all 835 rejected sheets, whereas the four remaining categories together accounted for 447 sheets. The difference between the largest and second-largest categories indicates a pronounced concentration of recorded nonconformities in sheet positioning. Structured quality-control tools applied to cardboard-box production provide an appropriate basis for ranking such categories before developing targeted corrective priorities (Pratanca & Wasesa, 2024). The check-sheet figures establish the scale of each category but do not independently demonstrate the financial cost or technical difficulty of preventing a given defect. Table 3 reproduces the original defect-category totals and preserves their recorded order.

Table 3. Check-Sheet Summary of Rejected Sheets

Defect Category	Rejected Sheets
Misalignment	388
Surface cracking	135
Splice marks	127
Delamination	105
Sheet buckling	80
TOTAL	**835**

The frequency distribution indicates that the five categories did not contribute equally to rejected production. Misalignment was recorded substantially more often than cracking, splice marks, delamination, or sheet buckling. The difference is relevant to operational prioritization because a defect affecting a larger number of sheets offers a larger numerical target for investigation, although the potential benefit of corrective action remains untested. Comparable packaging-quality analyses have used statistical quality-control methods to distinguish frequent nonconformities and support more focused inspection decisions (Whardana et al., 2024). Figure 4 presents the histogram corresponding to the category frequencies reported in Table 3. Its interpretation remains descriptive and should not be taken as evidence of specific failure mechanisms.

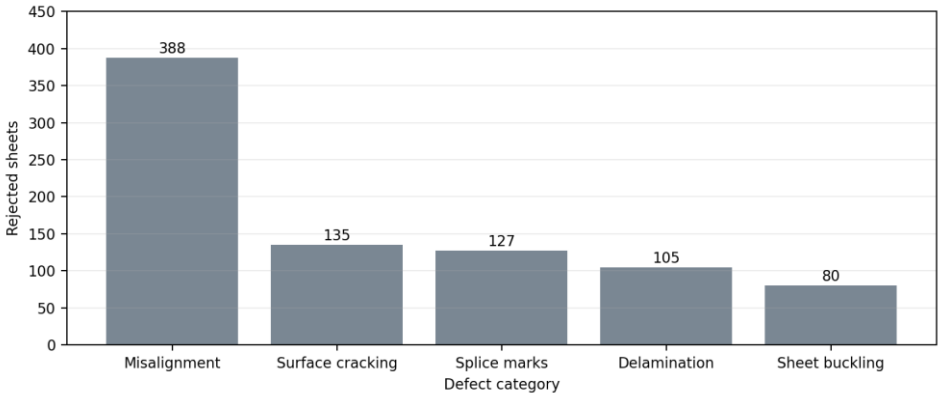


Figure 4. Histogram of Rejected Sheets by Defect Category

Taken together, the production record and defect classification establish the empirical basis for assessing where quality losses were concentrated during the observation period. The four-day record captures differences in production volume and reject frequency without supporting claims about longer-term trends. Misalignment emerges as the leading recorded defect, but cracking, splice marks, delamination, and buckling remain distinct quality concerns because they affect different characteristics of corrugated sheets. Earlier work on carton-box production has similarly used structured quality tools to organize manufacturing problems into categories that can be examined systematically (Amartya & Mahbubah, 2022). Research on packaging quality using Six Sigma and data-mining approaches further illustrates the analytical value of distinguishing recorded defect patterns before selecting improvement priorities (Ramadhani et al., 2023). The histogram and check-sheet totals support the identification of dominant defect categories, while the relative contributions are examined more explicitly through the Pareto assessment. Statistical assessment of run-to-run variation is also necessary because defect frequency alone cannot establish whether the corrugating operation was operating within reported control boundaries.

Defect Prioritization and Statistical Process Stability

Pareto analysis was applied to the 835 rejected corrugated sheets to determine the relative contribution of each defect category and identify the most concentrated sources of recorded production waste. The analysis used the five defect categories established through the check-sheet assessment, retaining their original frequencies while arranging them in descending order. Individual percentages

were calculated by dividing the number of rejected sheets in each category by the total rejected quantity and multiplying the resulting proportion by 100. Cumulative percentages were obtained by progressively combining the individual contributions, allowing the concentration of rejected products to be examined across successive defect categories. This approach distinguishes the numerical dominance of particular nonconformities from the wider distribution of manufacturing defects and provides a quantitative basis for selecting subsequent operational investigations. Research on quality-problem prioritization supports the use of structured quality-management tools to differentiate major nonconformities and establish systematic improvement priorities (Knop & Gejdos, 2024).

