ISSN (E): 3006-7030 (P) 3006-7022

Volume 2, Issue 4, 2024

Received: 10 October 2024
Accepted: 10 November 2024
Published: 25 November 2024

IMPROVEMENT OF QUALITY AND WASTES CONTROL OF SOAP MANUFACTURING USING SIX SIGMA ANALYSIS

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ABSTRACT

This research investigates the use of Six Sigma methods for the quality improvement and waste minimization of soap production processes. Other focuses of the research using the Define-Measure-Analyze-Improve-Control (DMAIC) approach are the causes of inefficiencies in the production process such as high level of defects and excessive wastage of raw materials. The research used leather production processes such as material handling, mixing, curing and packaging to gather data. The analyses achieved a decline in defect ratio from 19.9% to 7.1% and a 41.2% raw material waste minimized. Improvements were also made in the process efficiency in terms of reducing the cycle times by 26.1%. Six Sigma approach also advanced the improvement of process capability with Cp and Cpk values of 1.45 and 1.39 respectively. Financial analysis indicated that 43.6% of the production costs were cut due to lower levels of waste and rework. The findings of the research affirm the methodology of process improvement using Six Sigma approach in the soap industry with benefits of efficiency improvements, cost savings and higher product quality. The results are encouraging for other industries in particular where the targeted improvement is in the performance of processes with an emphasis on waste and quality management. Further investigations would assess the relationship between Six Sigma and Industry 4.0 integration for improvement of production processes.

Keywords: *Six Sigma, Soap Manufacturing, Quality Control, Waste Reduction, Process Improvement.*

1. INTRODUCTION

In the contemporary soap manufacturing industry, where the competition is fierce, the production of quality goods ‘yesterday’ has become a big ask, especially in the aspect of waste control. As said before, product quality or QC is of utmost importance, since consumers are expecting the products to perform uniformly, and laws keep on changing. Different from the social aspects but equally important in today’s model is the waste management, not just because it pollutes the earth, but also due to the extra costs that it brings. Effective defect reduction and resource wastage around many of the manufacturing outfits are weak and making such inefficiencies unsustainable and profiting [1].

Such a problem can be solved by implementation of a data driven methodology which is known as the six-sigma which seeks to reduce the variation in any process and eliminate defects. For example, the efficiency of manufacturing processes can be frustrating to many manufacturers, goals, achievable only by systematic approaches based on

DMAIC or Six Sigma. In soap manufacturing for instance [2], application of six sigma tends to promote consistency in production processes, minimize variances and eliminate wastes as well hence improve the efficiency of the resources used and the quality of the end products [3].

The current issues in waste management and quality control practices in the soap making industry is the reason of performing this study. Most of the time conventional quality management systems do not dwell into the problems that led to defects and waste thus making repetitive causes to hinder efficiency in the operations. Even though the existing ways may provide immediate effect, such does not have a systematic approach towards providing a lasting solution [4], thereof. Since six sigma concentrates on reducing defects to the level of zero and eliminating wastages as much as possible, it provides an alternative to the traditional ways.

Furthermore, soap manufacturing has involved several processes that create waste through misuse of resources or mistakes in the production. The process and product parameters say describes these conditions and could precisely aid the manufacturers in Six Sigma cycle, thus not only improving the quality outcomes but also the quality of operations [5]. This study shall attempt to suggest ways in which the application of six sigma in soap manufacturing can be possible to overcome these challenges by drawing examples of other industries such as water bottling and manufacturing of nutritional products where it has worked [6].

1.2. Literature Review

The Six Sigma methodology has gained traction in the manufacturing sectors because of its ability to improve quality and decrease wastage. The structure of Defining, Measuring, Analyzing, Improving, and Controlling processes - also known as DMAIC is in most instances utilized to understand processes erosion in an organized manner for defects and process improvement. A lot of research have attested its applicability to many industries. For example, Purnomo and Lukman [7] incorporated TRIZ into Lean Six Sigma in wood industry with the results helping in cutting down non-value adding activities. Likewise, Sukwadi applied Six Sigma on the processes of packing soy sauce and attained effective reduction of defect rate by controlling root cause through fishbone diagram and FMEA [8].

