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Strategies for Improving Production Quality in the Context of Product Transition in the Paper Manufacturing Industry

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ABSTRACT
Digital disruption has shifted global paper demand, reduced graphic paper consumption while increased packaging paper demand due to e-commerce growth. In response, a paper manufacturer converted one machine line (PM1) from newsprint to 50-gsm recycled-fiber packaging paper. Post-conversion, PM1 experienced non-salable output exceeding the 8% quality threshold, with three dominant defects accounting for 80.2% of occurrences (Pareto) and generating internal failure costs of IDR 4.39 billion in losses. The objective of this research is to determine the current baseline using Defect Per Million Opportunity (DPMO) and sigma level measurements and to address the elevated dominant defects. The study proposes a quality improvement framework that integrates Six Sigma–DMAIC with a Quality Improvement Matrix (QIM), primarily to map initial performance, identify the root causes of defects, and prioritize improvement actions by considering their effectiveness and implementation difficulty. From the implementation of the method, 14 alternative improvement actions were identified, which were then prioritized, resulting in 11 priority actions being implemented in the company. The results showed that the baseline process (prior to improvement) had a DPMO of 23,818 and a sigma level of 3.49. After the improvements were implemented, dominant defects related to colored spots, holes, and paper strength issue decreased by 88%, 61%, and 77%, respectively; the total broke percentage declined from 18.23% to 6.05%; DPMO decreased to 12,051; the sigma level increased to 3.82. These findings indicate that the integration of Six Sigma-DMAIC and the Quality Improvement Matrix was effective in improving the quality of PM1 production after conversion.

INTRODUCTION

The wave of digitalization in the last two decades has changed the competitive structure, business model, and value creation process across sectors (Skog, Wimelius and Sandberg, 2018). A similar phenomenon also occurs PT X is a paper manufacturing company in Indonesia that produces newsprint as its main product. PT X has two machines to produce newsprints, namely Paper Mill 1 (PM1) and Paper Mill 2 (PM2) with a capacity of 49,500 tons per year and 65,000 tons per year, respectively. The Marketing Department projects that the demand for newsprint in 2025 will be ± 60,000 tons per year so that as of January 2025, newsprint production in PM1 will be stopped due to weakening demand and the volume of newsprint is centered on PM2. To respond to market shifts, PT X implements a product conversion strategy (grade conversion) to switch from newsprint to other paper products that are more prospective.

In financial conditions due to the post-Covid-19 recovery and unstable market conditions, PT X's management plans to continue to use PM1 paper machines through targeted engineering on critical subsystems rather than the construction of new facilities (greenfield) to minimize CAPEX and accelerate time to market considering the company's limited financial capabilities. So, with the considerations, it was decided to switch to packaging paper with a low weight of 50 gsm (in accordance with the PM1 machine's capabilities) which will be marketed to be processed into small paper bags used in fast food (Bejjani et al., 2022; Dillon, n.d.; Tetteh, 2022).

Although the conversion of PM1 to packaging paper production is strategically able to prevent the cessation of operations and maintain the company's turnover, this change poses significant quality issues (Chauhan et al., 2024; KAMRAVA & RICHARD, 2025; Masoud et al., 2025; Veeramuthu & Flora, 2025). Since the start of packaging paper production in March 2025 to August 2025, the defect downgrade B and C are still below the quality limit of 3% each. However, non-salable category defects consistently exceed the maximum limit of 8% that the company has set based on global standard(TAPPI, 2017). The high rate of non-salable defects causes the product to be unsellable and must go through a rework process through broke handling. According to the finance department's calculations, each kilogram of paper reworked adds to the production cost by 20% of the total production cost. In addition, for make to order orders, rework also has the potential to cause delivery delays that can lower the level of customer confidence.

The company had already attempted several corrective actions after conversion, such as more frequent system cleaning, tighter operator inspection, and adjustments to incoming raw material and cut-out settings (Čaušević, 2024; Chowdhury, 2025). However, these efforts were sporadic and reactive. As a result, the observed improvements were temporary and unstable. This situation indicated that the problem was not merely a matter of day-to-day operational disturbance, but rather a broader quality-management issue requiring a structured, data-driven, and end-to-end improvement framework. Without a systematic and data-based analysis framework, quality improvement efforts have the potential to become trial and error and result in unsustainable improvements (Psarommatis and Azamfirei, 2024). Therefore, a quality management approach is needed to direct problem identification, performance measurement, root cause analysis, solution design, and control of improvement results in a structured manner.