The Pareto distribution identified liner/flute misalignment as the dominant defect, accounting for 388 rejected sheets or 46.47% of the recorded waste. Surface cracking occupied the second position with 135 sheets, representing 16.17%, while splice marks followed with 127 sheets or 15.21%. The combined contribution of misalignment and surface cracking reached 62.63%, indicating that nearly two-thirds of rejected production originated from these two categories. Including splice marks increased the cumulative proportion to 77.84%, leaving delamination and sheet buckling responsible for the remaining 22.16%. Delamination contributed 105 rejected sheets or 12.57%, whereas sheet buckling accounted for 80 sheets or 9.58%. Comparable applications of quality-control instruments in cardboard-box manufacturing demonstrate the relevance of defect-frequency classification for establishing inspection and improvement priorities (Pratanca & Wasesa, 2024). Table 4 presents the unchanged category counts and their corresponding individual and cumulative percentages in descending frequency order.

Table 4. Pareto Distribution of Defect Categories

Defect Category	Count	Individual (%)
Misalignment	388	46.47%
Surface cracking	135	16.17%
Splice marks	127	15.21%
Delamination	105	12.57%
Sheet buckling	80	9.58%
TOTAL	**835**	**100.00%**

The distribution reported in Table 4 indicates a pronounced concentration of waste in a limited number of defect categories rather than an approximately equal contribution from all five classifications. Misalignment alone produced almost three times as many rejected sheets as surface cracking, establishing a substantial numerical difference between the first and second priorities. The cumulative contribution of the three leading categories reached 77.84%, suggesting that investigations directed toward alignment, surface integrity, and paper-roll joining would address the majority of recorded nonconformities. Previous research combining Six Sigma principles with data-mining approaches has similarly emphasized the analytical value of distinguishing defect patterns when examining packaging quality (Ramadhani et al., 2023). Nevertheless, a high defect frequency does not independently establish the severity of individual defects, the financial consequences of rejected products, or the feasibility of corrective measures. The Pareto findings should consequently be interpreted as evidence for prioritizing further investigation rather than as proof that intervention in the largest category would produce a proportional reduction in manufacturing losses.

The cumulative pattern also demonstrates that the two less frequent categories cannot be excluded from the quality-improvement programme without considering their distinct technical characteristics. Delamination involves separation between bonded corrugated layers, potentially affecting the structural integrity of sheets even when its observed frequency is lower than that of alignment defects. Experimental and computational investigations of corrugated-board mechanical characteristics indicate that material structure and resistance to deformation are relevant dimensions of packaging performance (Boaca et al., 2024). Sheet buckling represents a different form of nonconformity, involving geometric distortion that may interfere with subsequent printing, converting, or assembly operations. The observed category frequencies establish the relative scale of these problems but provide no direct measurement of their mechanical severity or associated economic losses. A defensible improvement sequence would therefore begin with the most frequent category while

retaining inspection controls for less frequent defects that may affect product functionality. Figure 5 presents the Pareto distribution of recorded corrugating defects and illustrates the progressive accumulation of rejected-sheet percentages across the five categories.

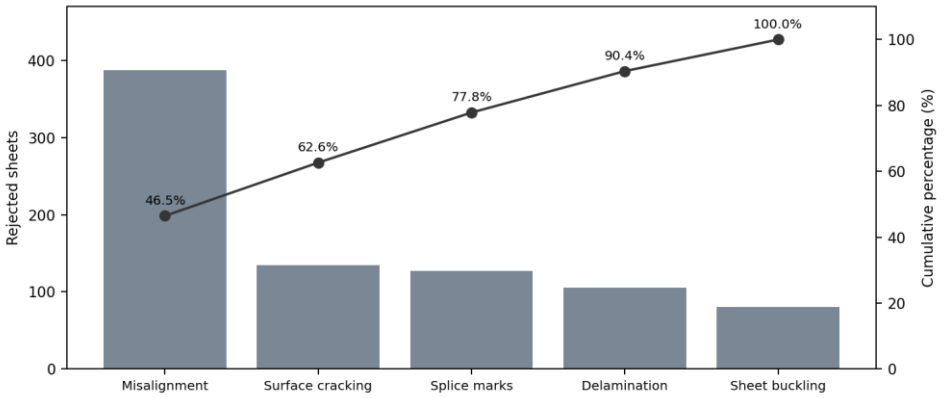


Figure 5. Pareto Chart of Recorded Corrugating Defects

Following the identification of dominant defect categories, Statistical Process Control was used to examine variation in the proportion of rejected sheets across the 30 production observations. The analysis employed a p-control chart, with each observation representing the number of rejected sheets relative to its corresponding production quantity. Observation volumes ranged from 210 to 7,500 sheets, creating substantial differences in the denominators used to calculate individual reject proportions. The submitted control-chart analysis reported a centre line of 0.0145, an upper control limit of 0.0226, and a lower control limit of 0.0063, applying these constant reference values to all observations. Statistical guidance on univariate control-chart monitoring emphasizes the importance of sampling structure and control-limit specification when interpreting departures from expected process behaviour (Zwetsloot et al., 2024). Table 5 reproduces the reported proportions and control-limit values without recalculating or replacing the original comparison boundaries.

