IMPROVING OPERATIONAL EFFICIENCY AND DOWNTIME REDUCTION: APPLYING LEAN SIX SIGMA IN MATERIAL RECOVERY FACILITIES

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Abstract

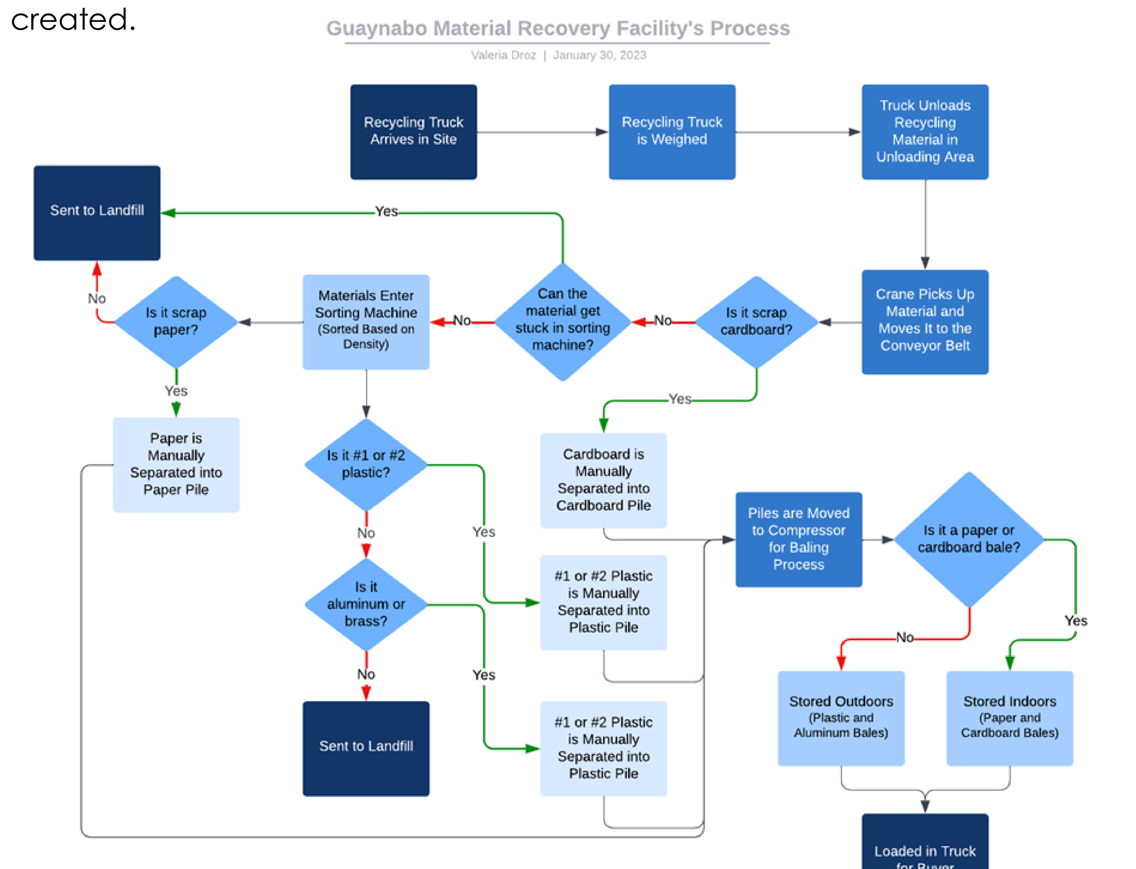
In response to challenges within the solid waste industry, this research focused on enhancing Material Recovery Facility (MRF) operations using Lean Six Sigma. Employing the DMAIC framework, the study tackled recurring downtime at a Guaynabo, Puerto Rico MRF. Key findings include identifying root causes, such as conveyor jams and material entanglements, and proposing improvements like ongoing training, proactive maintenance, and specialized equipment 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 wider waste management sector and affirming the value of data-driven enhancements.

Introduction

In recent years, Puerto Rico's solid waste industry has struggled with heightened challenges in waste management and recycling (Closed Loop Partners, 2020). Material Recovery Facilities (MRFs), vital to recycling infrastructure, frequently experience sorting process downtime, hindering efficiency and inflating costs. Adopting Lean Six Sigma methodologies for ongoing improvement is crucial to enhance MRF performance. Lean Six Sigma, recognized for its effectiveness across various sectors, combines waste reduction principles with statistical rigor to minimize defects (Koussaimi et al., 2016). However, its utilization in the solid waste sector, particularly in MRFs, remains constrained. This study focuses on a Guaynabo, P.R. MRF, aiming to customize Lean Six Sigma for its sorting process. This facility runs Monday through Friday, on a single shift from 6 a.m. to 3 p.m. To achieve the goals of this study, the DMAIC (Define, Measure, Analyze, Improve, Control) methodology was employed, a framework of Lean Six Sigma (Burke & Silvestrini, 2017).

