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Six Sigma DMAIC-Based Analysis of Defects in the Cement Bagging Process: A Case Study at PT Semen XYZ

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Abstract

This study evaluates quality performance in the cement bagging process at PT Semen XYZ using a Six Sigma framework with the Define, Measure, Analyse, Improve, and Control (DMAIC) stages. A descriptive quantitative case-study design was applied to production and rejected-bag records from September to November 2025, covering 6,315,978 inspected bags and 4,998 rejected bags. Data were collected through field observation, interviews with personnel in the packer area, and operational documentation. Under the explicit assumption that each inspected bag represents one opportunity for nonconformance, the analysis used defect proportion, defects per million opportunities (DPMO), sigma-level conversion, p control charts, Pareto analysis, a fishbone diagram, and root-cause analysis. The monthly DPMO values were approximately 741, 813, and 819, corresponding to sigma levels of 4.67, 4.65, and 4.64, respectively. These results indicate relatively good quality performance but also a gradual increase in the rejected-bag rate. Among classified defect occurrences, the rotary packer was reported as the leading process location, accounting for 46.87%, while the rotary packer and chute together accounted for 90.82%. Potential causes were mapped using the 5M+1E categories: man, machine, material, method, measurement, and environment. Because the recommended actions were not implemented during the observation period, the Improve and Control stages are presented as proposed improvement and control plans. The proposals prioritize preventive maintenance, material inspection, equipment calibration, operator competency development, procedure refinement, and environmental control.

1. Introduction

The cement manufacturing industry is strategically important to infrastructure development, while intense market competition requires producers to maintain consistent quality and operational efficiency. This production context increases the importance of controlling variation and preventing nonconforming products at each stage of the production system.

PT Semen XYZ operates a cement plant in West Java. The bagging process is the final production stage before distribution and therefore represents an important quality gate. Rejected bags may create material losses, rework, production disruption, customer dissatisfaction, and avoidable operating costs. Field observations indicated that packaging nonconformities may be associated with operator fatigue, packer and nozzle conditions, kraft-paper quality, reactive inspection practices, weighing-equipment calibration, humidity, temperature, and dust exposure. These observations suggest that packaging defects should be examined as the outcome of interacting process factors rather than as a machine problem alone.

Quality control is a systematic managerial process for ensuring that products conform to established requirements and customer expectations. This perspective is relevant to cement bagging because end-line rejection alone does not eliminate the underlying sources of process variation; prevention requires measurement, diagnosis, corrective planning, and continued monitoring.

Six Sigma provides a data-driven framework for measuring defects and reducing process variation. The DMAIC structure is generally described through five stages: Define, Measure, Analyse, Improve, and Control (Pyzdek & Keller, 2024). Syahril et al. (2024) elaborate that within this structure, the Define stage sets the scope of the quality problem, Measure quantifies the defect level, Analyse identifies the root cause, Improve designs corrective actions, and Control ensures that improvement is sustained over the long term. Mukhlis et al. (2023) further confirm that applying Six Sigma through the DMAIC approach can raise the sigma level of a quality-control process; after improvement recommendations were implemented, a cement company was reportedly able to increase its sigma value and reduce rework costs and defects, illustrating the effectiveness of Six Sigma in cement-industry practice. This structured approach is also increasingly relevant as manufacturing quality control moves toward more integrated, data-driven systems, including digitally enabled monitoring (Fathani et al., 2024).