Critical to manufacturing quality management approaches, Only For instance, the need for the Expansion of Six Sigma tools and methodologies to include the Taguchi process capability index, particularly in gaining multi-characteristic product quality [9]. The combination resulted into better quality of the products and less rework and scrap facilitating performance on the sustainability trip. At the same time, Condé et al. (2023) showed the possibility for the car parts manufacturing industry to reduce defects and illustrated that Six Sigma methods can improve the sigma level and eliminate process variations. These studies show that in particular, Six Sigma, with or without the adoption of Some Lean principles is a good tool for waste reduction and improvement of quality [10].

However, this cannot be said in the same regard about the literature with regards to soap manufacturing industries as Six-Sigma has been extensively used in industries including automotive and pharmaceuticals as well as wood manufacturing industries. Previous studies [11,12], focus on under different sectors but have relevant issues of waste reduction and quality improvement, implying that Six Sigma has potential in soap making industries as well.

1.3. Contribution

In this regard, the study finalizes some conclusions about the state of the Six Sigma methodologies within the context of soap manufacturing and attempts to bridge the identified gap. The focus of this study will be the production of soap while previous studies have researched on automotive industry [13] and pharmaceutical manufacturing [14], hence, in this study Six sigma will be put to test on the soap production process so as to eliminate wastages and improve quality. This particular aspect of the study will also help in making a unique contribution as it will show how the DMAIC framework can be successfully applied in this particular industry.

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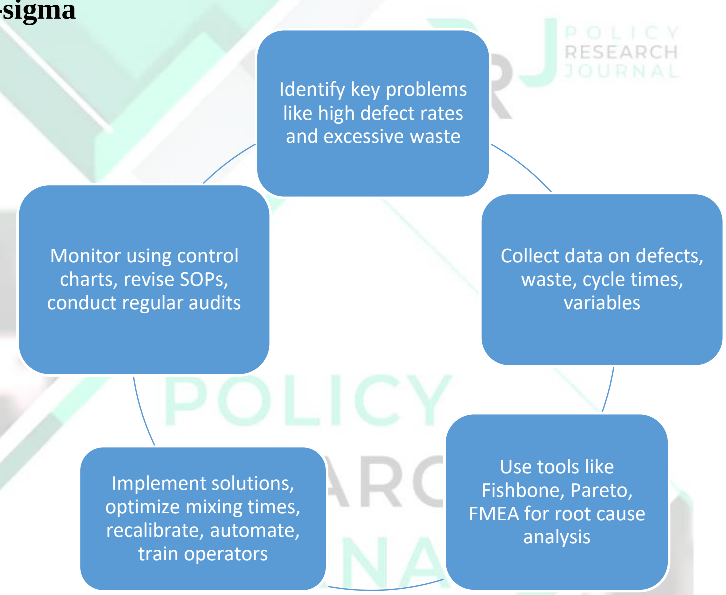
ISSN (E): 3006-7030 (P) 3006-7022

2. Materials and Methods

The Six Sigma approach is a gradual procedure that helps in mitigating the variation i.e. any deviation from the normal value in any process and the defects that arise, while at the same time bettering the performance and the quality. In this case, the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) indeed forms part of the strategies adopted to enhance the soap making process. Each stage in the cycle of DMAIC has strategic aims which help in the process improvements. Below is a detailed explanation of how the DMAIC cycle was put into use in the management of quality and reduction of waste in the soap making process.

Figure1: Approach of Six-sigma



2.1 Define Phase

The first step in the Six Sigma DMAIC process is referred to as the Define phase and it mainly deals with project scope and goals clearly defined and the problem described. The problem was therefore confined to generation of too much waste and average product quality during the soap making process. In order to meet these objectives, wastage reduction and quality improvement and production efficiency optimization were set out.

The necessary instruments utilized in the Define stage included project charters and a SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram. The SIPOC diagram was instrumental and assisted in tracing the soap production process further identifying the areas that required improvement. Within the scope of this engagement, such stakeholders involved production managers, quality control teams as well as machine operators to denote the project's boundary, its scope, and goals such as decreasing the defective soap bars by thirty percent and decreasing raw material waste by twenty five percent.