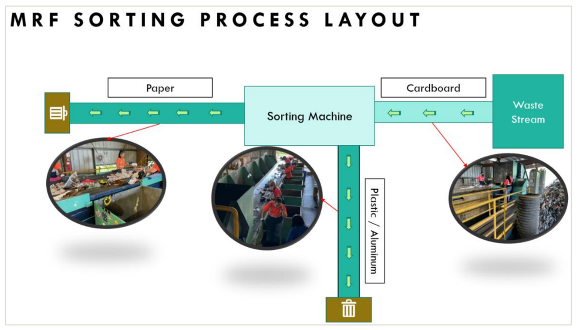
Define

To better picture the MRF's operations, a **flowchart** and process layout were created.



The define stage focuses on identifying and defining the challenges within the MRF's sorting process. A problem statement was created to map the project scope and objectives.

MRF SORTING PROCESS LAYOUT



Problem Statement:
The MRF experiences frequent and substantial downtimes during sorting process, with a 48.37% downtime rate observed from December through March. This issue hinders operational efficiency and productivity due to conveyor belt jams and unsuitable material entanglement. Stakeholders state that each downtime occurrence, suspected to last roughly 20 minutes and at least twice daily, underscores the urgency. However, the absence of systematic tracking inhibits comprehensive analysis and improvement efforts. Addressing this challenge is critical for optimizing sorting, enhancing productivity, and meeting customer expectations.

Methodology

Measure

The Measure stage delves into data collection to quantitatively assess the extent of downtime in the MRF's sorting process. A systematic **data collection plan** was developed.

Variable	Data Type	Units	Where?	How?	Sample Size
Downtime on Plastic Conveyor	Continuous	min	Plastic Conveyer	Stopwatch and portable clock	10 working days or 30 samples
Downtime on Paper Conveyor	Continuous	min	Paper Conveyer	Stopwatch and portable clock	10 working days or 30 samples
Downtime on Cardboard Conveyor	Continuous	min	Cardboard Conveyer	Stopwatch and portable clock	10 working days or 30 samples
Downtime Frequency	Discrete	count	Sorting Process	Manual count in notebook	As observed
Downtime Cause	Categorical	n/a	Sorting Process	Observe and describe in notebook	As observed

With the data collected, **descriptive statistics** were developed to better understand and view the data. The descriptive statistics revealed an evident pattern in the downtime durations for different materials in the sorting process. Cardboard had an average downtime of approximately 2.02 minutes with a standard deviation of 2.25 minutes, while paper showed an average downtime of 2.69 minutes with a standard deviation of 3.93 minutes. Plastic exhibited an average downtime of 2.63 minutes with a standard deviation of 3.92 minutes. Although their average downtimes were relatively similar, the larger standard deviations for paper and plastic indicated more significant variability in their downtime durations. Furthermore, the maximum downtime values for paper (25.20 minutes) and plastic (25.82 minutes) were substantially higher than cardboard's maximum downtime of 13.08 minutes. These figures underscored the variability in downtime durations among the different materials, suggesting occasional longer periods of inactivity for paper and plastic in comparison to cardboard.

Statistics

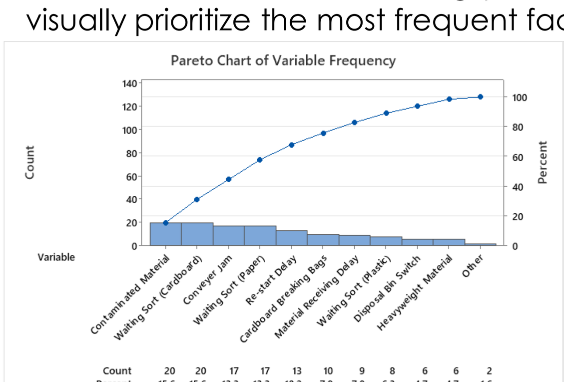
Variable	MATERIAL	Total Count	Mean	StDev	Variance	CoefVar	Minimum	Q1
TIME DIFFERENCE(MIN)	Cardboard	30	2.022	2.250	5.064	111.28	0.450	0.973
	Paper	52	2.692	3.930	15.445	145.98	0.520	0.897
	Plastic	45	2.631	3.926	15.412	149.22	0.380	0.905