The relevance of Six Sigma has likewise been demonstrated across other manufacturing sectors. Keanoubie & Kusumastuti (2025) show that Six Sigma-based quality control helps companies sustain customer satisfaction and market competitiveness, reducing not only defects but also the quality costs arising from nonconforming products and unstable processes. In the lightweight-brick packing context, Ariansyah & Nugroho (2025) similarly demonstrate the effectiveness of Six Sigma in controlling process variation and reducing defects, with DMAIC lowering elevated defect levels and improving both process stability and output quality. Widyaningrum & Al-faritsy (2026) found that the Define and Measure stages help determine Critical to Quality (CTQ) characteristics and sigma levels that are not yet optimal, while the Analyse stage can identify the main causes of defects originating from human, machine, and method factors, an approach that is similarly useful for identifying the causes of defects in product packaging. Fachrudin et al. (2025) show that the Six Sigma DMAIC method is effective in reducing the number of defective products in cotton-yarn production through dominant-defect identification, DPMO measurement, and process-improvement implementation that strengthens machine-usage understanding and operator work control, providing empirical evidence that Six Sigma DMAIC can systematically reduce process variation and defect rates in manufacturing. Perdana et al. (2024) add that the Analyse stage is key to successful Six Sigma implementation, because an error in identifying the primary cause will lead to an inappropriate solution. Rizkika et al. (2025) further emphasize that combining Six Sigma with a sustainability approach can generate energy efficiency and reduce industrial waste, producing a positive environmental impact. Saputra & Suef (2026) show that applying Six Sigma DMAIC together with digital, sensor-based control systems allows process performance to be monitored automatically, so that anomalies can be addressed immediately without waiting for manual inspection, an approach that is highly relevant for repetitive-process industries such as cement bagging.

Although cement-bagging quality has been examined in previous case studies, limited studies combine high-volume operational data, monthly defect-performance measurement, statistical stability assessment, process-location prioritization, and a 5M+1E-based improvement plan within one case. The present study therefore aims to: (1) evaluate quality performance in the cement bagging process using a DMAIC-based Six Sigma analysis; (2) identify priority defect modes, process locations, and potential causal factors using Pareto, fishbone, and root-cause analyses; and (3) formulate implementable improvement and control plans using the 5W1H framework.

2. Literature Review

2.1. Six Sigma, DMAIC, and Critical to Quality

Six Sigma is a data-driven approach for reducing defects and process variation. Conventionally, Six Sigma performance is associated with approximately 3.4 defects per million opportunities under the long-term 1.5-sigma shift assumption (Pyzdek & Keller, 2024). Mardiansyah et al. (2025) add that the essence of Six Sigma lies in continuous-improvement efforts that emphasize a deep understanding of the process, accurate measurement, and the use of statistical tools to identify root causes. A. Saputra & Hutagalung (2025) further explain that Six Sigma is increasingly developing into a more holistic approach through its integration with Lean Manufacturing and sustainability concepts, known as Lean Six Sigma (LSS), which focuses not only on reducing defects but also on eliminating non-value-added activities. Its value therefore lies in linking operational definitions, quantitative measurement, causal analysis, improvement decisions, and institutionalized control. Successful implementation nevertheless depends on management commitment, employee capability, reliable data, and a culture of continuous improvement; Prahara & Nawangpalupi (2021) highlight that Six Sigma implementation requires organizational-culture support, intensive employee training, and top-management commitment, and that without these factors, implementation often produces only short-term change without sustainability.

A Critical to Quality (CTQ) characteristic is a measurable product or process requirement that is important to the customer or to conformity with specifications. CTQs should therefore be distinguished from machines or process locations. In the present study, the principal CTQ is the conformity of the finished cement bag, particularly its physical integrity and suitability for handling and distribution. The rotary packer, conveyor, chute, and bag-cleaning unit are treated as process locations at which different defect modes may originate.

The DMAIC framework structures the analysis into five stages. Define specifies the problem, scope, CTQ, and process boundaries. Measure establishes baseline performance through defect proportion, DPU, DPO, DPMO, sigma-level conversion, and statistical process control. Analyze prioritizes the most important defect categories and investigates potential causes. Improve converts the diagnostic findings into corrective actions. Control specifies monitoring, responsibility, standardization, and verification mechanisms. In the present study, the Improve and Control stages are planning stages because the proposed actions were not implemented within the internship period.