Table 5. Reported P-Control-Chart Calculation Results

No.	Date	Produced	Defects	p	CL	UCL	LCL
1	02 Jun 2026	1,340	25	0.0187	0.0145	0.0226	0.0063
2	02 Jun 2026	840	20	0.0238	0.0145	0.0226	0.0063
3	02 Jun 2026	1,000	100	0.1000	0.0145	0.0226	0.0063
4	02 Jun 2026	320	10	0.0312	0.0145	0.0226	0.0063
5	02 Jun 2026	2,500	45	0.018	0.0145	0.0226	0.0063
6	02 Jun 2026	2,220	25	0.0113	0.0145	0.0226	0.0063
7	02 Jun 2026	2,000	25	0.0125	0.0145	0.0226	0.0063
8	02 Jun 2026	1,000	30	0.0300	0.0145	0.0226	0.0063
9	02 Jun 2026	4,000	30	0.0075	0.0145	0.0226	0.0063
10	02 Jun 2026	3,000	50	0.0167	0.0145	0.0226	0.0063
11	03 Jun 2026	3,150	30	0.0095	0.0145	0.0226	0.0063
12	03 Jun 2026	3,000	10	0.0033	0.0145	0.0226	0.0063
13	03 Jun 2026	2,851	45	0.0158	0.0145	0.0226	0.0063
14	03 Jun 2026	1,240	50	0.0403	0.0145	0.0226	0.0063
15	03 Jun 2026	1,051	50	0.0476	0.0145	0.0226	0.0063
16	03 Jun 2026	210	10	0.0476	0.0145	0.0226	0.0063
17	03 Jun 2026	1,875	20	0.0107	0.0145	0.0226	0.0063
18	03 Jun 2026	3,500	20	0.0057	0.0145	0.0226	0.0063
19	03 Jun 2026	3,500	20	0.0057	0.0145	0.0226	0.0063
20	03 Jun 2026	7,500	20	0.0027	0.0145	0.0226	0.0063
21	04 Jun 2026	746	30	0.0402	0.0145	0.0226	0.0063

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22	04 Jun 2026	228	10	0.0439	0.0145	0.0226	0.0063
23	04 Jun 2026	945	10	0.0106	0.0145	0.0226	0.0063
24	04 Jun 2026	2,000	20	0.0100	0.0145	0.0226	0.0063
25	04 Jun 2026	572	20	0.035	0.0145	0.0226	0.0063
26	05 Jun 2026	1,050	20	0.019	0.0145	0.0226	0.0063
27	05 Jun 2026	3,000	25	0.0083	0.0145	0.0226	0.0063
28	05 Jun 2026	572	15	0.0262	0.0145	0.0226	0.0063
29	05 Jun 2026	1,000	20	0.0200	0.0145	0.0226	0.0063
30	05 Jun 2026	1,550	30	0.0194	0.0145	0.0226	0.0063
Total	—	**57,760**	**835**	—	—	—	—

The control-chart results in Table 5 show considerable variation in recorded reject proportions across individual production observations. Using the original constant comparison limits, observations 2, 3, 4, 8, 14, 15, 16, 21, 22, 25, and 28 exceeded the upper control limit of 0.0226. Observations 12, 18, 19, and 20 fell below the lower control limit of 0.0063, producing four additional departures from the reported reference interval. These classifications yielded 15 observations outside the original limits, comprising 11 upper-limit exceedances and four lower-limit deviations. The third observation recorded the highest reject proportion at 0.1000, corresponding to 100 rejected sheets among 1,000 produced sheets. Investigations of statistical control-chart procedures distinguish unusually high defect proportions from observations exhibiting lower-than-expected values, since both types of deviations may indicate departures from an assumed stable process distribution (Alevizakos et al., 2024). Nevertheless, the identified observations represent departures from the fixed boundaries used in the submitted analysis and should not automatically be interpreted as equivalent to signals obtained from control limits adjusted for individual subgroup sizes.

