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Improving Operational Efficiency and Reducing Downtime: Applying Lean Six Sigma in Material Recovery Facilities

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Abstract

In response to challenges within the solid waste industry in Puerto Rico, this research focused on enhancing Material Recovery Facility (MRF) operations using Lean Six Sigma. Employing the DMAIC framework, the study tackled recurring downtime at one Puerto Rico MRF. Key findings include identifying root causes, such as conveyor jams and material entanglements, and proposing improvements like continuous professional development, preventive system upkeep, and specialized equipment additions like the Industrial Bag Opener and Motorized Brush. The study projected a 30% downtime reduction, yielding an annual saving of around $97,630. This ROI calculation factored in operational enhancements and equipment costs, highlighting the financial benefits of Lean Six Sigma integration. Emphasizing Lean Six Sigma's value in MRF operations, the study provides insights for the industry and underscores data-driven waste management enhancements. Moreover, its alignment with UN Sustainable Development Goals 8, 9, and 11 highlights contributions to decent work and economic growth (SDG 8), industry, innovation, and infrastructure (SDG 9), and sustainable cities and communities (SDG 11). The research showcases the practical advantages of Lean Six Sigma in MRF operations, serving as a model for the broader waste management sector and affirming the value of data-driven enhancements.

Keywords
Industrial engineering, Downtime, Lean Six Sigma, Recycling, Solid Waste Industry

1. Introduction
This research paper examines the challenges faced by the solid waste industry in Puerto Rico, particularly in material recovery facilities (MRFs), which are essential for sorting and processing recyclables. According to EPA & FEMA (2020), these facilities need more downtime, decreasing operational efficiency, increasing costs, and potential waste accumulation. The study explores the application of Lean Six Sigma, a methodology combining Lean's waste-elimination and process-optimization principles with Six Sigma's focus on reducing process variation and defects, as a solution to these challenges. While Lean Six Sigma has been successful in other industries, its application in Puerto Rican solid waste management, particularly in MRFs, is under-researched (Closed Loop Partners, 2020).

The research focuses on a case study of an MRF in Puerto Rico, implementing Lean Six Sigma and its DMAIC methodology. Considering its unique operational context, it aims to identify strategies and best practices for applying this methodology in this MRF. The study will discuss the results and advantages of Lean Six Sigma implementation in the MRF, address challenges and barriers, and provide recommendations for successful integration. This research contributes to understanding Lean Six Sigma's application in the solid waste industry and material recovery facilities, offering potential solutions to improve efficiency and reduce downtime.

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2. Problem Description

The Material Recovery Facility (MRF) in Guaynabo, Puerto Rico, faces a critical challenge with frequent and unmeasured downtime during the sorting process, severely impacting operational efficiency and productivity. Key issues contributing to this problem include conveyor belt jams and the entanglement of unsuitable materials in machinery. Preliminary observations suggest that downtime occurs at least twice daily, averaging 20 minutes per incident. This inefficiency disrupts operations and incurs significant costs, often leading to expensive overtime work. Addressing this issue is crucial for enhancing the MRF's efficiency and reducing operational costs. The primary goal of this research is to develop a strategy to reduce downtime by 30%, thereby improving overall productivity and customer satisfaction.

3. Related Research

The study 'Lean Six Sigma at a Material Recovery Facility: A Case Study' by Franchetti and Barnala (2013) in the International Journal of Lean Six Sigma offers valuable insights into Lean Six Sigma's application in the recycling industry. Focused on a government-operated Material Recovery Facility (MRF) in Toledo, Ohio, USA, the study employed the DMAIC methodology to improve process efficiency and increase facility capacity.

Key findings demonstrated notable productivity increases: 7.3% for paper bales, 12.8% for commingled bales, and 1.6% for OCC bales, alongside over $65,000 in annual savings. While the study's scope was limited to a single case and area, its implications are significant for researchers and practitioners in the recycling industry, showcasing the tangible benefits of Lean Six Sigma in this sector.

4. Methodology

To address the identified challenges at the Material Recovery Facility in Puerto Rico, this study employs the Lean Six Sigma DMAIC methodology, a structured approach to improve operational efficiency and reduce downtime.