In many cases, the Six Sigma method has proven to be effective in reducing process variations and reducing defect rates through a data-driven approach and the DMAIC stages in manufacturing (Mejjaouli and Algublan, 2020; Shameem and Mittal, 2023; Bossert, 2024). However, given the limitations faced by companies and the business recovery challenges following the Covid-19 pandemic, it is essential to ensure accuracy in determining improvement strategies. Accordingly, companies require a method that can assist in prioritizing improvement alternatives that are both appropriate and effective. Six Sigma itself only focuses on controlling process variations but does not explicitly provide a framework to sort which areas must be improved first based on the level of urgency, cost impact, and consequences on customer satisfaction (Antony, Sony and Gutierrez, 2022).

Muhammad and Karningsih (2018) introduced the Quality Improvement Matrix (QIM) method which is a prioritization method that is specialized in quality improvement. This method is the result of modification and a combination of the House of Quality (HOQ), Failure

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Mode and Effect Analysis (FMEA), and Root Cause Analysis (RCA) methods. This method is carried out by identifying the type of defect that will then be searched for the root cause of the defect with the RCA method, then an assessment is also carried out on the severity of the defect and the occurrence rate of the root cause which is then aggregated so that the priority of the root cause appears in the form of ranking. From the aggregation results, it will also be related to alternative corrective actions, and the effectiveness of the corrective action is also determined. In addition to effectiveness, an assessment of the difficulty level of the repair steps is also carried out, which is the corrective aspect of the improvement steps. The result of this method is the improvement steps that will be the priority.

Accordingly, this study aimed to integrate Six Sigma–DMAIC with QIM to reduce dominant non-salable defects after grade conversion at PM1. More specifically, the study sought to establish the baseline process condition, identify the root causes of the dominant defects, prioritize improvement actions based on both impact and feasibility, validate selected actions through experimentation, and assess the resulting quality and cost performance. By doing so, the study contributes a structured improvement framework that links diagnosis, prioritization, implementation, and validation within a single industrial case. The benefits of this research are twofold. Theoretically, this study contributes to the quality management literature by demonstrating the integration of Six Sigma-DMAIC with the Quality Improvement Matrix as a novel framework for prioritizing improvement actions in a post-conversion manufacturing context. Practically, this research benefits the company by providing a structured, data-driven approach to reduce non-salable defects, lower internal failure costs, and improve process stability. For the broader paper manufacturing industry, the findings offer insights into managing quality issues during grade conversion. For future researchers, this study serves as a reference for applying integrated quality improvement frameworks in other industrial settings.

METHODS

This research was conducted as a single case study on the PM1 production line in a paper manufacturing company undergoing grade conversion. The flow of process using DMAIC (Define, Measure, Analyze, Improve, Control) as framework and combined with Quality Improvement Matrix that used in Analyze and Improve phase.

Define Phase

In the Define stage, quality records from March–August 2025 were examined to identify critical-to-quality problems after conversion. Pareto analysis was then used to determine the dominant defects that warranted priority attention (Geleta Oljira et al., 2023; Eralda et al., 2024).

Measure Phase

In the Measure stage, process stability was evaluated using a demerit u-chart because the quality data consisted of defect counts per unit with varying sample sizes and different class of defects (Nembhard et al., 2000). Process capability was assessed through Defects per Million Opportunities (DPMO) and sigma level (Apriani et al., 2024). In the PM1 context, nine defect categories were treated as defect opportunities per unit, consistent with the plant’s quality classification. DPMO was calculated from total defects divided by total units multiplied by opportunities per unit, then scaled to one million opportunities and converted into sigma level.

Analyze Phase: Root Cause Analysis and QIM 1

In the Analyze phase, the study combined Root Cause Analysis (RCA) and Quality Improvement Matrix 1 (QIM 1) to identify and prioritize the most influential causes of the dominant non-salable defects.