2.2 Measure Phase

The Measure phase is planned in a way that assists in defining the problem better. Data collection was performed to find out the product quality performance on the soap manufacturing process at this stage. Several important indicators of the process were highlighted: the volume of the waste produced per batch, the total number of watershed defect soap bars and the times for each cycle of the process.

Data Collection was incorporated into this study with the use of data collection sheets and process mapping to study the various constituents/cycles in the soap production process namely, mixing, molding, and packaging, therein, in detail. Orthogonal task decomposition also composed detailed acquisition of defective products and wasted raw materials. Baseline sigma level was calculated applying statistic tools including descriptive statistic, and its level was found at 3.2 statistical sigma level, which shows a lot of defects. On top of these I/O related metrics cycle time and production lead time measure amply, helped define the pinch points in the process. Analyze Phase During the Analyze phase, the analyzed data was addressed with the emphasis on identifying the possible reasons for the detected inefficiencies and defects. This phase also focused on characterizing the sources of the waste and quality problems in soap manufacturing.

2.3 Analyze Phase

As in the case of fishbone diagram, or Ishikawa's diagrams, here such diagrams were seco used in order to explore particular possible reasons of wastage and defects of a material. The reason which can be attributed as possible contributory factors involves breakdown of machines, mistakes made by operators, differences in the quality of raw materials as well as inefficiencies in scheduling of production. Next, the major reasons of the defects were evaluated applying the Pareto diagram, where practically 80% of the reasons are explained by 20% of the factors, such as mixing time and temperature during soap curing process. Failure Modes and Effects Analysis (FMEA) was also used for the assessment of all the possible failure points of the production line in regard to its severity, occurrence and level of detection.

2.4 Improve Phase

This phase concentrates on confirming that the solutions drafted in the analyze phase where appropriate and therefore to the problems identified in the improve phase. From the results drawn out, a number of corrective actions were approved and adopted. Particulars' of these measures were to fit the machines and take the processors through further learning.

One of the key improvements was related to the temperature control of the soap during the curing stage. In order to investigate the appropriate temperature values several temperature variations were applied and the results obtained revealed that maintaining the temperature constant at 45°C helped in reducing the number of faults concerning the improper hardening of soap. The other improvement was about the ow of production which included the use of computerized systems for weighing the raw materials and thus controlling the proportions of the ingredients used to make the soap which minimized the inconsistencies in products.

The team also utilized production management such as a color coded control panel which signaled an operator to the parameters of production when anything went out of range. The use of these auditory methods also led to a reduction in cases of human error. Employees were put into work teams with specific tasks to implement changes as well as having their processes improved through the organization of improvement events known as Kaizen events. Defects were however reduced by 40% while the raw material wastage rate was below 35%.

2.5 Control Phase

The Control phase was the tightening step for the improvement made in the previous phase by preventing any instability with the process over time. Control charts were introduced in the restoration process to follow the process parameters like temperature, mixing time, and production output. Such out of control charts assisted the team in ensuring that any irrational operating conditions were remedied before there were many defects.

The Standard Operating Procedures (SOPs) were restructured in accordance with the new changes in the processes, and employees were sensitized with these changes. There was also a standard KPI for each waste reduction and each related to the quality with respect to the KPIs regarding waste and product quality. In addition, there were review audits planned on a regular basis to ensure that the new processes that had been put in place would be followed in order to retain the benefits obtained during the Improve phase. The process improvements were able to reach 4.1 sigma where this was an increase in the levels of quality delivered with defects being reduced.

2.5 Data Collection

The collection of data was an essential part of this study because it allowed for measuring the state of the existing soap manufacturing process and the value of its improvements. Information was obtained from and recorded at different levels of the soap production, such as raw materials acquisition, mixing, molding, curing and packing. Key metrics most relevant are given below:

- **Defective Product Rate:**

The measure of the scrapped number of defective soap bars produced previously in a specified batch. Defects included: improper shapes, weights and surface blemishes.

- **Raw Material Waste:**

This is conceptualized as some amount of raw materials such as fats, oils and alkali which are left or become waste during the production process and this includes spillages, excess materials, off-spec batches and any other redundancy.

- **Cycle Time:**

Duration at which a single batch developmental cycle is from the initial stage of Modern materials preparation to the conclusive stage of packaging soap bars.