4.1. Define

In the Define phase of the DMAIC methodology, the goal and scope of the study at the Material Recovery Facility (MRF) in Guaynabo, Puerto Rico, are established. The focus is on analyzing and improving the MRF's sorting process, particularly addressing downtime issues. Engagement with stakeholders, including MRF management, operational, and maintenance staff, is crucial in this phase to incorporate their expertise and perspectives. A SIPOC (Suppliers, Inputs, Process, Output, Customers) diagram was created to provide a broad understanding of the facility's operations, capturing vital elements of the MRF's workflow (Table 1).

Table 1. SIPOC of Material Recovery Facility

SIPOC Element	Description
Suppliers	Municipality of Guaynabo: Provides the facility, water, and electricity
	Municipalities of Puerto Rico: Supply the recyclable materials to the MRF for sorting and processing.
Inputs	Recyclable Materials: Includes various types of waste collected from municipalities.
	Sorting Equipment and Employees
Process	Recycling Truck Unloads at MRF
	Manual Sorting: Remove potential hazardous items and Separate cardboard
	Mechanical Sorting: Lighter materials to Paper Sorting / Heavier materials to Plastic & Aluminum
	Manual Sorting: Separate Paper or Separate Plastic & Aluminum
	Compress into Bales
	Non-Recyclable Materials: Transported and discarded to Landfill
Outputs	Sorted Materials: Paper, plastic, cardboard and aluminum ready for sale.
	Landfill waste
Customers	Municipalities: Primary customers paying for sorting services.
	Recycling Facilities (e.g., Ifco): Customers who purchase sorted materials for further processing or export.

A further view of the sorting process was achieved through a process map, which illustrates the waste stream, machine locations, and the roles of operators along the conveyor belt. This map helps pinpoint specific areas within the sorting process that may contribute to inefficiencies and downtime (Figure 1).

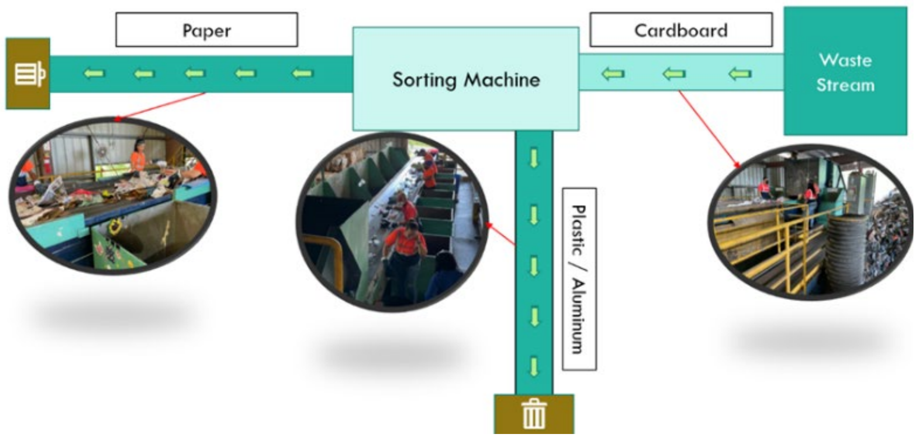

Figure 1. MRF Sorting Process Layout

A comprehensive flowchart was developed to gain a more detailed view of the facility's processes. This flowchart visually represents the sequence of operations within the MRF (Figure 2).