The need for a comprehensive approach is also consistent with a broader view of quality control as a systematic effort to minimize defective production rather than as an isolated inspection activity. This supports integrating measurement, process diagnosis, procedural control, and managerial follow-up in manufacturing quality systems.

2.2. Statistical Process Control Using the p Chart

The p control chart is appropriate for attribute data in which each inspected unit is classified as conforming or nonconforming. Munawaroh et al. (2024) notes that statistical process control is central to modern quality management because it enables variation to be identified, measured, and controlled before it accumulates into significant nonconformance. The centre line is the average proportion nonconforming, while the upper and lower control limits vary with the number of inspected units in each observation period. A point outside the control limits indicates potential special-cause variation that should be investigated. However, the absence of points outside the limits is not sufficient by itself to demonstrate an acceptable process; run, trend, clustering, and other non-random patterns should also be examined.

Process stability and quality performance are conceptually different. A statistically stable process may consistently operate at an unacceptable defect level, while a process with a low average defect rate may still be unstable because of special causes. Consequently, p-chart interpretation should be discussed separately from DPMO and sigma-level interpretation.

3. Methods

3.1. Research Design and Setting

This research used a descriptive quantitative case-study design, conducted through an internship placement that combined direct work practice with data collection. Wilopo et al. (2025) found that internship experience and soft-skill competencies significantly influence students' work readiness, supporting the use of an internship-based design for this study, while Ainiyah et al. (2025) emphasize that structured personnel management, including field mentoring, contributes to operational productivity, a consideration reflected in how the Packer Division's personnel were engaged throughout data collection. The study was conducted in the Packer Division of PT Semen XYZ in West Java. The field placement ran from 1 September to 30 December 2025, while the production and rejected-bag data analysed in this article cover September-November 2025.

3.2. Unit of Analysis and Data Sources

The unit of analysis was an individual cement bag inspected during the bagging process. The quantitative dataset comprised monthly and daily production counts and rejected-bag records. Qualitative operational information was obtained from direct observations and interviews with personnel involved in the packer area, including the field coordinator, packer operators, and field attendants. Operational documents included production records, rejection records, maintenance information, calibration information, and applicable procedures where available.

3.3. Data Collection

Data were collected through three complementary techniques presented as a continuous process rather than as isolated procedures. Operational observation was carried out through direct observation of the bagging sequence, equipment conditions, operator activities, bag handling, and environmental conditions in the packer area, allowing the researcher to record process behaviour as it actually occurred on the production floor. This observation was triangulated with interviews conducted with relevant personnel, including the field coordinator, packer operators, and field attendants, to obtain explanations of recurring defects, machine disturbances, work methods, material conditions, measurement practices, and environmental constraints that could not be captured through observation alone. Finally, documentation was compiled from production volumes, rejected-bag counts, defect classifications, and supporting operational records, which together provided the quantitative basis for calculating quality indicators and constructing the control charts used in the Measure and Analyse stages.

3.4. Analytical Procedure

In the Define stage, the process boundary was mapped from cement discharge and bag filling through conveyor movement, chute transfer, bag cleaning, and preparation for distribution. The CTQ was defined as a conforming finished cement bag with acceptable physical integrity and handling condition. Defect modes and their process locations were then identified.

In the Measure stage, let D denote the number of rejected bags and U the number of inspected bags. DPU was calculated as D/U. Because the available records classified each bag as accepted or rejected, each inspected bag was treated as one opportunity for nonconformance (OP = 1). Accordingly, TOP = U x OP, DPO = D/TOP, and DPMO = DPO x 1,000,000. The sigma level was calculated using the conventional conversion sigma = NORM.S.INV(1 - DPMO/1,000,000) + 1.5. Monthly yield was calculated as (1 - D/U) x 100%. Process stability was evaluated using the p-chart. The centre line was p-bar = total D/total U. For observation i with sample size n_i, UCL_i = p-bar + 3√[p-bar(1 - p-bar)/n_i], and LCL_i = max{0, p-bar - 3√[p-bar(1 - p-bar)/n_i]}. Out-of-control points and non-random patterns were investigated as potential special causes.