- **Rework Costs:**

This cost deals with financial implications incurred when products which do not meet specifications are reworked in relevant batches that are not possible or when good products are disposed of.

Data collection involves manual entry by the operators as well as automatic recording of data using sensors placed in important machines including the mixers and molders. In regard to each batch, hours used in production, amounts of waste and number of defects produced were carefully documented. The company records also enabled reviewing of historical data n production in order to support the introduction of new measures.

2.6 Analysis Tools

In this study, several Six Sigma tools were used to analyze the data collected and find room for improvement. Below are the main tools

- **Pareto Charts:** These were applied in ranking the key sources of defects and wastage in the soap production process. The 80/20 principle was evident here as relatively few causes were found to make most of the defects or wastes in the process.
- **Fishbone Diagrams (Ishikawa):** These are supported diagram structures which are used to logically depict and examine the probable origins of problems and losses. They are focused in an area of interest: equipment, material, processes and human beings.
- **Process Capability Analysis:**

This was necessary in establishing the level of quality that the production system was able to achieve and maintain at any particular given time. It gauge the amount of variation that was present in the process and Assess the level of defect free products that the process was able to produce.

- **Control Charts:**

These were geared in the Control phase to crosscheck the efficiency of the processes employed to once again ensure that the returns had not been short-lived. Control charts enabled timely responses to any growing trends that would lead to defects.

With the help of these instruments, the team was able to analyze the sources and causes of quality defects and waste, make constructive changes, and improve and maintain the long run stability of processes.

5. Results

The introduction of Six Sigma principles into the manufacturing of soap brought about measurable benefits both on the aspects such as quality control, waste and process improvements. The results from each phase of the Six Sigma DMAIC are provided below with the appropriate information through data and graphics. This part describes the general enhancement of product quality, improvement in waste generation, and minimization of cycle time whilst tables are provided to show the collected baseline and post implementation data.

3.1 Improvement in Quality Metrics

The reduction of the number of defective soap bars produced in batch is one of the main objectives of this project. Prior to the Six Sigma intervention, an unacceptably high average of defect ratio was recorded due to mixing the ingredients for 'wrong' time laps, uneven curing and malfunctioning of the machines. Diagnostic investigation at this stage indicated that the defect rate went down on the average since there was effective standardization of process parameters. Table 1 shows defect rates before the improvement and defect rates after the improvement for each type of defects.

Table 1: Defect Rates Before and After Six Sigma Implementation

Defect Type	Before Implementation (%)	After Implementation (%)	Reduction (%)
Inconsistent Weight	5.6	2.1	62.5
Surface Imperfections	4.3	1.5	65.1
Improper Curing	6.8	2.4	64.7
Shape Deformities	3.2	1.1	65.6
Total Defect Rate	**19.9**	**7.1**	**64.3**

The Total Defect Rate went down with 64.3%. Raising the sigma level of the process from 3.2 to 4.1. This has shown the achievement of this DMAIC strategy as it investigates the problem of quality in the soap industry and provides lasting solutions to it.

3.2 Waste Reduction

Reducing raw materials waste is also another important objective of the six sigma program. Baseline: Few raw materials such as fats, oils, alkaline were used properly and a great deal of them was wasted because of overuse, spilling and wrong formulation. After the changes were introduced including but not limited to controlled mixing time and automated dispensing of the materials, the waste went to the levels shown in table 2.

Table 2: Raw Material Waste Before and After Six Sigma Implementation

Material	Before Implementation (kg/batch)	After Implementation (kg/batch)	Reduction (%)
Fats and Oils	12.5	7.8	37.6
Alkali	8.3	4.9	41.0
Additives (Fragrance, Color)	3.2	1.9	40.6
Packaging Material	5.4	2.7	50.0
Total Waste	**29.4**	**17.3**	**41.2**

Another advantage with respect to the enhancement of the method and the reduction of the cost was the decrease of the raw material waste per batch by 41.2%. The waste in packagings was also notably cut owing to the inapplicability of manual operations and rigid control to specific areas of packaging materials.

3.3 Process Efficiency and Cycle Time

Process efficiency improvements were this area of activity, which is another concerning point, were a major focus. In the absence of the Six Sigma intervention, difficulties arose with the production cycle because cycle times were unable to be controlled and there were regular interruptions in production owing to machine failures, poor handling of materials, and delays in workflow. However, after the process improvement, cycle times were short, and the performance in production increased.