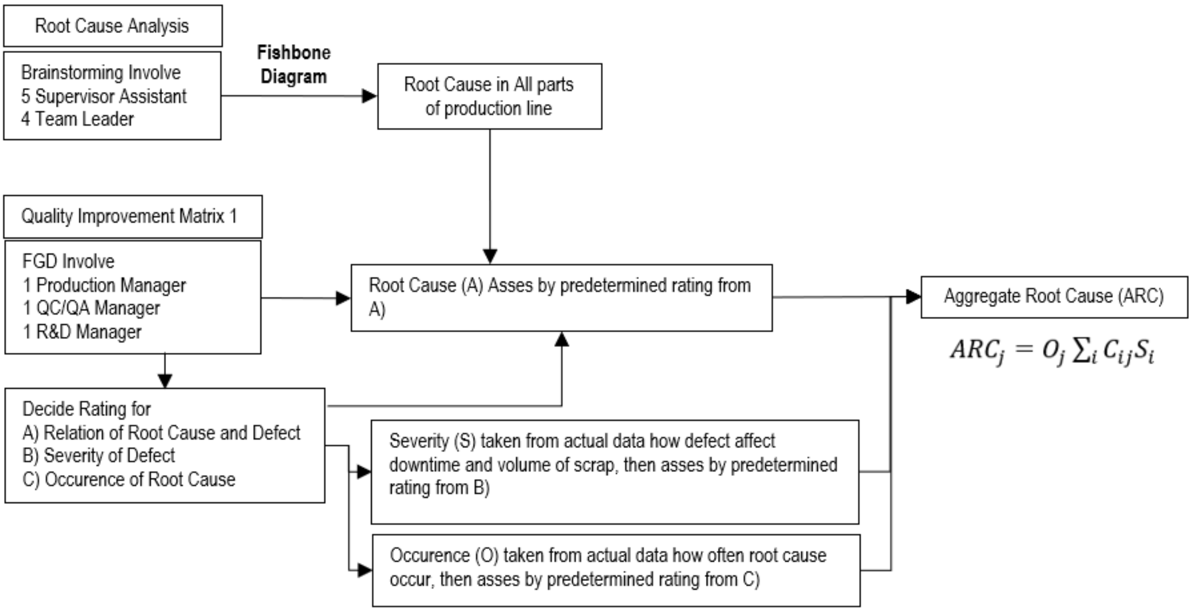

Figure 1. Flow process to decide Aggregate Root Cause as part of QIM 1

Source: Author's own work, 2025 (adapted from Muhammad & Karningsih, 2018)

As illustrated in Figure 1, the RCA stage began with structured brainstorming involving five assistant supervisors and four team leaders to identify potential causes across all parts of the production line. The identified causes were then organized into a fishbone diagram to systematically map the possible sources of defects before prioritization. In line with the study methodology, the causes were further structured under the categories of Man, Machine, Method, Material, Measurement, and Environment, and were cross-checked against production and quality records to improve the reliability of the analysis(Antony, McDermott and Sony, 2023).

The prioritized evaluation of the identified causes was subsequently carried out using QIM 1 through a Focus Group Discussion involving the Production Manager, QC/QA Manager, and R&D Manager. At this stage, three assessments were performed using predetermined rating scales. First, the relationship between each defect and each root cause (C_{ij}) was evaluated to determine the strength of the causal association. Consistent with the QIM framework adopted in this study, the relationship score was assigned on a 0-1-3-9 scale, representing no, weak, moderate, and strong relationship, respectively. Second, defect severity (S_i) was determined from actual operational data, particularly the extent to which each defect contributed to downtime and scrap generation, and score was assigned on 1 to 9 scale, representing very low to very high. Third, root-cause occurrence (O_j) was established from actual production data on how frequently each root cause appeared and score was assigned on 1 to 10 scale representing very low to very high. This procedure ensured that the prioritization process did not rely solely on expert judgment but also incorporated measurable operational evidence.

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After these three elements had been established, the Aggregate Root Cause (ARC) value for each root cause j was calculated as follows:

$$ARC_j = O_j \sum_i C_{ij}\, S_i$$

where O_j denotes the occurrence of root cause j, C_{ij} represents the relationship between defect i and root cause j, and S_i denotes the severity of defect i. Then, ARC ranked from highest to lowest values. Root causes with higher ARC values were interpreted as higher priority causes because they simultaneously reflected frequent occurrence, strong causal influence, and severe operational impact. Very low ARC values can be considered non-priority and could be eliminated for next stage process. Therefore, QIM 1 served as a structured bridge between qualitative root-cause identification and quantitative prioritization, providing a rigorous basis for selecting corrective actions in the subsequent Improve phase.

