RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VI, v.1 2026 | Submission: 20/02/2026 | Accepted: 22/02/2026 | Publication: 24/02/2026

Reducing Polypropylene Waste in a Snack Food Packaging Process through the Implementation of DMAIC

Reduction of Polypropylene Waste in a Snack Food Packaging Process through the Implementation of DMAIC

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Summary

In a snack food production plant, the constant generation of polypropylene waste was identified, highlighting an opportunity for improvement, since the waste generated represented an additional cost that did not add value to the product, in addition to affecting the efficiency of the process. Based on this identified problem, this work describes the application of the DMAIC methodology with the objective of reducing packaging material waste. This analysis allowed the identification of factors related to waste generation, among which were: product obstructions, unscheduled stoppages, lack of standardization in handling failures, and operational differences between different shifts. To analyze the problem, tools such as the Pareto diagram and the cause-and-effect diagram were used, which facilitated the identification of the most important causes and the definition of improvement actions; thus, the implemented actions focused on standardizing adjustments, maintenance actions, and personnel training. Applying the DMAIC methodology allowed for the improvement of process conditions and the optimization of polypropylene use, thus confirming its usefulness in the continuous improvement of industrial processes.

Keywords: DMAIC, polypropylene scrap, packaging, continuous improvement.

Abstract

In a snack production plant, the constant generation of polypropylene waste was identified, a situation that revealed an opportunity for improvement, since the waste generated represented an additional cost that did not add value to the product and also affected process efficiency. Based on this identified problem, the present study describes the application of the DMAIC methodology in order to reduce packaging material waste. This analysis made it possible to identify the factors related to waste generation, among which the following were identified: product jams, unplanned stoppages, lack of standardization in failure handling, and operational differences between the different shifts. To analyze the problem, tools such as the Pareto diagram and the cause-and-effect diagram were used, which facilitated the identification of the most significant causes and the definition of improvement actions; Thus, the implemented actions focused on standardizing adjustments, maintenance-oriented actions, and personnel training. The application of the DMAIC methodology made it possible to improve process conditions and optimize the use of polypropylene, thereby confirming its usefulness in the continuous improvement of industrial processes.

Keywords: DMAIC, polypropylene waste, packaging, continuous improvement.

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Introduction

Quality in industrial processes represents a determining factor for the competitiveness and permanence of companies in the market. When a process presents constant variations or generates waste, the effects are directly reflected in costs, resource utilization, and customer satisfaction. Therefore, controlling variability and reducing waste becomes an important task.

In manufacturing processes, waste is often normalized as part of routine operational problems. In some cases, it may seem small or insignificant when observed separately, but when accumulated over weeks or months, it ultimately becomes clearly reflected in production costs; this situation makes evident the importance of analyzing the process more thoroughly. The use of Structured improvement methodologies not only make it possible to detect where losses are being generated, but also to understand why they occur and what adjustments can be made to achieve a more stable and efficient process.

In this context, it is relevant to describe the DMAIC methodology, which is part of the Six Sigma approach and is used to improve processes; its main objective is to reduce variability through data analysis, that is, to understand what is actually happening in the process before making decisions. DMAIC consists of five phases: Define, Measure, Analyze, Improve, and Control. These stages make it possible to first clearly understand the problem, then measure its impact, identify what is causing it, and finally implement and monitor improvements.

Among its main advantages is that it promotes decisions based on real information and not only on assumptions. In addition, it helps improve process performance and maintain solutions over time through standardization. However, its application also involves certain challenges, such as having reliable data, allocating the necessary time to develop each stage, and achieving the commitment of the personnel involved, since without active participation it is difficult for improvements to be sustained.

In recent years, several studies have supported the application of the DMAIC methodology as an effective tool for process improvement and variability reduction. For example, APARICIO HERNÁNDEZ; MORA CASTAÑEDA; LÓPEZ CRUZ (2024) describe how the incorporation of statistical tools within the Six Sigma approach allows a more precise definition of critical process variables and, based on systematic data analysis, the identification of root causes associated with both human errors and machine failures or deficiencies in work methods.