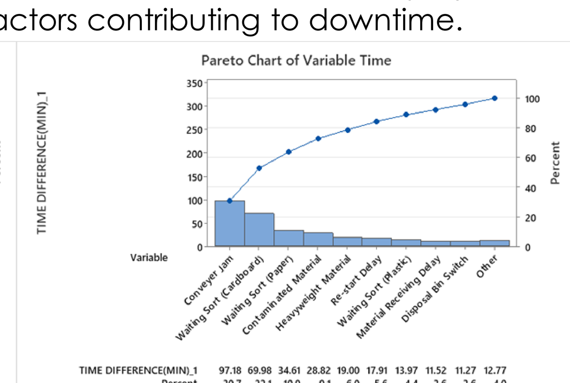
Variable	MATERIAL	Median	Q3	Maximum
TIME DIFFERENCE(MIN)	Cardboard	1.585	2.410	13.080
	Paper	1.260	2.947	25.200
	Plastic	1.330	3.350	25.820

	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**

Analyze

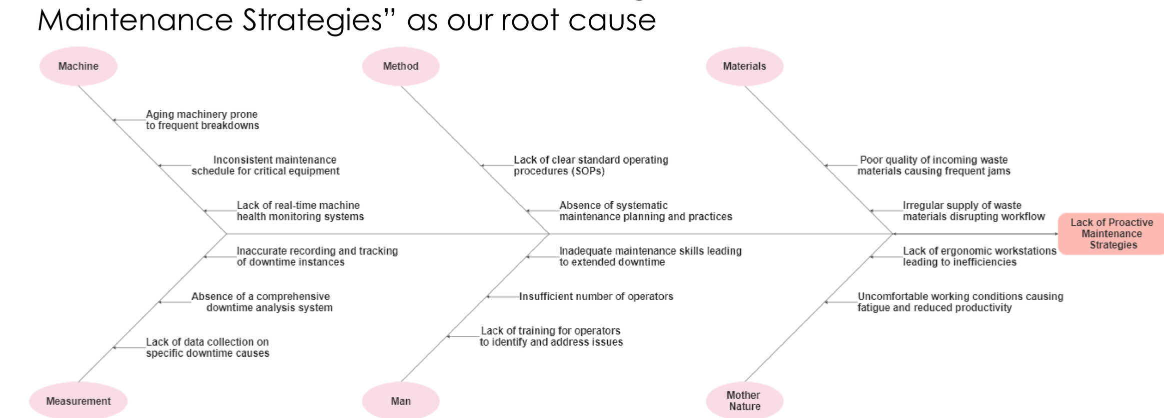
In the Analyze phase, investigation was conducted to delve into the collected. The focus was on identifying the root causes of downtime occurrences within the sorting process. **Pareto charts** were employed to visually prioritize the most frequent factors contributing to downtime.





The Frequency Pareto analysis unveiled the two most frequent sources of downtime in the MRF's sorting process: the need to halt and discard "contaminated material" to avert entanglements, and the extended time required for "cardboard sorting." Moreover, the Time Pareto chart analysis revealed that the longest downtimes were caused by "conveyor belt jams," followed by "cardboard sorting delay." These findings validated primary source of downtime in the sorting process to be "Conveyer Jams", but also sheds a light on the downtimes occurring in the Paper and Plastic conveyers due to cardboard sorting delays, avoiding a continuous flow.

The following **Fishbone diagram** highlights the factors that underlie the problem statement of "Downtime in the Sorting Process." Root causes are categorized into branches. These branches encompass issues such as inadequate training, equipment breakdowns, poor material quality, insufficient data collection, ect. Leaving us with the "Lack of Proactive Maintenance Strategies" as our root cause



An **Analysis of Variance (ANOVA)** was performed to assess significant differences in downtime durations across the different conveyers. The obtained p-value of 0.694 suggested insufficient evidence to assert significant differences in the downtime in each area. Similarly, an F-value of 0.37 indicated that within-group variability could be similar or greater than between-group variability, supporting the notion of no significant mean differences. These findings led to the conclusion that downtime durations among various conveyers in the sorting process were statistically comparable, aligning with expectations due to the interconnected nature of the classification process, particularly within the area with frequent interruptions like cardboard handling.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
MATERIAL	2	9.52	4.758	0.37	0.694
Error	124	1612.69	13.006		
Total	126	1622.20			

Results

Improve

After our comprehensive analysis, the following recommended enhancements for the Improve phase were made.