Improve Phase

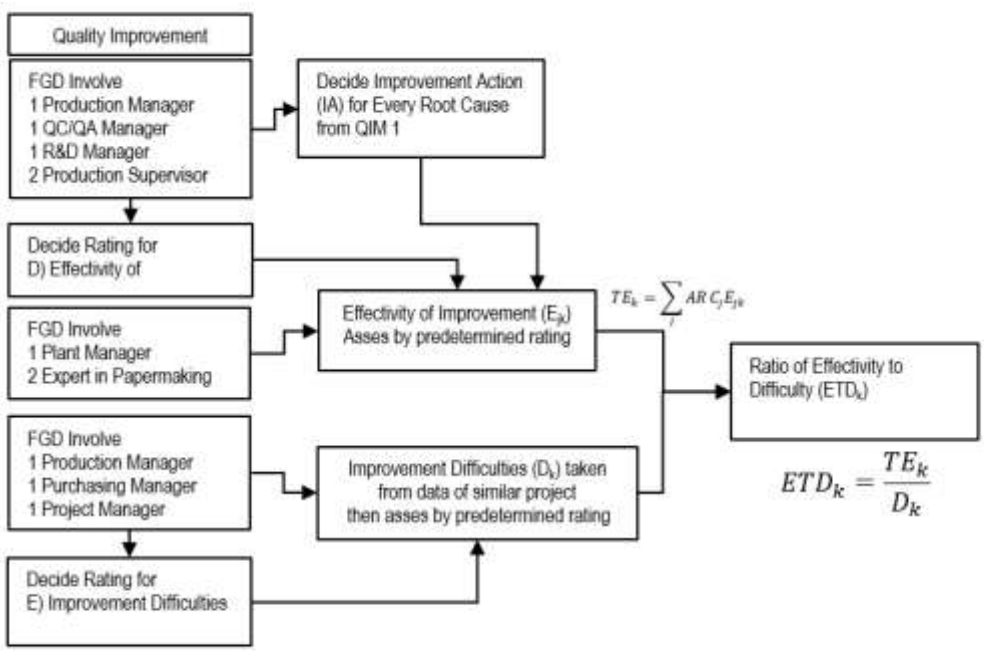

Figure 2. Flow process to decide Ratio of Effectivity to Difficulty as part of QIM 2
Source: Author's own work, 2025 (adapted from Muhammad & Karningsih, 2018)

In the Improve phase, the study employed Quality Improvement Matrix 2 (QIM 2) to translate the prioritized root causes generated in QIM 1 into feasible and measurable corrective actions. Each prioritized Aggregate Root Cause (ARC) was first converted into one or more improvement actions (IA_k). As shown in Figure 2, this stage was conducted through a Focus Group Discussion involving the Production Manager, QC/QA Manager, R&D Manager, and two Production Supervisors, while the proposed actions were subsequently verified against plant conditions and theoretical considerations. The objective of this stage was to ensure that every priority root cause was linked to a practical corrective action that could either eliminate the cause or significantly reduce its probability of occurrence.

The effectiveness of each proposed improvement action was then assessed using a second evaluation stage in QIM 2. In accordance with the study design, the effectiveness score (E_{jk}) reflected the extent to which improvement action k could mitigate root cause j. This assessment was carried out through expert judgment involving one Plant Manager and two papermaking experts, using a predetermined effectiveness scale. The scale that already predetermined ranged from 0, 1, 3, 5, 7, to 9, representing no effect, very weak effect, weak effect, moderate effect, high effect, and very high effect, respectively. The total effectiveness of each action (TE_k) was then calculated by aggregating the product of the ARC value and the corresponding effectiveness score across all relevant root causes, as expressed in the following equation:

$$TE_k = \sum_j AR\,C_j E_{jk}$$

A higher TE_kvalue indicated that the proposed action had greater expected leverage in addressing the prioritized causes of dominant defects.

Following the effectiveness assessment, the implementation difficulty of each corrective action (D_k) was evaluated. This assessment drew on data from similar projects and was discussed through a Focus Group Discussion involving the Production Manager, Purchasing Manager, and Project Manager. Implementation difficulty was operationalized through two components: the completion-time rating (P_k) and the cost rating (B_k). The completion-time rating used a 1–3 ordinal scale, where 1 represented implementation in less than two weeks, 2 represented implementation in two to four weeks, and 3 represented implementation requiring more than four weeks. The cost rating used a 0–4 ordinal scale, where 0 indicated no cost, 1 indicated an investment below IDR 25 million, 2 indicated IDR 25–100 million, 3 indicated IDR 100–250 million, and 4 indicated more than IDR 250 million. The overall implementation difficulty was then calculated as:

$$D_k = P_k + B_k$$

This modification allowed the study to account for both execution difficulty and financial investment when prioritizing corrective actions.

The final priority index in QIM 2 was obtained by comparing the total effectiveness of each action with its implementation difficulty through the Effectiveness-to-Difficulty ratio (ETD_k), as follows:

$$ETD_k = \frac{TE_k}{D_k}$$

Improvement actions with higher ETD_kvalues were interpreted as more attractive because they offered a higher expected impact relative to the effort and cost required for implementation. Accordingly, the proposed actions were ranked from the highest to the lowest ETD_k, and when equal scores occurred, the final order was determined using financial impact or implementation speed as tiebreakers. Thus, QIM 2 served not only as a prioritization tool, but also as a decision-support mechanism for selecting the most beneficial corrective actions under practical resource constraints. Corrective actions that required parameter adjustment or process setting changes were subsequently validated through Design of Experiment (DOE). DOE was performed directly on the machine under agreed production schedule and prepared contingency plan to minimize risk. The principal response variables were production runnability and the occurrence of defects.