Similarly, PÉREZ-DOMÍNGUEz et al. (2020) report the implementation of DMAIC in a medical products company, where the use of tools such as the cause-and-effect diagram, histograms, and control plans contributed to reducing defects, rework, and delivery times, generating a reduction in quality-related costs. In the food sector, PARRA CRESPO et al. (2024) document improvements in production process performance through the identification of critical variables linked to inputs and

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operating times. Likewise, GUIMAREY LÓPEZ; HERNÁNDEZ MONSALVE; VASQUEZ CORONADO (2021) show that, in the textile field, the application of DMAIC made it possible to increase productivity through the reduction of raw material waste and the standardization of processes.

Taken together, these antecedents demonstrate that the DMAIC methodology constitutes an effective approach to control variability and improve performance in different industries environments. However, specific documentation on its application in packaging lines in the snack sector, particularly in the control of packaging material waste such as polypropylene, is still limited. This highlights the need for applied studies that analyze this type of problem under real operation conditions.

In this context, the present research applies the DMAIC methodology to the snack packaging process, where a recurrent generation of polypropylene waste was identified during the June–September period. The variability observed between packaging machines and shifts made evident the need for a structured analysis that would allow a more precise understanding of the causes associated with waste. The objective of the study is to reduce polypropylene waste by at least 30% with respect to the baseline, through the systematic application of the five DMAIC phases, thus contributing to strengthening process stability and performance.

Theoretical Framework

To optimize resource utilization, reduce operating costs, and increase competitive capacity, it is essential that industrial processes be continuously improved. In production environments where Various operational and technical variables are involved, process variability may result in failures, waste material, or inefficiencies that impact overall performance. In this context, Six Sigma is presented as a method that seeks to systematically reduce variation through statistical analysis and data-based decision-making.

Within Six Sigma, DMAIC (Define, Measure, Analyze, Improve, Control) is a structure for solving problems in existing processes. This model enables the definition of the problem, measure current performance, identify root causes, implement improvements, and sustain them over time. According to BARO et al. (2024), the DMAIC method incorporates specific quality tools at each of its stages, enabling the structured resolution of improvement projects and strengthening evidence-based management.

In the Define stage, the scope of the project is determined by identifying critical-to-quality (CTQ) variables and aligning objectives with process needs. The Measure stage consists of data collection in order to evaluate current performance and existing variability. Then, in the Analyze stage, statistical and quality tools are used to identify the root causes that generate the problem. In the

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Improve stage, corrective measures are planned and implemented to optimize the process, and the Control stage ensures the sustainability of improvements through continuous monitoring and the standardization of work procedures.

The DMAIC methodology has been validated in various studies across different industries sectors, especially in production processes where variability directly affects input consumption and efficiency. For example, in packaging operations, the absence of control over operational variables may result in packaging material waste, increasing process costs and compromising stability.

In the context of the packaging process in a snack production plant, polypropylene waste can be considered an expression of variability linked to material usage. Therefore, the use of a structured methodology such as DMAIC is appropriate to examine how the process operates, detect causes related to waste generation, and defines control mechanisms that facilitate improved material utilization without compromising the quality of the final product.

Methodology

This research was conducted in a plant dedicated to snack production, with a primarily quantitative approach. Although the organization operates through three production blocks (C, D, and E), the problem was detected in the product packaging area.

The baseline analysis period covered June to September. During this period, a systematic record of polypropylene consumption in the packaging machines was established through the weighing of the kilograms used and the quantification of the waste generated.

The information was organized considering the packaging machine, the month, and the operating shift as analysis variables. The main indicator established was the waste percentage.

To detect waste concentrations and variability patterns, descriptive statistical tools were used to examine the data. Simultaneously, direct observations were conducted in the packaging area to confirm operating conditions and the factors that could be related to waste generation.

The structured implementation of the DMAIC methodology was carried out to determine the root causes and propose improvement measures, based on the diagnosis obtained. After the implementation of the improvements, the indicator continued to be monitored during the Control phase in order to evaluate the comparison with respect to the baseline and verify process stability.