The plotted observations also reveal differences between periods characterized by elevated reject proportions and those with comparatively low recorded rejection. Several upper-limit exceedances occurred on 2 and 3 June, whereas the fourth observation day included additional deviations associated with smaller production runs. The record does not establish whether these changes coincided with particular machine settings, paper lots, work orders, operating personnel, or environmental conditions. Research on manufacturing quality monitoring emphasizes the analytical importance of linking statistical signals with process information before attributing variations to specific operational mechanisms (Bono et al., 2023). Figure 6 displays the individual proportions against the original centre line and fixed control limits, preserving the comparison procedure documented in the submitted analysis. The resulting pattern indicates inconsistent recorded reject proportions under those boundaries, while leaving the underlying mechanisms and the effect of unequal observation sizes unresolved.

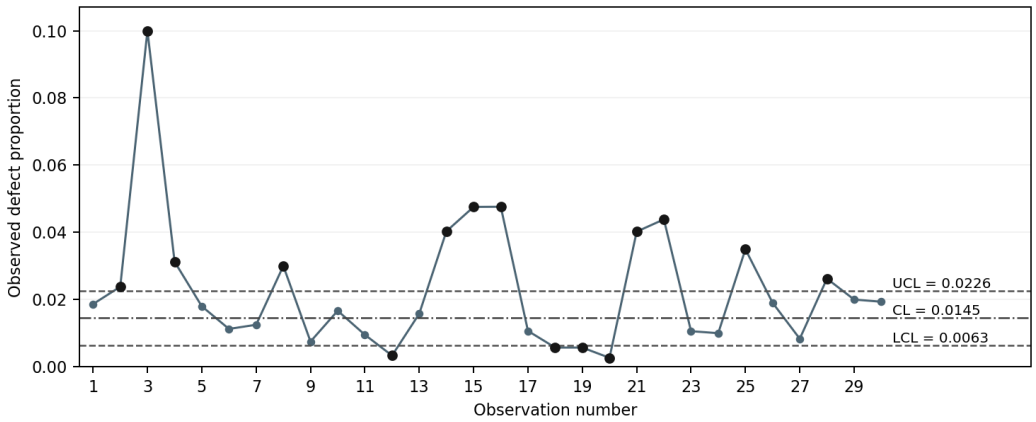


Figure 6. P-Control Chart Using the Control Limits Reported in the Original Analysis

The reported control-chart assessment suggests that the corrugating operation exhibited substantial variation in reject proportions during the four-day observation period. However, the use of

identical upper and lower limits across production runs ranging from 210 to 7,500 sheets introduces a methodological limitation because the sampling variability of a proportion depends on its denominator. Under a conventional p-control-chart formulation, observation-specific limits would account for subgroup size, potentially changing which points are classified as exceeding their statistical boundaries. Practical discussions of univariate control charts emphasize that inappropriate limit specification can affect the reliability of interpretations concerning process stability (Zwetsloot et al., 2024). The existing record therefore supports the identification of 15 deviations under the originally reported constant limits, but it does not establish that the same observations would remain outside limits calculated separately for each production volume. The Pareto findings and reported control-chart results serve different analytical purposes, with the former identifying dominant defect categories and the latter describing variation in rejected-sheet proportions across production observations. These findings provide a basis for investigating possible operational contributors through cause-and-effect analysis, without establishing causal relationships or demonstrating that any corrective intervention has already reduced manufacturing defects.

Root Cause Analysis and Proposed Quality Improvements

Cause-and-effect analysis was conducted to organize the potential contributors to corrugated-sheet defects identified through the production records, check-sheet assessment, and reported statistical process monitoring. The investigation classified possible sources of nonconformity into five operational dimensions: people, machines, materials, methods, and environment. These categories were developed from observed defect characteristics and descriptions of the corrugating operation, rather than from experimental manipulation or independently verified causal measurements. Research integrating statistical quality control with root-cause analysis in carton-box manufacturing provides a related analytical approach for connecting product nonconformities with potential production problems (Ataya & Marodiyah, 2026). Failure Mode and Effect Analysis and Fault Tree Analysis have also been applied to packaging-process quality assessment, illustrating alternative structured procedures for investigating manufacturing failures (Argaputra et al., 2025). Figures 7–11 present the indicated causes of misalignment, surface cracking, splice marks, sheet buckling, and delamination, preserving the five-factor classification and technical explanations provided in the original production assessment.