Control Phase

The control phase is the last stage of the DMAIC framework which aims to ensure that the implementation of improvement actions that have been successfully applied in the company is still applied in a sustainable manner. The best performing factor combination obtained from DOE was then used to establish new operating ranges, which were later formalized into Standard Operating Procedures (SOPs).

RESULT AND DISCUSSION

Problem Magnitude and Baseline Performance

The Define phases confirmed that the post conversion quality problem in PM1 was both significant and persistent. As shown in Figure 3, Pareto analysis of production data from March to August 2025 showed that three dominant non-salable defects, colored spots, holes, and burst paper accounted for 80.2% of all defect occurrences.

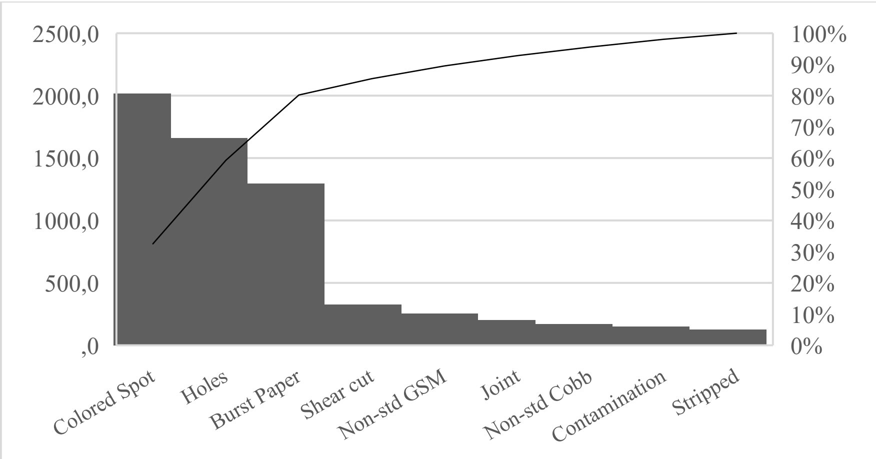

Figure 3. Pareto analysis of defect pre-improvement

Source: Author's analysis based on company production data (March–August 2025)

At the measure phase, the process stability and production capabilities of packaging paper in PM1 with a grammage of 50 gr/m^2 were measured in the period of March 2025 to August 2025 in 23 weeks of production. Process stability measurement was carried out using a demerit u-chart with the result after processed using *Minitab* as shown in Figure 4

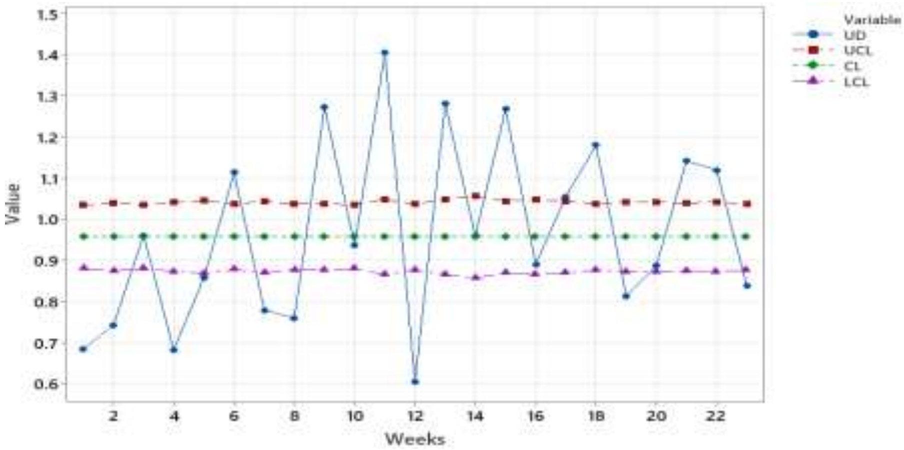

Figure 4. Pre-Improvement demerit u-chart

Source: Author's analysis using Minitab based on company production data (March–August 2025)

The results of the control map show that there were multiple observations (UD) are outside the control limits so that the production process is unstable.

The measurement of process capability was carried out through the calculation of Defect Per Million Opportunity (DPMO) which was then converted into sigma values. The average DPMO during the measurement period was obtained at 23,818 or equivalent to the sigma level of 3.49. which indicates that this condition clearly needs improvement and it served as baseline before the improvement was made and still had the potential to be improved.

Root Cause Structure and QIM 1 Prioritization

The Analyze phase identified 30 root causes across the production line. However, the QIM 1 procedure showed that not all causes had equal strategic importance.