Results and Discussion

4.1 Results

Define

During the analysis period, the behavior of polypropylene waste was recorded in the different packaging machines. Figure 1 shows the distribution of waste by packaging machine and by month.

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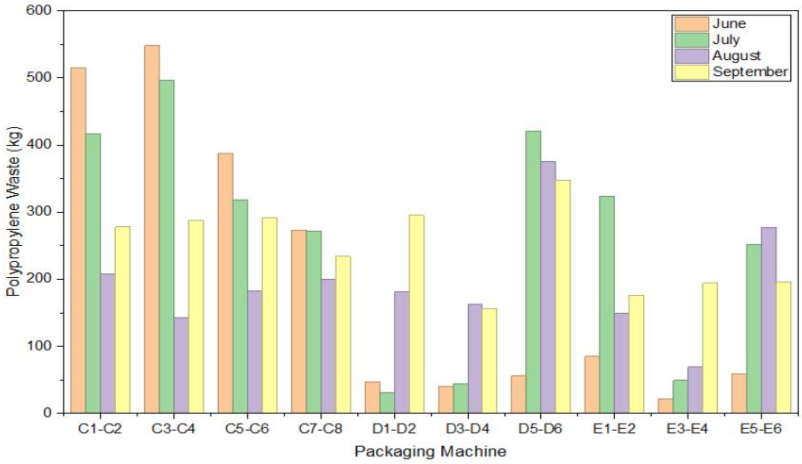
Figure 1

Polypropylene waste distribution



Based on this initial graph, it can be observed that the highest concentration of waste occurs in several packaging machines belonging to block C, which indicates that waste is not uniformly distributed throughout the process. The variability observed among the packaging machines highlights the need for an analysis that makes it possible to identify critical concentrations and potential causes related to equipment performance or operating practices.

As a result of the preliminary findings, the project "Reduction of Polypropylene waste in the Packaging Process" was formally defined, with the objective of reducing material waste by at least 30% with respect to the baseline of the study period through an analysis of its behavior by month, shift, and packaging machine.

Based on the above, the Project Charter was established, which is shown in Table 1 of the project, where the objective, the business case, the performance metrics, as well as the scope and out-of-scope of the study are formalized.

Table 1

Project Charter

Project Title	Reduction of Polypropylene Waste in the Packaging Process.
Business Case	In the packaging process of snack products, polypropylene is used as the primary packaging material. During the study period from June to September, a constant generation of waste of this material was identified. Although the overall efficiency of polypropylene consumption remains at high levels, the accumulated waste represents non-productive use of the material, revealing an opportunity for improvement.
Problem Statement	The packaging process presents recurring polypropylene waste, with monthly percentages ranging between 4.49% and 5.21%.
Objective	To reduce polypropylene waste in the packaging process by at least 30% compared to the baseline of the study period, through an analysis of waste behavior by month, shift, and packaging machine.

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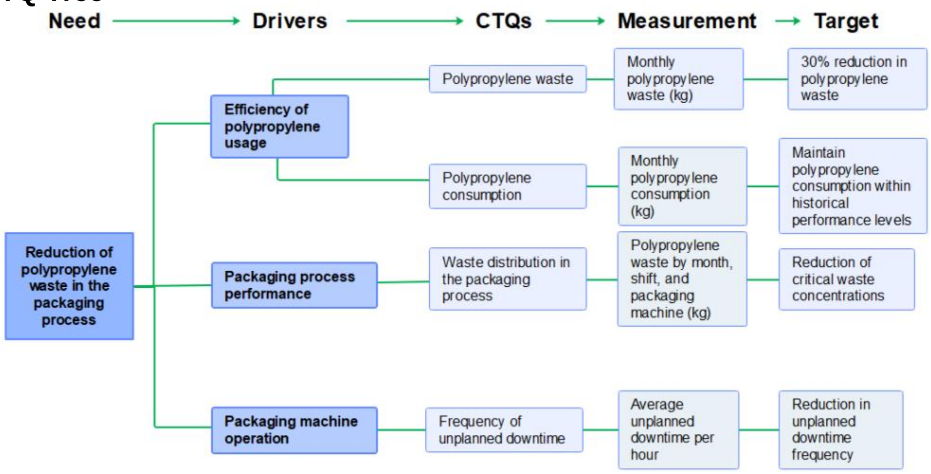
Metrics (CTQ)	Polypropylene (kg/month). waste Polypropylene consumption (kg/month). Waste distribution by month, shift, and packaging machine (kg). Unplanned downtime.
Scope	Analysis of polypropylene waste considering monthly information by shift and packaging machine.
Out of Scope	Changes in packaging material design, substitution of the polypropylene type, and redesign of the packaging machines.