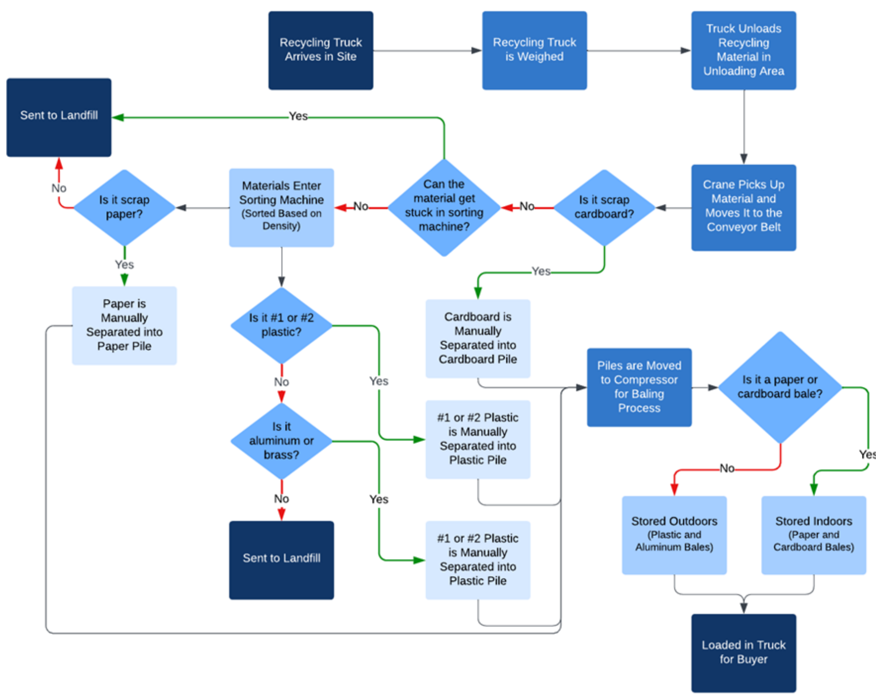

Figure 2. Flowchart of MRF

Finally, a precise problem statement was formulated: Critical downtime issues were identified in the sorting process, significantly affecting operational efficiency and productivity. Significant causes of downtime include conveyor belt jams and entanglement of materials in machinery, with each incident lasting about 20 minutes and occurring at least twice daily. The lack of systematic monitoring exacerbates the issue, preventing practical analysis and improvement.

This downtime leads to substantial financial costs, approximately $437.50 per hour of lost production, and necessitates costly overtime to meet demands. The study aims to reduce downtime by 30% to enhance efficiency, productivity, and customer satisfaction while reducing related costs.

4.2. Measure

In the Measure phase of the DMAIC methodology, a comprehensive data collection plan was implemented to address the issue of frequent downtime in the sorting process at the Material Recovery Facility (MRF). This plan outlines the systematic approach to collecting data, specifying how and when data will be gathered to ensure a rigorous analysis. Data was collected at one-hour intervals from December to March (Table 2).

Table 2. Data Collection Plan

Variable	Data Type	Units	Where?	How?	Sample Size
Downtime on Plastic Conveyor	Continuous	min	Plastic Conveyer	Military time clock	A minimum 30 samples
Downtime on Paper Conveyor	Continuous	min	Paper Conveyer	Military time clock	A minimum of 30 samples
Downtime on Cardboard Conveyor	Continuous	min	Cardboard Conveyor	Military time clock	A minimum of 30 samples
Downtime Frequency	Discrete	count	Sorting Process	Manual count in notebook	As observed
Downtime Cause/Variable	Categorical	n/a	Sorting Process	Observe and describe in notebook	As observed

Analysis of the collected data resulted in a table of descriptive statistics, providing insights into the duration of downtime for different materials in the sorting process. The statistics revealed patterns in downtime durations. Notably, paper and plastic had higher maximum downtime values than cardboard, suggesting a more significant impact on downtime durations (Table 3).

Table 3. MRF Descriptive Statistics in Minutes

Statistics

Variable	MATERIAL	Total Count	Mean	StDev	Variance
TIME DIFFERENCE(MIN)	Cardboard	30	2.022	2.250	5.064
	Paper	52	2.692	3.930	15.445
	Plastic	45	2.631	3.926	15.412

Variable	MATERIAL	Median	Q3	Maximum
TIME DIFFERENCE(MIN)	Cardboard	1.585	2.410	13.080
	Paper	1.260	2.947	25.200
	Plastic	1.330	3.350	25.820

This phase's outcome includes a table summarizing critical statistics for downtime based on 127 data points across cardboard, paper, and plastic, considering the plant's 8-hour workday in the sorting process. These statistics offer an approximate perspective on the efficiency of the current system (Table 4).