Table 1. Quality Improvement Matrix 1 Prioritization

Rank	Root Cause of Defect	Code	ARC
1	No established raw material sorting system	A3	1,296
2	No supervisor assigned before entering the pulping process	A2	774
3	No incoming material standard regarding color variations in OCC	A1	567
4	No standard procedure for checking the freeness of raw materials	A29	504
5	The doctor blade frequently experiences wear	A16	486
6	Dry strength chemicals are not used as fiber-bonding agents	A26	378
7	The system is not equipped with an automatic canvas cleaner	A24	243
8	The LDC type requires upgrading	A6	216
9	No standard range for paper moisture content	A28	189
10	Operators experience difficulties during the cleaning process	A23	162
11	ASA flow rate is too high	A12	162
12	Cationic flow rate is too high	A13	162
13	Chemical injection points require optimization	A19	162
14	Operators do not perform cleaning activities periodically	A5	108
15	Basket type has an excessively large slot size	A7	90
⋮	⋮	⋮	
↓	↓	↓	
30	No SOP for checking the disperger output.	A8	9

Source: Author's analysis based on FGD with Production Manager, QC/QA Manager, and R&D Manager, 2025

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The company decided that ARC values above 100 were retained for the next phase, thereby narrowing the improvement focus to 14 high impact causes. This step was important because it allowed the project to concentrate on recurring and consequential causes instead of dispersing effort across low impact issues. From Table 1, the highest-priority root cause was A3: absence of a raw-material sorting system, with an ARC value of 1296. This was followed by A2: no appointed supervisor for incoming raw material before pulping (ARC = 774), A1: no incoming-material standard for OCC color load (ARC = 567), A29: no standard for checking raw-material freeness (ARC = 504), and A16: frequent doctor-blade wear (ARC = 486). The causal structure also showed that the problem was not driven primarily by the machine alone.

Prioritization of Improvement Actions and QIM 2

Based on the 14 prioritized root causes, the study formulated 14 improvement actions. As shown in Table 2, In terms of total effectiveness, the highest-scoring actions were IA1: creating raw material sorting system (TE = 11,664), IA2: training for raw-material supervision standards (TE = 6,966), and IA3: SOP implementation for colored raw material (TE = 5,103).

Table 2. Quality Improvement Matrix 2 Prioritization

Code	Improvement Action	TE_k Values	D_k Values	ETD_k Values	Rank
IA1	Creating raw material sorting	11,664	2	5,832	1
IA2	Training for supervision std.	6,966	2	3,483	2
IA3	SOP for colored raw material	5,103	3	1,701	3
IA4	SOP for freeness check	2,520	2	1,260	4
IA5	Change doctor material	4,374	4	1,094	7
IA6	Using dry strength	3,402	3	1,134	5
IA7	Invest in Canvas Cleaner	3,321	7	312	11
IA8	Invest in LDC	1,512	7	216	12
IA9	SOP for Moisture standard	945	1	945	8
IA10	Invest in holder cleaner	486	5	97	13
IA11	Optimal ASA flow trial	1,134	1	1,134	6
IA12	Optimal cationic flow trial	1,134	3	378	10
IA13	Injection point trial	810	2	405	9
IA14	SOP for periodic cleaning	108	2	54	14

Source: Author's analysis based on FGD with Plant Manager and papermaking experts, 2025

After the effectiveness scores were corrected by implementation difficulty, the ranking changed to an effectiveness-to-difficulty. This confirms that QIM 2 did not privilege technically promising actions alone, but rather actions that combined high impact with practical implementation.

Different with Aggregate Root Cause prioritization that solely depends on number, the company imposed a practical implementation constraint of 20 weeks and a maximum budget of IDR 750 million. Under this constraint, 11 improvement actions were selected as priorities: IA1, IA2, IA3, IA4, IA6, IA11, IA5, IA9, IA7, IA13, and IA12. Three actions, IA8, IA10, and IA14 were excluded because their cumulative execution would have exceeded the budget threshold. Conceptually, the 11 priority actions can be grouped into three clusters for the next validation method that were raw-material control and sorting (IA1–IA4), chemical and process parameter optimization (IA6, IA9, IA11, IA12, IA13), and equipment related intervention (IA5 and IA7).

Validation of prioritized action and control outputs

The priority actions that required new operating standards were validated through a sequential Design of Experiment (DOE) program. Three experiments were conducted based on the improvement action clusters that had been developed. Experiment 1 focused on testing the sorting and control of incoming raw materials. Experiment 2 focused on optimizing chemical additives and process parameters, while Experiment 3 focused on the addition of equipment. The three experiments were not conducted simultaneously but were carried out sequentially, starting with Experiment 1. The best result from Experiment 1 was used as the standard condition for Experiment 2, and this procedure was continued until Experiment 3.