Table 3: Process Cycle Times Before and After Six Sigma Implementation

Process Stage	Before Implementation (Minutes/Batch)	After Implementation (Minutes/Batch)	Improvement (%)
Raw Material Preparation	60	45	25.0
Mixing	90	70	22.2
Molding	45	30	33.3
Curing	120	90	25.0
Packaging	30	20	33.3
Total Cycle Time	**345**	**255**	**26.1**

Based on the information provided in Table 3, the total cycle time required for the production of each batch of soap was reduced from 345 minutes to 255 minutes representing an improvement of 26.1%. This reduction in total cycle time was mainly due to some improvements made on the curing process and the movement of materials and an efficient flow of operations at the packaging segment.

3.4 Financial Impact of Waste Reduction

The constriction of raw material waste plus the reduction of defects had a corresponding effect on the total production cost. Table 4 Whence displays the cost benefit obtained from a reduced quantity of defective and/or waste products.

Table 4: Cost Savings from Waste Reduction

Category	Before Implementation (Cost per Batch)	After Implementation (Cost per Batch)	Savings (%)
Defective Products	$150.00	$70.00	53.3
Raw Material Waste	$250.00	$150.00	40.0
Energy Consumption	$120.00	$95.00	20.8
Labor Costs (Rework)	$180.00	$80.00	55.6
Total Savings	**$700.00**	**$395.00**	**43.6**

From the above analysis, the percentage savings per batch from waste reduction and reduced defect rates has been rated at 43.6%, which is indeed a significant financial encouragement towards the acceptance of the Six Sigma methodologies. Even in terms of labor costs of rework of defective products for diagnosis will be substantially lowered, with decrease of defects.

3.5 Process Capability Improvement

Process capability has been included in the critical success factor of the six-sigma framework. This is an indicator of how the process performs in producing products that conform to product requirements. The process capability analysis was conducted both before and after the six-sigma implementation as it is done in table 5.

Table 5: Process Capability Index (Cp) and Process Performance Index (Cpk) Before and After Implementation

Metric	Before Implementation	After Implementation
Cp (Process Capability Index)	0.94	1.45
Cpk (Process Performance Index)	0.87	1.39

The quality control process improvement measured by process capability (Cp) and process performance (Cpk) before implementation was 0.94 and 0.87 but the results after the improvement progressed to 1.45 and 1.39 respectively. This suggests that the processes have been enhanced in a way that they can consistently meet the quality standards required and are able to keep variability in control.

3.6 Employee Productivity and Training Impact

Quality control was extended to the machine operators and production supervisors with training involving the Six Sigma quality improvement program and the revised Standard Operating Procedures (SOPs). Table 6 illustrates the influence of employees' training on their productivity.

Table 6: Impact of Training on Employee Productivity

Metric	Before Training	After Training	Improvement (%)
Average Output (Units per Hour)	500	650	30.0
Errors per Operator	8	3	62.5
Downtime Due to Operator Error (Minutes/Day)	90	45	50.0

As a result, employee productivity was increased by 30% with the 50% reduction in downtime caused by operator error. Further, the number of errors per operator was reduced further by 62.5%, among other factors improving the efficiency of the process.

The incorporation of Six Sigma principles into the soap making process brought significant positive changes about the quality of the end product, waste management, and efficiency of the process. The levels of Defect rates lowered by 64.3% and raw material wastage was alleviated by 41.2%, thus leading to great cost aspirations. All of these resulted in reduced process cycle times by 26.1% and increase in process capability indices suggesting better management of production variations. This demonstrated that there was value of Six Sigma as a strategy to improve the manufacturing processes as representative in a decrease of production costs by 43.6 percent. Development in professionalism was also key in helping the company in maintaining these improvements enhancing productivity and curbing errors.

4. Discussion

The results of this study are also consistent with similar studies conducted in the past which show that Six Sigma approaches are useful in waste management, improved product delivery, and increased overall efficiency of the processes followed. The average defect rate and amount of raw material utilized in soap making were significantly lower than those reported in this study and other studies such as Purnomo and Lukman (2020) where wood manufacturing wastes were practically diminished due to Lean Six Sigma non-value-added activities [14] the deterioration in defect rates was virtually eradicated.