In the Analyse stage, Pareto analysis was used to prioritize process locations or defect categories. Potential causes were mapped using a fishbone diagram structured around the 5M+1E categories: man, machine, material, method, measurement, and environment. Root-cause analysis used operational observations, interview information, and supporting records to assess the plausibility of the identified causes.

In the Improve and Control stages, improvement actions were formulated using 5W1H. Because implementation and post-intervention measurement were outside the observation period, the study reports a proposed improvement plan and a proposed control plan rather than verified causal effects.

3.5. Evaluation Criteria

The analysis was considered complete when it: (1) defined the CTQ and defect modes consistently; (2) reported transparent calculations of defect proportion, DPMO, yield, and sigma level; (3) differentiated process stability from defect performance; (4) prioritized process locations and mapped potential causes using 5M+1E; and (5) produced an operationally assigned improvement and control plan. Reduction in the rejected-bag rate was not treated as an achieved outcome because the proposed actions were not implemented during the study period.

4. Results and Discussion

4.1. Baseline Production and Rejected-Bag Data

The dataset covered 6,315,978 inspected cement bags and 4,998 rejected bags from September to November 2025. Monthly production volume was relatively stable, whereas the rejected-bag proportion increased across the observation period. Table 1 presents the baseline data.

Table 1 Inspected and Rejected Cement Bags, September-November 2025

No	Month	Units inspected (U)	Rejected bags (D)	Rejected proportion (D/U)
1	September	2,066,234	1,532	0.000741
2	October	2,137,791	1,737	0.000813
3	November	2,111,953	1,729	0.000819
	Total	6,315,978	4,998	0.000791

Source: Processed from PT Semen XYZ production records (2025).

The rejected proportion rose from approximately 741 per million inspected bags in September to 813 per million in October and 819 per million in November. Although the absolute increase was small relative to total production, the direction of change indicates deterioration rather than improvement and warrants investigation. Across the full period, the rejection rate was approximately 791 per million inspected bags, with an overall yield of 99.9209%.

4.2. Define Stage: CTQ, Defect Modes, and Process Locations

The principal CTQ was defined as a finished cement bag that maintained physical integrity and acceptable handling condition through the final production stage. The observed issues were therefore classified as defect modes, while the rotary packer, conveyor, chute, and bag-cleaning unit were classified as process locations or potential sources. This distinction prevents machines and process stages from being incorrectly treated as CTQ characteristics.

Table 2 Priority Defect Modes and Associated Process Locations

No	Process location	Priority defect mode	Operational description
1	Rotary packer	Filling-related nonconformity	Inadequate filling/discharge performance or insufficient bag venting during filling.
2	Conveyor	Puncture or tearing	Contact with bolts or conveyor components creates holes or tears.
3	Chute	Impact damage	Bags are damaged by impact or friction during transfer through the chute.
4	Bag-cleaning unit	Collision or jamming damage	Jamming and bag-to-bag collision damage the packaging.

Source: Processed by the researchers (2026).

4.3. Measure Stage: Defect Performance and Statistical Stability

Table 3 DPMO, Yield, and Sigma Level, September-November 2025

No	Month	DPMO (rounded)	Yield (%)	Sigma level
1	September	741	99.9259	4.67
2	October	813	99.9187	4.65
3	November	819	99.9181	4.64
	Overall	791	99.9209	4.66

Source: Authors' calculations.

The results indicate relatively good quality performance above the four-sigma benchmark, but a substantial gap remains before five-sigma performance (approximately 233 DPMO) and Six Sigma performance (approximately 3.4 DPMO under the conventional shifted model). The process should therefore be described as performing between four and five sigmas, not as approaching world-class quality.