The validated actions were subsequently translated into control outputs and embedded into plant standards. These changes included an SOP for raw-material sorting of OCC, reassignment of conveyor operators into formal raw-material supervisory roles, an incoming-material standard limiting color load to 5%, a freeness standard of 450 csf, a dry-strength standard of 1000 g/ton, an ASA standard of 10 kg/h, a moisture setting of 7%, a standardized injection configuration in which cationic starch remains before the screen and dry strength is added after the screen, and a cationic-starch standard of 2,000 L/h. These recommendations were then incorporated into revised SOP documents under the company's ISO 9001:2015 documentation structure.

Post improvement evaluation

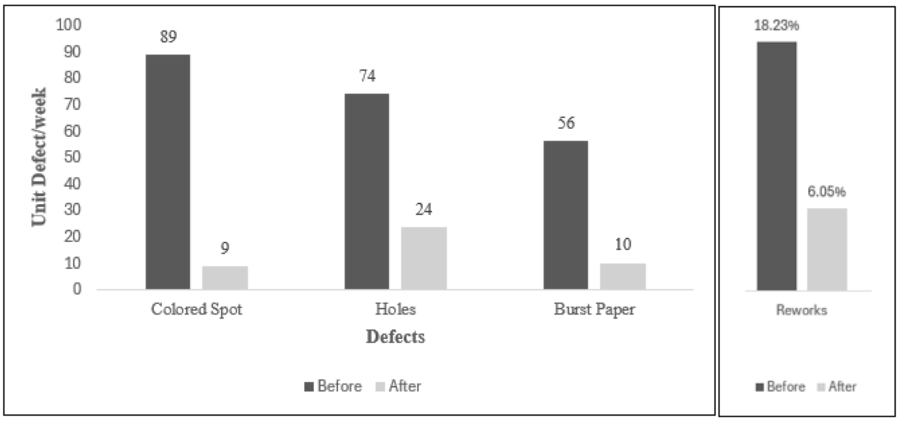

Figure 5. Post improvement response for defect

Source: Author's analysis based on company production data (November 2025–March 2026)

Post improvement evaluation was conducted using routine plant data from the third week of November 2025 to the third week of March 2026. The defect comparison showed substantial reductions in all dominant categories. As in Figure 5, Colored spots fell by 88%, holes by 61%, and burst paper by 77%. At the broader process level, total reworks declined from 18.23% to 6.05%, moving the plant below the company's internal maximum threshold of 8%.

The stability analysis after implementation also showed improvement. After excluding trial weeks, all remaining observations fell within the control limits, indicating that the regular post-improvement process had become statistically more stable than the pre-improvement process. The post-improvement capability analysis confirmed the same pattern. The average process capability improved from 23,818 DPMO and 3.49 sigma before improvement to 12,051 DPMO

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and 3.82 sigma after improvement. This indicates a lower level of process variation and a reduced likelihood of defect occurrence.

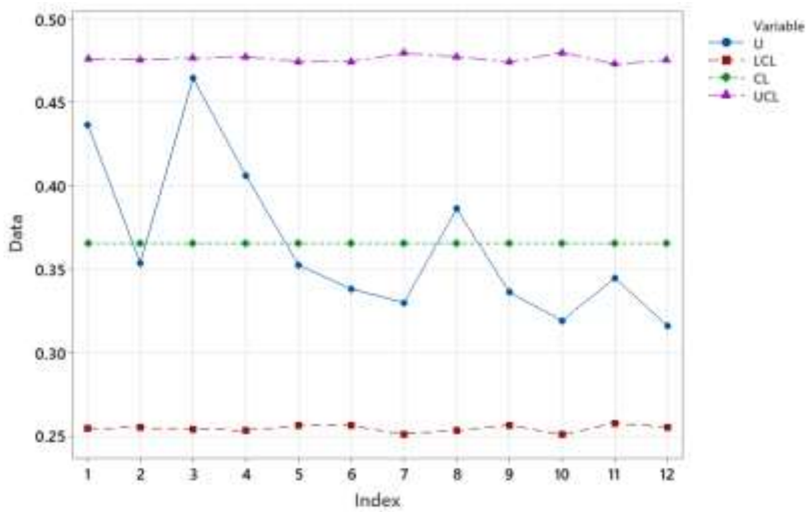

Figure 6. Post Improvement demerit u-chart

Source: Author's analysis using Minitab based on company production data (November 2025–March 2026)

The findings show that the integration of Six Sigma–DMAIC and QIM was effective because the two methods played complementary roles. DMAIC provided a structured improvement cycle, beginning with problem definition and baseline measurement, followed by analysis, improvement, and control. QIM strengthened the Analyze and Improve phases by providing a quantitative prioritization mechanism. Without QIM, the project team could have identified many possible causes and actions but would still have faced difficulty determining which issues should be addressed first. QIM 1 transformed the root-cause analysis into a ranked structure by combining severity, occurrence, and the strength of defect–root cause relationships. This was especially important because the RCA stage identified 30 possible causes. Treating all causes equally would have diluted improvement resources. By applying ARC calculation, the study narrowed the focus to 14 root causes that were either recurring or had significant quality impact. QIM 2 then converted these root causes into ranked corrective actions based on effectiveness and implementation difficulty. This ensured that improvement decisions reflected both technical impact and practical feasibility.