Table 4. Downtime Frequency and Time Averages per Material

	Average frequency per hour	Average downtime per material	Minutes per hour	Minutes per shift	To hours
Cardboard	2.73	2.02	5.52	44.12	0.74
Paper	4.73	2.69	12.72	101.78	1.70
Plastic	4.09	2.63	10.76	86.10	1.43
			Average downtime per 8hr shift:		**3.87**

4.3. Analyze

In the analysis phase of the DMAIC methodology, we delved deeper into the collected data and previously obtained descriptive statistics to identify the root causes of downtime in the MRF sorting process. Our analysis begins with the application of Pareto charts.

Figure 3 (a) Pareto chart highlights the most frequent variable for downtime, revealing that the primary causes are stopping the machinery from discarding contaminated material and delays due to sorting cardboard, which stops the production line. Figure 3 (b) Pareto chart focuses on the duration of these downtime incidents. It shows conveyor belt jams and cardboard sorting are the most time-consuming downtimes (Figure 3).

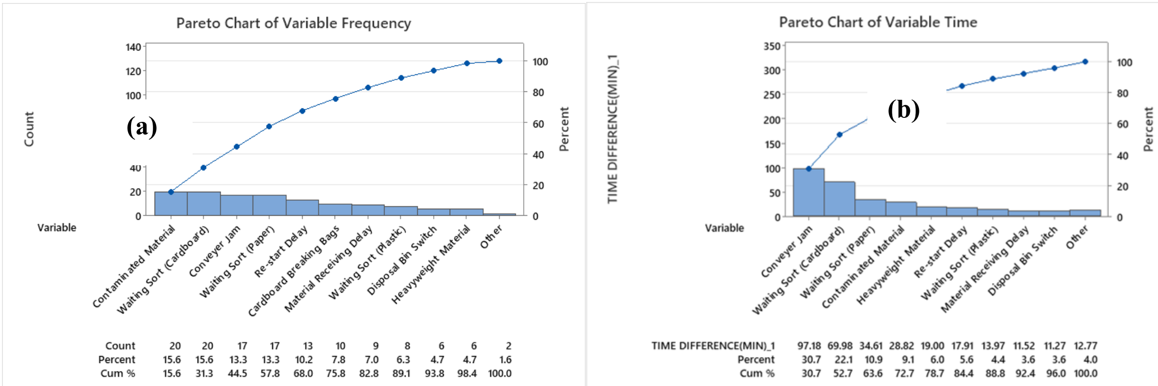

Figure 3. Pareto Charts of Frequency and Duration (min)

Subsequently, an Analysis of Variance (ANOVA) was performed to assess differences in downtime between materials. The results, with a P-value of 0.694 and an F-value of 0.37, suggested no significant differences in downtime across different materials, indicating that the downtimes for cardboard, paper, and plastic are statistically similar. This finding aligns with the connected nature of the sorting process, where delays in one area, especially cardboard sorting, can lead to downtime in others.

Finally, a Fishbone diagram was created to identify key factors contributing to downtime in the sorting process at the MRF, with a focus on the lack of proactive maintenance strategies. These analyses revealed that significant contributors to downtime include contamination issues, cardboard sorting inefficiencies, and conveyor belt jams. Importantly, downtime durations were statistically similar across different materials, highlighting the interconnectedness of the sorting process stages. These insights guide our next steps toward targeted improvements and efficiency optimization in the MRF's operations (Figure 4).