The monthly p-chart analysis reportedly identified at least one point above the UCL in September and one in October, whereas the November points were reportedly within the calculated limits. This indicates greater statistical stability in November, but it does not indicate better defect performance: November had the highest DPMO and the lowest sigma level of the three months. Stability and quality level must therefore be interpreted separately.

4.4. Analyse Stage: Pareto Prioritization and Potential Causes

Among the classified defect occurrences used for the Pareto analysis, the rotary packer was reported to account for 1,301 occurrences or 46.87%, while the combined rotary-packer and chute categories accounted for 90.82%. These results place the two process locations at the highest priority for further diagnosis and corrective planning.

The fishbone and root-cause analyses identified potential causal mechanisms across six categories. These should be interpreted as operationally plausible causes derived from observations, interviews, and available records rather than as statistically verified causal effects.

Table 4 Summary of Potential Causes Using the 5M+1E Framework

No	Category	Potential cause	Possible effect on rejected bags
1	Man	Inconsistent stacking, PPE/procedure noncompliance, and fatigue	Reduced concentration and handling precision.
2	Machine	Conveyor contact, chute damage, rotary-packer disturbances, and inadequate maintenance	Collision, tearing, puncture, or filling-related nonconformity.
3	Material	Inadequate vent-hole dimensions or weak/variable kraft-paper quality	Lower resistance during filling and handling.
4	Method	Reactive quality monitoring, inconsistent filling/handling methods, and inadequate stacking procedure	Higher probability of recurring nonconformity.
5	Measurement	Inadequate calibration frequency or unstable weighing accuracy	Undetected filling deviations and unreliable process decisions.
6	Environment	High temperature, humidity, and dust exposure	Reduced bag durability and operator concentration.

Source: Processed by the researchers (2026).

Quantitative validation would strengthen the causal claims. Relevant evidence could include defect rates by machine, shift, and operator; maintenance and breakdown history; measured bag-paper properties and vent-hole dimensions; calibration records; bag-weight deviations; temperature and humidity records; and a documented Five Whys analysis for each priority defect mode.

4.5. Proposed Improvement Stage

Based on the diagnostic findings, Table 5 presents a proposed improvement plan. The actions have not yet been tested; their effectiveness should be evaluated through pre-post comparison or a controlled pilot where operationally feasible.

Table 5 Proposed Improvement Plan

No	Action	Rationale	Area	Timing	Responsible unit	Implementation method	Verification indicator
1	Revise rejected-bag inspection and handling procedures	Monitoring is predominantly reactive	Packer area	Monthly review	QC supervisor	Revise procedure, brief operators, verify understanding	Procedure-compliance score and rejected-bag trend
2	Conduct preventive maintenance on the rotary packer, conveyor, chute, and bag cleaner	Machine-related disturbances are a priority source	Packer area	Weekly/monthly schedule	Maintenance team	Component checklist, planned maintenance, closure of findings	Maintenance completion, downtime, defects by machine
3	Strengthen incoming bag-material inspection	Vent-hole and paper quality may vary	Receiving area	Every receipt	Material QC team	Sampling, specification checks, supplier corrective action	Acceptance rate and supplier nonconformity rate
4	Calibrate weighing and filling measurement systems	Measurement error may conceal filling variation	Packer area	Defined calibration interval	QC/metrology and maintenance	Zero/span checks, calibration, status labeling	Calibration compliance and bag-weight conformity
5	Conduct operator competency and fatigue-control measures	Handling variability and fatigue may contribute to defects	Packer area	Quarterly and after procedure changes	Production and HR	Technical training, assessment, shift review, coaching	Competency scores and defects by shift

No	Action	Rationale	Area	Timing	Responsible unit	Implementation method	Verification indicator
6	Control humidity, temperature, and dust	Environmental conditions affect bags and operators	Packer area	Continuous monitoring	HSE team	Monitoring, ventilation/exhaust improvement, housekeeping	Environmental readings and corrective-action closure

Source: Processed by the researchers (2026).