The results indicate that the dominant post-conversion quality problems were strongly influenced by upstream raw-material control. The highest ARC value was assigned to the absence of a raw-material sorting system, followed by the absence of raw-material supervision before pulping and the absence of a color-load standard for incoming OCC. These findings suggest that the conversion from newsprint to recycled fiber packaging paper created a new raw-material variability problem. OCC contains different contaminants, color variations, and fiber characteristics compared with old newsprint, making raw material control a critical determinant of downstream quality.

The study provides several managerial implications for paper mills undergoing grade conversion. First, quality assurance after conversion should begin at the raw-material gate. The results show that downstream inspection and machine adjustment are insufficient when incoming material variability is not controlled. Establishing raw-material sorting, color-load standards, and freeness standards can reduce defect risk before the stock enters the machine system. Second, improvement actions should be prioritized explicitly under resource constraints. In this case, QIM 2 prevented the company from implementing all technically possible actions without considering feasibility. Third, improvement actions should be translated into formal control outputs. The study did not stop identifying optimum settings. It converted the results into SOPs, job-description changes, raw-material standards, chemical standards, process standards, and equipment standards. This step is important because post-conversion improvement can easily return to trial-and-error behavior if new standards are not institutionalized.

This study contributes to the quality-improvement literature by demonstrating how QIM can be operationalized within DMAIC in a paper-manufacturing context. DMAIC defines the improvement flow, QIM 1 ranks the root causes, QIM 2 ranks the corrective actions, DOE validates the parameter-based actions, and Control standardizes the results. This combination provides a practical model for companies facing complex quality problems with limited resources. The study also contributes by showing how expert judgment and operational data can be combined. The QIM process did not rely solely on subjective discussion. Severity was linked to downtime and scrap impact, occurrence was linked to actual root-cause frequency, and action difficulty considered implementation time and cost. This combination improved the transparency and defensibility of prioritization decisions.

This study has several limitations. First, it was conducted on a single paper machine and one converted product grade, so the findings may not be directly generalized in all paper-manufacturing contexts. Second, the study focused only on three dominant non-salable defects selected through Pareto analysis. Other defects were outside the improvement scope and may require separate analysis.

CONCLUSION

This study demonstrated that integrating Six Sigma–DMAIC and the Quality Improvement Matrix is an effective strategy for reducing dominant non-salable defects after grade conversion in paper manufacturing. The framework enabled the company to define the quality problem, measure baseline performance, identify and prioritize root causes, select feasible corrective actions, validate process settings, and institutionalize the improvements into operational controls. The QIM 1 analysis showed that the most critical root causes were related to raw-material sorting, raw-material supervision, color-load standards, freeness standards, and selected process-equipment issues. QIM 2 translated these root causes into prioritized improvement actions, resulting in 11 main actions covering raw-material control, chemical and parameter optimization, and equipment-related intervention. DOE validation established practical operating standards, including maximum 5% OCC color load, 450 csf freeness, 2,000 L/h cationic starch, 10 kg/h ASA, 7% moisture, injection point A, and dry strength at 1000 g/ton. After implementation, colored spots decreased by 88%, holes by 61%, and strength-related paper breakage by 77%. Total rework decreased from 18.23% to 6.05%, DPMO decreased from 23,818 to 12,051, and the sigma level increased from 3.49 to 3.82. Internal failure cost was reduced by 69%, generating approximately IDR 132 million in weekly cost

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savings. These results confirm that the DMAIC–QIM integration provides a systematic, data-driven, and feasible approach for improving production quality in a post-conversion paper-manufacturing environment. Based on the findings, several recommendations are proposed. For the company, it is recommended to regularly review and update the established SOPs, conduct periodic training for operators on raw-material sorting and process parameter control, and extend the DMAIC-QIM framework to other machine lines and product grades. For future researchers, it is suggested to apply this integrated framework in different manufacturing contexts or with other quality improvement tools such as Lean or Total Quality Management (TQM). Additionally, longitudinal studies tracking the sustainability of improvements beyond six months would provide valuable insights into the long-term effectiveness of the DMAIC-QIM integration.

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