In addition, the process efficiency results such as the decrease of 26.1% in the cycle times are in agreement with the results of other studies which extended the application of Six Sigma to the manufacturing processes. For instance, In a plastic injection-molding facility, process capability and product yield were substantially improved after fine-tuning critical process parameters [15]. Reducing defects and material shortfall not only improved product class but also resulted in cost benefits, in similarly observed in this study where

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ISSN (E): 3006-7030 (P) 3006-7022

Process Six sigma strategies led to decreasing production costs and process variation in the sorbitol industry [16].
It would still be prudent to point out some differences in the extent of improvements when interested with 'other studies in this area'. For instance, in this study, the waste of raw material was reduced by 41.2%, which is a little lesser compared to the 50% waste reduction on coconut briquettes production using Lean Six Sigma [117]. This variation can be well understood from the nature of soap production as a process because the different raw materials and different processing stages offer different waste generation problems.
Similar trends have been reported in other studies of process capability indices (Cp and Cpk) improvements. In this case, process capability indices have raised from 0.94 to 1.45, similar to the findings of Yu et al., in which application of Six Sigma Aeemed to improve more complex and multi-characteristic products in favour of higher yield performances [18].
In general, the results of this study support the initial hypothesis that validly implemented Six Sigma tools can help to solve quality issues and problem of waste minimization, By defining direction of improvement of process efficiency and organizational performance in the scope of soap industry change agents. The level of these improvements fits within that found in other segments of the manufacturing industry arguing for benefits of Six Sigma within any sector.
As in soap manufacturing, this study has further broader implications that highlight the importance of Six Sigma for process improvement in a wide range of industries. In such scenarios where factors such as waste minimization and quality are of utmost importance, Six Sigma provides a systematic and objective way to eliminate wastage and implement processes that work. Competitive efficiency, cost cutting and enhancement of customer value [16] has also been demonstrated in the food, cement [14] and plastic molding [15] industries with effective deployment of Six Sigma. For various industries facing operational challenges which stem from process variation, Six sigma is able to standardize different processes to injury procedural adherence. In the current study as seen, there was a considerable reduction in process variability in the soap making process resulting to a more stable product quality. The same applies in industries like automotive industry where product consistency is one of the critical areas for competitive advantage retention [19].
Moreover, the waste reduction strategies implemented had significant environmental and financial returns in this study, indicating that Six Sigma may be used to develop sustainability in industries defined by excessive waste generation . There are considerable cost benefits to enterprises since less raw material is spent and defects are also less, therefore meeting the objectives of sustainable manufacturing [20].
In the context of the transition to Industry 4.0, which emphasizes automation, data analysis and smart manufacturing as the core characteristics of this industrial revolution, this is where Six Sigma methodologies can further bolster the adaptability of industries to the aforementioned changes. Enveloping Six Sigma practices in an Industry 4.0 context is about continuously realigning the market to the present predicament of improved efficiency, product quality and attention span. This is a highly fruitful area for future studies focusing on Six Sigma and new technologies within the manufacturing industry.

5. Conclusion

It has been proven within this study that Six Sigma techniques are effective in the improvement of the soap manufacturing process. DMAIC. The drum resources wastage was also significant as it was reduced by 41.2% which was a positive indicator of cost efficiency and time savings. Such results are also produced in the findings of other works within different industries establishing the fact that Six Sigma is useful within all areas of operation where processes are undertaken.
The enhancement in the process capability indices also denotes the degree of control or consistency attainable in the manufacture of the end product through the application of Six Sigma. Besides, the reduction of the wastes and the defects has yielded not only business but also financial returns through the application of the Six Sigma methodologies to the manufacturing processes.
To sum up, Six Sigma is a practical approach, which can be applied to various aspects of

operations, such as the processes of production, reduction of wastage and enhancing the quality of the products. Another area which merits further study is that of Six Sigma as a system within the paradigm of the Industry 4.0 concept, being a promising area with plenty of potential for optimization and sustainability of processes in various industries.

Funding: This research received no external funding\
Conflicts of Interest: The authors declare no conflict of interest

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