4.6. Proposed Control Stage

The proposed control plan includes: (1) routine monitoring of rejected-bag proportion, DPMO, and p-charts; (2) controlled revision and periodic audit of operating and inspection procedures; (3) preventive-maintenance and calibration schedules with documented completion; (4) competency assessment following training; (5) supplier and incoming-material quality monitoring; (6) environmental monitoring and HSE corrective action; and (7) monthly management review of trends, special causes, action owners, and overdue items. A verified reduction in rejected bags should be assessed only after implementation and an adequate post-intervention observation period.

4.7. Evaluation of the DMAIC-Based Analysis

The study completed the analytical components of Define, Measure, and Analyze and produced proposed Improve and Control plans. It did not complete an intervention cycle because the recommendations were not implemented and post-improvement performance was not measured. Accordingly, the findings provide a structured baseline and operational decision framework, but they do not demonstrate that the proposed actions reduce the rejected-bag rate.

4.8. Comparison with Previous Research and Managerial Implications

The emphasis on machine and method factors is consistent with earlier cement-bagging studies. Sugiyanto et al. (2014) similarly found that torn-bag defects in cement packing were closely tied to machine adjustment and handling method. Yonathan et al. (2020) likewise reported that cement-bagging quality problems at another cement producer were dominated by machine and work-method factors. This pattern is also broadly consistent with other DMAIC studies of packaging and manufacturing defects: Ariansyah & Nugroho (2025) reported that Six Sigma DMAIC was effective in controlling packing-related process variation in a comparable bulk-product setting, while Mukhlis et al. (2023) reported that the DMAIC method was effective in reducing paper-bag defects in the cement industry. The prominence of the rotary packer in the present study is therefore operationally plausible because filling accuracy, bag positioning, venting, discharge pressure, and component condition converge at this process point.

The present results also illustrate why process stability cannot be equated with good quality performance. November was reportedly statistically stable but recorded the highest rejected-bag proportion. This implies that common-cause variation may have stabilized around a performance level that still requires improvement. Managerial attention should therefore address both special-cause events and the underlying system that determines the baseline rejection rate.

The proposed 5W1H actions support a holistic quality-control system consistent with Ahmad (2025), who emphasizes the importance of integrated, continuously evaluated quality-management practice in reducing defective output. In the present study, this integration is reflected through standard procedures, equipment reliability, operator capability, material control, measurement assurance, and periodic evaluation. However, priorities should be selected using expected impact, implementation feasibility, cost, and the strength of available causal evidence.

5. Conclusion

This study applied a DMAIC-based Six Sigma analysis to 6,315,978 inspected cement bags and 4,998 rejected bags recorded from September to November 2025. Under a one-opportunity-per-bag assumption, monthly DPMO increased from approximately 741 to 813 and 819, while the corresponding sigma level declined from 4.67 to 4.65 and 4.64. The process therefore demonstrated relatively good but deteriorating quality performance between four and five sigmas.

The CTQ was clarified as finished-bag conformity and physical integrity, while the rotary packer, conveyor, chute, and bag cleaner were treated as process locations associated with priority defect modes. The rotary packer was reported as the dominant category in the classified Pareto data, and potential causes were mapped across man, machine, material, method, measurement, and environment. These causes require further empirical validation using maintenance, calibration, material, environmental, and shift-level evidence.

The study proposes preventive maintenance, incoming-material inspection, measurement-system calibration, procedure refinement, operator competency development, environmental control, and periodic audit. Because the actions were not implemented during the study period, no causal reduction in rejected bags can yet be claimed. Future research should use a longer observation period, reconcile the complete Pareto dataset, publish the p-charts and daily data, implement prioritized interventions, and conduct post-intervention measurement using methods such as FMEA, designed experiments, or interrupted time-series analysis where appropriate.

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