Misalignment constituted the principal quality problem, accounting for 388 rejected sheets or 46.47% of the recorded production waste. The personnel-related factors included insufficient attention to sheet positioning, delayed detection of positional deviations, and incorrect adjustments during machine operation. Potential machinery contributors involved off-centre paper rolls, inconsistent paper tension, and imprecise cutting or positioning components that could disturb the relationship between the liner and fluted layer. Differences in paper width, lateral roll displacement, and variations in material positioning were identified as material-related conditions potentially affecting sheet alignment. Method-related factors concerned unsuitable alignment settings, inconsistent tension adjustment, and delayed corrective responses, while changes in workplace temperature and humidity were considered possible environmental influences. Previous applications of Statistical Process Control to carton-box production support the examination of recurring manufacturing defects through process-level observations and structured quality monitoring (Rahmawati & Shalshabilla, 2025). However, the available production records did not contain corresponding measurements of alignment settings, tension fluctuations, material dimensions, or environmental conditions sufficient to establish which indicated factor produced each rejected sheet.

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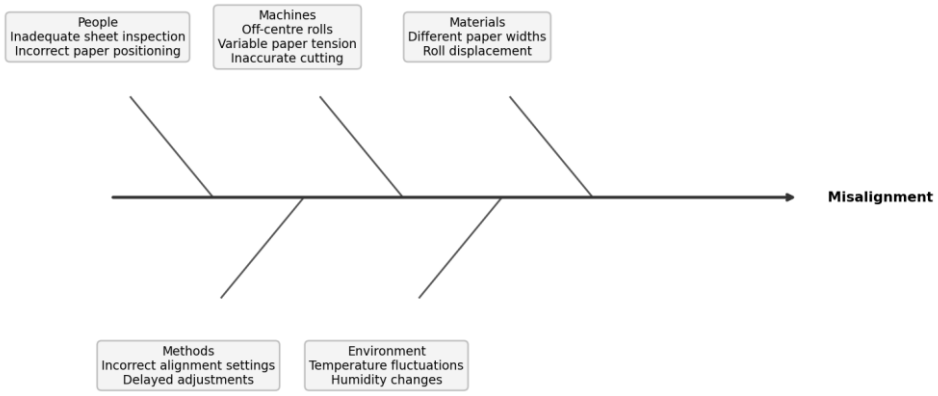


Figure 7. Cause-and-Effect Diagram for Misalignment

Surface cracking represented the second-largest defect category, with 135 rejected sheets, and was associated with possible irregularities in pressure application, flute formation, drying conditions, and paper characteristics. The identified contributing conditions included excessive corrugating-roll pressure, insufficiently controlled temperature, uneven adhesive application, and excessively dry paper that could increase susceptibility to visible surface fractures. Mechanical investigations of corrugated cardboard demonstrate the relevance of material deformation and stress response to packaging performance, although such findings do not independently confirm the cracking mechanisms proposed for the observed production process (Boaca et al., 2024). Splice marks accounted for 127 rejected sheets and were linked to improper paper-roll joining, inaccurate splice positioning, inconsistent material movement, and delayed recognition of joining irregularities. Research using the Taguchi method for cardboard quality improvement provides a related approach to examining manufacturing parameters, although the present assessment did not experimentally vary splice-positioning or paper-joining conditions (Siahaan et al., 2025). Predictive investigations of cardboard compression strength address measurable structural properties rather than the specific operational causes of visible splice marks, reinforcing the need to distinguish mechanical performance assessment from defect-source identification (Gajewski et al., 2024).