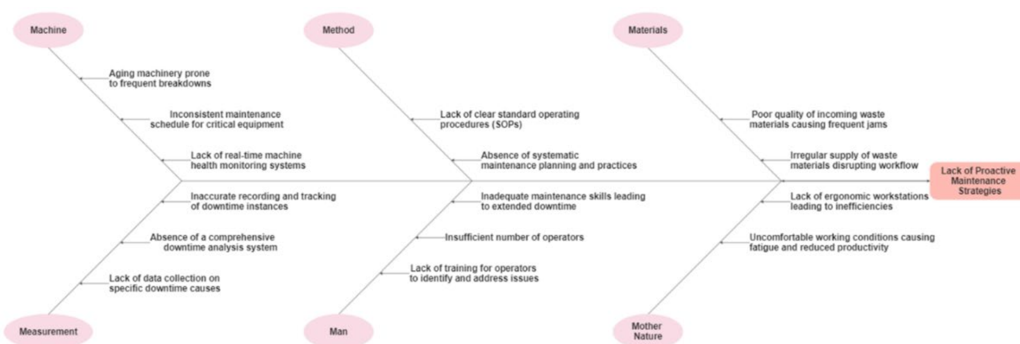

Figure 4. Fishbone Diagram

4.4. Improve

In the Improvement phase for the MRF, strategies for enhanced efficiency and their respective costs include:

- Regular Training: Enhancing operator skills with ongoing training programs. Cost: $3,700.
- Proactive Maintenance: Shifting to preventative equipment maintenance to minimize downtime. Cost: $1,500.
- Supplier Collaboration: Improving material quality through better supplier relations.
- Idle Time Tracking: Monitoring machine idle time with QR codes for improvements.
- Additional Workforce: Hiring an extra employee for the triage process to boost productivity. Cost: 29,120.
- Equipment Investments:
    - Industrial Bag Opener: To accelerate the sorting process in the Cardboard section. Cost: $30,000.

- Motorized Industrial Brush: To address spillage and prevent conveyor jams. Cost: $5,000.

The total costs for these initiatives: $69,320

4.5. Control

In the Control phase of this research, the focus was on maintaining the success of the improvements implemented in the MRF through continuous monitoring and optimization. Key strategies adopted included:

- Predictive Maintenance Strategy: A data analytics strategy was implemented to anticipate equipment issues, reduce unplanned downtime, and optimize operations.
- Standard Operating Procedures (SOPs): Clear SOPs were established, and regular training sessions were conducted to equip operators with the skills to manage downtime situations effectively.
- Regular Review and Follow-Up Meetings: Periodic meetings were held to evaluate the implemented improvements, analyze Key Performance Indicators (KPIs), and adjust strategies for continuous reduction in downtime.

5. Results

As of the article's publication date, the Improvement stage proposed for the Puerto Rico MRF is in the process of implementation. Effective cleaning of conveyor belts in an MRF, especially when facing constant contamination, is expected to reduce downtime significantly. Drawing on industry benchmarks and operational analyses, such as those by Koussaimi et al. (2016), downtime reduction can vary from 20% to 50%. For the Guaynabo MRF, a conservative estimate of a 30% reduction in downtime was chosen for calculating the final Return on Investment (ROI), considering the current lack of robust conveyor belt cleaning procedures and the problem of contaminated incoming waste streams. The financial impact of this reduction is substantial, reducing downtime by 301.6 hours. Considering the hourly operating cost of $437.50, the annual savings are estimated to be $131,950. The ROI is achieved in 5.7 months, yielding a net savings of $62,630. Annually, after the first year, the savings amount to $97,630, accounting for annual operating costs of $34,320. This figure illustrates the financial benefits of investing in conveyor belt cleaning and optimization and emphasizes its potential to enhance operational efficiency and profitability at MRFs.

6. Conclusion

This research applied Lean Six Sigma principles within the DMAIC framework to improve operations at one Materials Recovery Plant (MRF) in Puerto Rico, focusing on reducing downtime in the sorting process. Key findings identified conveyor belt jams, material entanglements, and cardboard sorting delays as primary causes of downtime. Recommendations include ongoing workforce training, proactive maintenance strategies, enhanced supplier collaboration, and the integration of specialized equipment like the Industrial Bag Opener and Motorized Industrial Brush. The study predicts a significant 30% reduction in downtime, leading to an estimated annual savings of around $97,630, considering both the costs of operational improvements and equipment acquisition. This highlights Lean Six Sigma methodologies' financial benefits and effectiveness in optimizing MRF operations. Moreover, the research aligns with the United Nations Sustainable Development Goals, particularly SDG 8 (decent work and economic growth), SDG 9 (industry, innovation, and infrastructure), and SDG 11 (sustainable cities and communities), demonstrating its broader positive impact on society and the environment. This study underscores the value of data-driven improvements in waste management practices

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