Finally, based on the preliminary information, the CTQs shown in Figure 2 were defined with the objective of focusing the analysis on those variables that directly impact the generation of waste polypropylene. The identification of the CTQs made it possible to translate the observed issue into measurable indicators, such as the kilograms and percentage of polypropylene waste, as well as its distribution by month, shift, and packaging machine, thereby establishing a clear basis for evaluating process performance and for developing the subsequent phases of the DMAIC methodology.

Figure 2
CTQ Tree



Measure

In order to quantify the behavior of polypropylene waste and prioritize the areas with the greatest impact, waste records by packaging machine corresponding to the study period were analyzed. Based on this information, a Pareto chart was developed. This chart is shown in Figure 3.

According to the Pareto principle, the packaging machine C3-C4, C1-C2, D5-D6, C5-C6, and C7-C8 were identified as the main contributors to the accumulated polypropylene waste, accounting for approximately 80% of the total process waste. Therefore, these packaging machines were selected as the focus of analysis in the subsequent stages.

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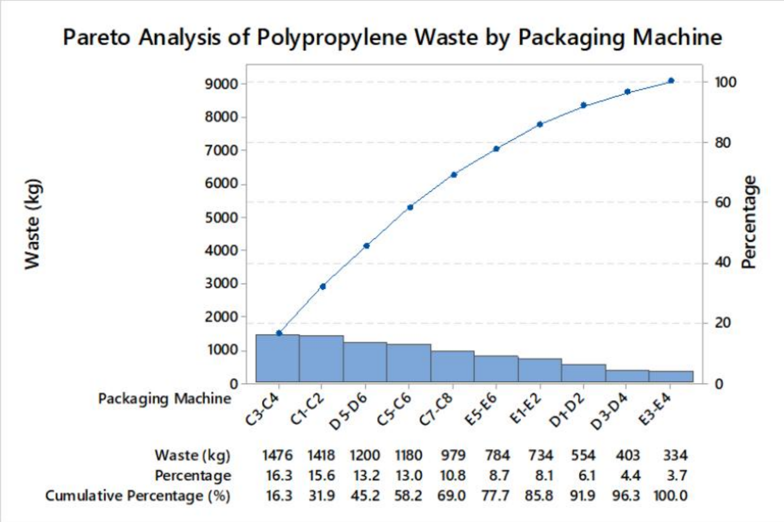
Figure 3



Based on direct observation of the process and the collection of insights from the involved areas, a brainstorming session was conducted in order to identify the possible causes that could be generating waste in the prioritized packaging machine.

The ideas obtained through this exercise made it possible to establish an initial set of causes, which were subsequently organized and analyzed during the Analyze phase of the DMAIC methodology.

Analyze

Based on the previously identified causes, the Analyze phase of the DMAIC methodology was carried out with the objective of gaining a deeper understanding of the factors influencing the generation of polypropylene waste.

To achieve this, cause-and-effect analysis tools were used to structure, refine, and validate the potential causes of the problem.

As a first step, the causes identified during the brainstorming session were organized using an Ishikawa diagram, considering the six categories of analysis (6M): Machinery, Method, Manpower, Material, Measurement, and Environment.