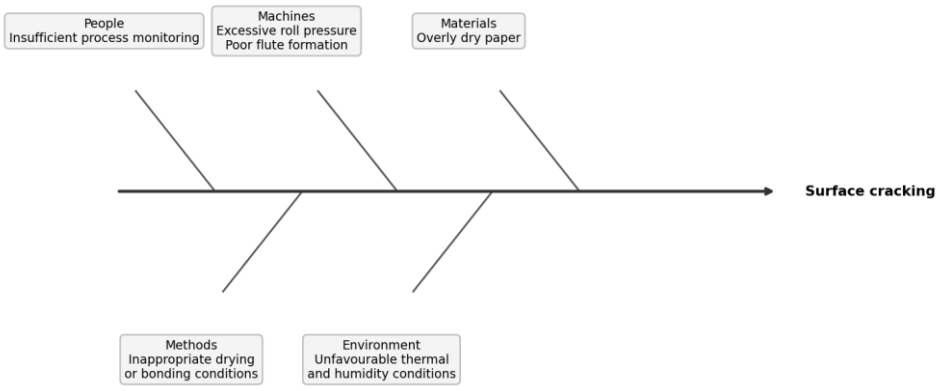


Figure 8. Cause-and-Effect Diagram for Surface Cracking

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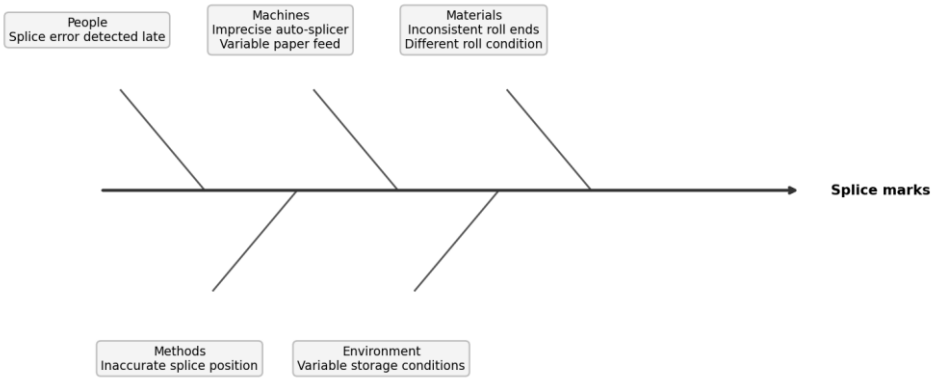


Figure 9. Cause-and-Effect Diagram for Splice Marks

Sheet buckling and delamination represented different manifestations of corrugated-sheet nonconformity, accounting for 80 and 105 rejected sheets, respectively. Buckling was associated with fluctuating paper tension, unstable flute formation, unequal roller pressure, and variation in the moisture condition of paper materials, potentially resulting in curved or folded sheets. Experimental research on corrugated paperboard subjected to sustained compression demonstrates the importance of material deformation characteristics, although those experimental conditions cannot establish the causes of buckling observed in the present corrugating operation (Fehér et al., 2024). Delamination involved separation between the liner and fluted layer, with uneven adhesive distribution, unsuitable glue thickness, insufficient bonding pressure, and ineffective drying identified as potential contributors. Particular attention was directed toward the glue roll, doctor roll, press roll, and hot plate because these components are associated with adhesive application and bonding conditions during corrugated-sheet formation. Research on the compressive performance of containerboard and corrugated boxes establishes the relevance of paperboard structural behaviour to packaging reliability, without providing direct evidence of the adhesive failures suspected in the observed operation (Holmvall, 2022). Studies using image-based classification of deformed corrugated board further distinguish the identification of physical defects from the verification of their manufacturing causes, a distinction retained in the interpretation of the present fishbone diagrams (Rogalka et al., 2024).

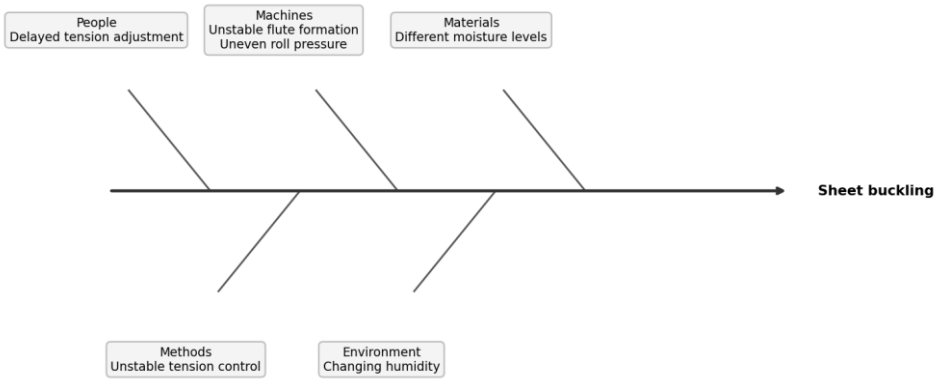


Figure 10. Cause-and-Effect Diagram for Sheet Buckling

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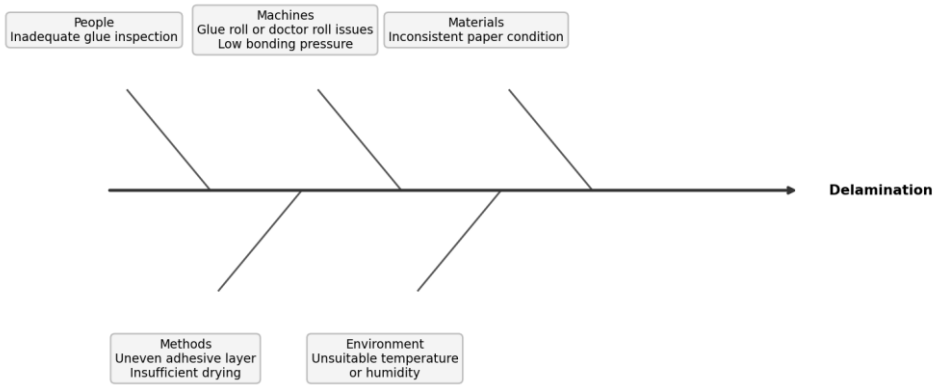