Operational optimization:

- The creation of **continuous, quarterly training programs for operators** in all areas to enhance skills and awareness to rapidly tackle issues.
- Shifting from a reactive "fix-it-when-it-breaks" maintenance approach to a proactive **"replace-it-before-it-breaks" strategy** to minimize unplanned downtimes and enhance equipment efficiency.
- Further cultivate and **strengthen collaborative efforts** with waste suppliers to enhance material quality, reducing jams and delays.
- The implementation of a **downtime tracking system** through QR codes located in each machine to identify patterns and critical areas. Along with downtime management strategies to involve stakeholders for efficient response.
- Improve workforce efficiency by adding an **extra employee** for sorting process.

Scan to view form

Equipment Enhancements:

- **Industrial Bag Opener**: Mechanically separates and opens bags, allowing efficient sorting and processing of various waste materials contained within; approximate price of $30,000.
- **Industrial Motorized Brush**: To address the challenges of carry-back and material spillage; approximate price of $5,000.

Figure 1: For Rec Bag Opener

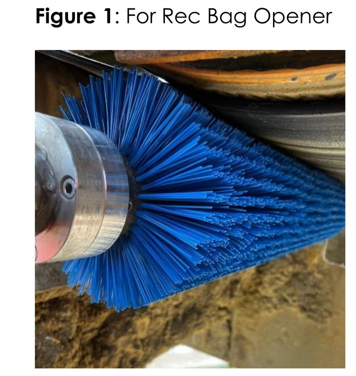


Figure 2: Hoverdale Motorized Brush

Costs

Annual training costs: $3,700
Employee cost: $29,120
Total machine costs: $35,000
Annual maintenance costs: $1,500

Total costs: $69,320

Control

In the Control phase, the focus shifts towards ensuring the sustained success of the implemented improvements through effective monitoring, evaluation, and ongoing optimization.

Management should adopt:

1. **Predictive Maintenance Strategy**: Leverage data analytics to anticipate equipment issues, reducing unplanned downtimes and optimizing operations.
2. **SOPs and Training**: Establish clear Standard Operating Procedures and conduct regular training to skill operators in effectively managing downtime scenarios.
3. **Review Meetings and KPIs**: Hold periodic review meetings to assess implemented improvements, analyze Key Performance Indicators, and adjust strategies for sustained downtime reduction.

Return on Investment (ROI)

Effective conveyor belt cleaning in a MRF with constant contamination can potentially yield a substantial downtime reduction of around 20% to 50% or more, based on industry benchmarks and operational analyses (Koussaimi et al., 2016). An estimate of 30% downtime reduction and increased productivity was chosen to calculate ROI, considering the MRF's current lack of significant belt cleaning procedures and the prevalent contamination of incoming waste streams with non-recyclable materials.

$$3.87\ hr/day\ downtime * 30\% = \mathbf{1.16\ hr/day\ downtime\ reduction}$$

$$1.16\ hr * 260\ labor\ days = \mathbf{301.6\ hr\ returned}$$

When we multiply the avoided downtime hours (301.6 hours) by the hourly operating cost of $437.50/hour, we find that the MRF stands to save approximately **$131,950 annually**.

$$\$131{,}950\ savings - \$34{,}320\ annual\ costs = \mathbf{\$97{,}630\ Yearly\ Savings\ (after\ year\ 1)}$$

$$\$97{,}630\ savings - \$35{,}000\ machine\ costs = \mathbf{\$62{,}630\ First\ Year\ Savings}$$

Conclusion

In response to industry challenges, this research focused on improving Material Recovery Facility (MRF) operations using Lean Six Sigma. Employing the DMAIC framework, the study addressed downtime during sorting at the Guaynabo, Puerto Rico MRF.

Key takeaways:

1. **Identification of Root Causes:** A thorough analysis successfully pinpointed the primary sources of downtime, notably conveyor belt jams, material entanglements, and delays in cardboard sorting.
2. **Advancements in Operations and Equipment:** The research proposed a range of specific enhancements, including ongoing training programs, a shift towards proactive maintenance strategies, improved collaboration with suppliers, and the integration of specialized equipment such as the Industrial Bag Opener and Industrial Motorized Brush.
3. **Realized Savings and ROI:** The study's efforts culminated in a projected 30% reduction in downtime, translating to an estimated annual saving of approximately $97,630 after ROI. This ROI calculation included both operational improvements and associated equipment costs, underscoring the financial benefits achievable through the successful integration of Lean Six Sigma methodologies.

This research emphasizes Lean Six Sigma's value in MRF operations, offering insights for the industry and highlighting data-driven waste management enhancements. Moreover, its alignment with UN Sustainable Development Goals 8, 9, and 11, addressing decent work and economic growth (SDG 8), industry, innovation, and infrastructure (SDG 9), and sustainable cities and communities (SDG 11).

References

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