Within the Machinery category, causes such as product jams, unplanned downtime, sealing failures, and insufficient maintenance were identified. In the Method category, a lack of standardization in response to failures, adjustments made without defined criteria, and operational variation between shifts were detected. In the Manpower category, insufficient training and differences in personnel training levels were included. The Material category considered inconsistent quality of the polypropylene roll, while in measurement, deficiencies in the temporal recording of waste were identified. Finally, in the Environment category, a high production pace and pressure to meet

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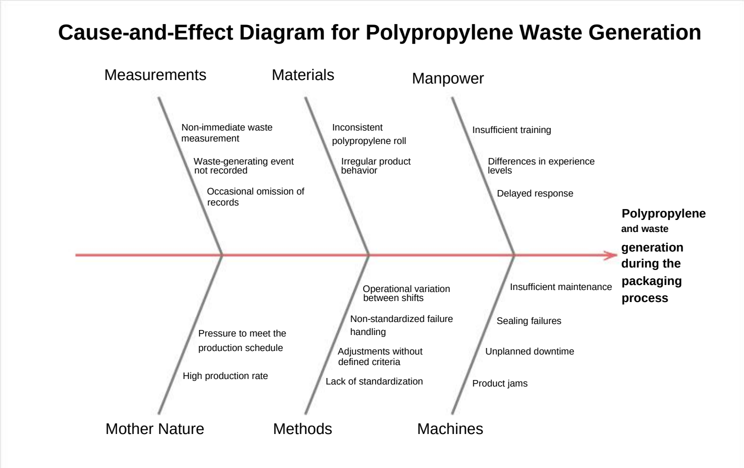
the production schedule was considered. Figure 4

Figure 4



Subsequently, a cause validation was carried out in order to confirm those with the greatest influence on the generation of waste. For this purpose, only the causes classified as critical and intermediate were analyzed using direct process observation, shift-based data analysis, visual inspection of the material, and interviews with operational personnel.

The validation results, presented in Table 2, confirmed product jams, unplanned downtime, lack of standardization in response to failures, and insufficient personnel training as critical causes, as they demonstrated a direct relationship with increases in polypropylene waste. Likewise, intermediate causes such as adjustments made without defined criteria and inconsistent roll quality were validated, as they contribute to process variability.

Table 2
Cause Validation

Cause	Category	Type of Cause	Evidence	Validation Method	Result
Product jams	Machinery	Critical	Direct Observation: long strips of packaging material during downtime.	Direct observation	Validated
Unplanned downtime	Machinery	Critical	Frequent stoppages in critical equipment. An average of 6 stoppages per hour was observed, with an average duration of 1 minute.	Observation and interviews	Validated
Lack of standardization in response to failures	Method	Critical	Different ways of responding between shifts.	Observation and shift comparison	Validated
Insufficient personnel training	Manpowner	Critical	differences in waste levels between shifts.	Shift-based data analysis. Waste distribution was observed as follows: First shift: 3606 kg; Second shift: 2538 kg; Third shift:	Validated

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				2918 kg.	
Adjustments without defined criteria	Meth od	Interme diate	Adjustments made according to operator experience.	Direct observation	Valid ated
Inconsistent roll quality Mater	ial	Interme diate	Surface roughness observed on the roll.	Visual inspection	Valid ated

The analysis conducted made it possible to define the priority causes that were addressed in the Improve phase, focusing attention on those factors with the greatest impact.

Improve

Based on the causes validated in the Analyze phase, improvement actions were defined to reduce polypropylene waste in the packaging process. The actions focused on operational standardization, preventive maintenance, and strengthening personnel competencies.

Table 3 presents the relationship between the validated causes and the proposed improvement actions, which include the definition of procedures for addressing product jams and recurrent failures, as well as preventive maintenance routines for critical components of the packaging machines. In addition, operational training for personnel was proposed, with emphasis on the first shift, along with the definition of basic criteria for making process adjustments. Finally, look inspection of the polypropylene roll was incorporated as a preventive action to reduce variability associated with the material.

Table 3
Improvement Actions

Validated Cause	**Improvement Action**	**Focus**
Product jams	Define and document a standard procedure to ensure the immediate response to product jams.	General application, with emphasis on critical packaging machines.
Unplanned downtime	Establish a preventive maintenance routine focused on material feeding, sealing, and cutting components of the packaging machine.	Priority in critical packaging machines.
Lack of standardization in response to failures	Integrate procedures for addressing product jams and recurrent failures into a visual instruction guide.	General application.
Insufficient personnel training	Implement operational training.	General application, prioritizing the first shift, 39.79% of the total waste originates from this shift.
Adjustments without defined criteria	Defines basic operating parameters and intervention criteria for making process adjustments.	General application.
Inconsistent polypropylene roll quality	Implement visual inspection of the roll prior to installation.	Preventive action.