Figure 11. Cause-and-Effect Diagram for Delamination

The corrective-action framework was developed by relating the dominant defect categories to the potential contributing conditions identified in the five cause-and-effect diagrams. Misalignment received the highest improvement priority because its 388 rejected sheets represented the largest individual contribution to recorded waste, while corrective measures for cracking, splice marks, buckling, and delamination were retained to address other aspects of production quality. Fifteen proposed actions were organized around operator performance, machinery condition, raw-material conformity, operating procedures, and environmental stability, reflecting the operational dimensions identified through the analysis. Research integrating total productive maintenance with Lean Six Sigma in cardboard-box manufacturing supports the examination of equipment condition and process reliability as interconnected elements of production improvement (Mares Castro & Ramírez Pérez, 2024). Studies of zero-defect manufacturing similarly emphasize the relationship between preventive quality practices and production performance, supporting an improvement orientation that extends beyond the segregation of rejected products (Fragapane et al., 2023). Table 6 reproduces the fifteen proposed corrective actions and their associated contributing factors, without introducing untested interventions or modifying the original recommendations.

Table 6. Proposed Corrective Actions by Contributing Factor

Factor	Indicated Issue	Proposed Improvement
People	Inattentive operator inspection	Provide clear operating instructions and reinforce careful machine setting and process inspection.
People	Incorrect position and pressure settings	Establish setting standards and train operators to follow production requirements.
People	Insufficient monitoring of sheets, tension, and glue	Increase in-process inspections and correct deviations immediately.
Machines	Imprecise mill roll stand and slitter	Inspect and adjust machine positions regularly to maintain accurate sheet alignment.
Machines	Unstable tension meter	Inspect and calibrate the tension meter periodically.
Machines	Imprecise auto splicer	Inspect the auto splicer and verify adherence to roll-splicing standards.
Machines	Suboptimal corrugating and press rolls	Inspect roll condition and verify that roll pressures meet specified process settings.
Machines	Suboptimal glue roll, doctor roll, and hot plate	Inspect adhesive supply, glue thickness, press-roll pressure, and hot-plate temperature.
Materials	Inconsistent paper width	Check roll dimensions and condition before use.

Materials	Excessive dryness or nonuniform humidity	Store paper under suitable conditions to preserve moisture consistency.
Materials	Uneven roll ends and variable roll condition	Inspect roll ends before splicing and replace nonconforming material.
Methods	Incorrect alignment and tension settings	Specify alignment and tension settings and check them before production.
Methods	Incorrect pressure and temperature settings	Define pressure and temperature standards for corrugating rolls, press rolls, and the hot plate.
Methods	Uneven adhesive application	Check the distribution and thickness of adhesive and settings of the glue and doctor rolls.
Environment	Unstable temperature and humidity	Monitor production-area temperature and humidity and maintain suitable process conditions.

The personnel-oriented recommendations in Table 6 emphasize consistent operator inspection, accurate initial machine settings, and timely responses when sheet alignment, paper tension, or adhesive application deviates from operating requirements. Related applications of Statistical Process Control combined with error-prevention methods illustrate the relevance of standardized operating practices, although the present investigation did not implement or test a Poka-Yoke intervention (Fatimah & Iriani, 2022). Machinery recommendations address the mill roll stand, slitter, tension meter, auto splicer, corrugating roll, press roll, glue roll, doctor roll, and hot plate, with particular attention to positioning accuracy and operating consistency. Preventive inspection and periodic calibration were proposed to identify equipment irregularities before they contributed to additional rejected sheets, while maintenance documentation was recommended to support the examination of recurring machine-related conditions. Research applying Statistical Process Control in assembly operations demonstrates the broader relevance of integrating defect records with manufacturing-process monitoring, although the operating characteristics differ from corrugated-sheet production (Ilmi et al., 2023). Studies combining Statistical Process Control and Failure Mode and Effect Analysis in printing operations provide another methodological comparison for linking production defects with technical failure investigations (Saputra & Tauhida, 2024). Machine-learning approaches to quality monitoring in multistage manufacturing offer more advanced analytical alternatives, but no predictive algorithm or automated fault-detection model was implemented in the present observational assessment (Ismail et al., 2022).

Material-related recommendations concentrate on verifying paper width, inspecting roll-end conditions, identifying nonconforming materials before production, and maintaining suitable storage conditions to limit excessive variation in paper moisture. Operating-method recommendations include standardizing alignment and tension adjustments, specifying pressure and temperature requirements, and checking adhesive thickness and distribution before and during corrugating operations. Environmental recommendations concern the monitoring of production-area temperature and humidity because variation in these conditions was identified as a possible influence on paper stability, flute formation, and bonding consistency. Research on defect reduction in the packaging industry demonstrates the operational relevance of structured quality-improvement programmes, although findings from flexible packaging cannot be assumed to establish equivalent results in corrugated carton manufacturing (Keanoubie & Kusumastuti, 2025). Waste-minimization research applying the DMAIC methodology to packaging operations similarly illustrates the importance of linking corrective planning with subsequent evaluation, whereas the current investigation did not include an implemented improvement cycle (Dabic-Miletic, 2025). These recommendations remain operational proposals derived from the observed defect distribution and indicated contributing factors, since direct measurements of material moisture, adhesive thickness, equipment calibration, and environmental variation were not available to verify their respective effects.

The proposed improvement measures provide a structured basis for subsequent quality-control activities but do not constitute evidence that the identified defects have already been reduced. The observational design was restricted to 30 production observations over four working days, without experimental interventions, post-improvement measurements, or independent confirmation of the relationships represented in the fishbone diagrams. Earlier applications of Statistical Process Control to

plastic-box manufacturing demonstrate the broader use of statistical monitoring in box-product quality assessment, although their findings cannot establish the effectiveness of the recommendations developed for PT Bahana Buana Box (Mukti, 2021). Research on electrical-panel box quality similarly illustrates the transferability of statistical monitoring principles across manufacturing products while retaining differences in materials, production arrangements, and defect characteristics (Sudarsono, 2024). Statistical Process Control applications in industrial quality improvement indicate the relevance of evaluating manufacturing variation through documented production information rather than assuming that corrective proposals necessarily produce improved results (Mahaputri et al., 2025). Comparative literature on Statistical Process Control implementation further supports systematic evaluation of process conditions, although a review of applications cannot substitute for plant-specific verification of corrective effectiveness (Suyatno et al., 2025). Future validation would require continued production monitoring, documented adjustments, and comparison of rejection patterns after implementation, while the present contribution remains an observational integration of defect prioritization, reported statistical control-chart assessment, and operational cause analysis for corrugated carton quality improvement.

CONCLUSION

Quality control assessment at PT Bahana Buana Box during 2–5 June 2026 identified 835 rejected sheets from 57,760 corrugated sheets produced, representing an aggregate rejection rate of approximately 1.45%. Liner/flute misalignment constituted the dominant defect category, accounting for 388 rejected sheets (46.47%), followed by surface cracking (135 sheets), splice marks (127 sheets), delamination (105 sheets), and sheet buckling (80 sheets). The check-sheet analysis, histogram, and Pareto assessment established misalignment as the principal improvement priority, while the three leading defect categories collectively contributed 77.84% of recorded production waste. Statistical Process Control assessment using the originally reported constant limits of 0.0145 for the centre line, 0.0226 for the upper control limit, and 0.0063 for the lower control limit identified 15 observations outside the stated boundaries, comprising 11 upper-limit exceedances and four lower-limit deviations. These findings indicated substantial variation in recorded rejection proportions under the reported control-chart procedure, although differences in production-run sizes limited the statistical interpretation of the fixed control limits. Cause-and-effect analysis identified potential contributors across five operational dimensions—people, machines, materials, methods, and environment—without establishing experimentally verified relationships between individual factors and observed defects.

The findings support prioritizing corrective measures involving operator inspection and training, preventive machinery maintenance, paper-roll verification, standardized alignment and tension settings, adhesive application control, and workplace temperature and humidity monitoring. Particular attention should be directed toward the mill roll stand, slitter, tension meter, corrugating rolls, and other components affecting sheet positioning because misalignment accounted for the largest proportion of recorded nonconformities. The integration of defect classification, Pareto prioritization, statistical process monitoring, and five-factor cause-and-effect analysis provides a plant-specific analytical framework for identifying quality problems and organizing operational improvement priorities. However, the investigation was limited to 30 production observations collected over four working days at a single manufacturing facility, restricting conclusions about longer-term process behaviour and applicability to other production environments. The unequal production-run sizes and use of constant control limits further require subsequent verification through observation-specific statistical limits, while the proposed corrective actions remain untested because no post-intervention evaluation was conducted. Future assessments should document operating conditions, implement the prioritized improvements, and compare subsequent defect rates and statistical control-chart results to determine whether the recommended measures produce measurable and sustained reductions in corrugated-sheet rejection.

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