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Control

Once the improvement actions were implemented, the Control phase was carried out with the objective of verifying the behavior of the packaging process and ensuring the sustainability of the results achieved. To this end, periodic monitoring of the defined CTQs was established, primarily the kilograms and percentage of polypropylene waste by packaging machine, shift, and period, comparing them with the baseline in order to detect process deviations.

The monitoring of these indicators made it possible to evaluate process stability after the implementation of the improvements, revealing a reduction in variability. Likewise, standardized procedures, preventive maintenance routines, and material inspection were integrated into daily operations. Additionally, personnel training ensured the proper application of these practices, aimed at the sustained reduction of waste and the stabilization of the process.

Although the project established a target of a 30% reduction relative to the baseline, the post-implementation monitoring period was limited, which prevented full quantitative confirmation of the achievement of this objective. However, the behavior of the indicator showed a favorable trend and a decrease in process variability, suggesting a positive impact of the implemented actions.

Discussion

The DMAIC methodology was implemented in the packaging process to analyze the problem of polypropylene waste, which made it possible to identify its behavior by packaging machine and highlight critical concentrations in specific parts of the process. These findings are consistent with those reported by PÉREZ LÓPEZ and GARCÍA CERDAS (2014) in the implementation of DMAIC–Six Sigma in the packaging line of the Fábrica Nacional de Licores (Fanal), where systematic monitoring of indicators enabled the identification of specific failures and the direction of corrective actions toward particular process elements.

The measurement stage was crucial in both studies for understanding the magnitude of the problem. In the case of Fanal, overall equipment effectiveness was measured using the OEE indicator (PÉREZ LÓPEZ; GARCÍA-CERDAS, 2014); in this study, kilograms and the percentage of polypropylene waste were used as key process variables. Although the indicators differ, in both cases the objective quantification of performance allowed improvement actions to be focused on the aspects with the greatest impact.

Similarly, in the textile industry it has been reported that the systematic application of the DMAIC methodology enabled the identification of fundamental process variables, the examination of root causes, and the determination of improvement proposals aimed at reducing variability

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(ORDÓÑEZ ALCÁNTARA;TORRES CASTAÑEDA, 2014). This study also revealed non-homogeneous patterns in waste generation, suggesting the presence of factors related to equipment performance and shift-based operations.

However, unlike the textile research, this study did not develop experimental instruments such as R&R studies or design of experiments. This represents an opportunity for further in-depth analysis in future work. Although a favorable trend was observed after implementation, the subsequent analysis period was limited; therefore, it is necessary to strengthen the continuous monitoring of the CTQs to ensure the sustainability and stability of the improvements over time.

Final Considerations

The application of the DMAIC methodology in the packaging process made it possible to address in a structured manner the issue associated with polypropylene waste, creating a defined framework to diagnose, prioritize, and act. The systematic analysis of the indicator's behavior enabled the identification of critical points in the process and guided the determination of focused actions on operational standardization, preventive maintenance, and the strengthening of personnel skills.

The primary contribution of the study lies in the incorporation of analytical tools that made it possible to transform a routine operational situation into a formal improvement project with established indicators and monitoring methods. This approach not only optimizes the use of packaging materials but also strengthens operational management through the systematic control of critical indicators.

The results confirm that the DMAIC method is useful as a systematic approach for the continuous improvement of the packaging process. Therefore, the consistent incorporation of critical indicator monitoring can consolidate operational stability and ensure that the achieved improvements are sustained over time.

As a limitation of the study, the post-implementation evaluation period was limited, which prevented a more precise quantification of the overall percentage reduction achieved relative to the established target. In this regard, it is recommended to extend the monitoring period in future research in order to strengthen the quantitative validation of the results and assess the long-term sustainability of the improvements.

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