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Enhancing Operational Efficiency in an Animal Feed Pelleting Line Using Preventive Maintenance and Standard Work

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Abstract

This study addresses the low operational efficiency of the pelletizing line in a Peruvian animal feed production company, where the Overall Equipment Effectiveness (OEE) averaged 80%, falling short of the international benchmark of 85%. The diagnostic analysis identified five critical sources of performance loss: unplanned stoppages caused by mechanical failures, high levels of reprocessed waste, dosing deviations, manual operational errors, and defective products requiring rework. To overcome these limitations, an integrated improvement strategy combining Total Productive Maintenance (TPM) and Standard Work was designed to strengthen equipment reliability, reduce process variability, and stabilize operational performance. The proposed approach was evaluated through a discrete-event simulation model developed in Arena v.16, comparing the current operating condition (As-Is) with an improved scenario (To-Be). The results demonstrated substantial and measurable gains: waste reprocessing events decreased from 11.4 to 5.5 per round (–51.8%), defective output dropped from 0.867 to 0.233 bags (–73.1%), total production increased from 368 to 464 bags (+26.1%), and total cycle time was reduced from 2.29 h to 1.82 h (–20.5%). These improvements enabled the pelletizer to reach an OEE of 85%, closing the performance gap and aligning the process with international standards. Overall, the study provides a practical and replicable methodology showing how combining TPM and Standard Work can significantly enhance operational efficiency, optimize resource use, and improve the stability and competitiveness of feed manufacturing systems.

Keywords

Total Productive Maintenance (TPM), Standard Work, Overall Equipment Effectiveness (OEE), Arena Simulation, Operational Efficiency.

1. Introduction

The animal feed manufacturing industry requires efficient and reliable production processes due to their direct impact on product quality, operating costs, and competitiveness. Within this context, the pelletizing stage is considered the main bottleneck of the production line, as its performance directly affects throughput and process stability.

In the company analyzed, the pelletizing machine operates with an Overall Equipment Effectiveness (OEE) of 80%, which is below the international benchmark of approximately 85%. This gap indicates the presence of inefficiencies that limit productivity and increase operational losses, as reported in previous studies that identify 85% as a reference value for efficient industrial operations (Indriartiningtias et al., 2024).

A diagnostic analysis revealed that 83.2% of the lost productive time is associated with production stoppages, mainly caused by mechanical failures due to the lack of preventive maintenance (48.4%), high levels of waste reprocessing (31.4%), and dosing deviations (3.4%). The remaining 16.8% is related to reprocessing generated by manual operational errors, such as inadequate cleaning, equipment overload, improper assembly, and defective products leaving the pelletizer.

These findings indicate that the low efficiency of the pelletizing process is primarily driven by the absence of structured preventive maintenance practices and insufficient standardization of operating tasks, which increase equipment downtime, process variability, and quality losses. In this context, Total Productive Maintenance (TPM) and Standard Work represent complementary improvement strategies aimed at increasing equipment reliability and reducing operational variability. Therefore, this study proposes an integrated TPM and Standard Work approach to improve the operational efficiency of a pelletizing line in an animal feed production company and to align its performance with international standards (Figure 1- Figure 2).

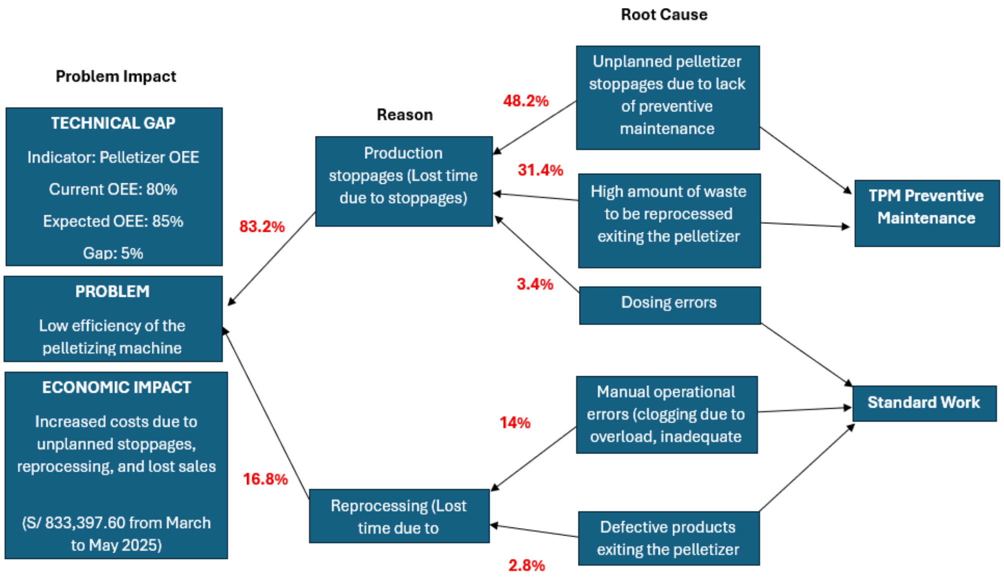


Figure 1. Root-cause problem tree

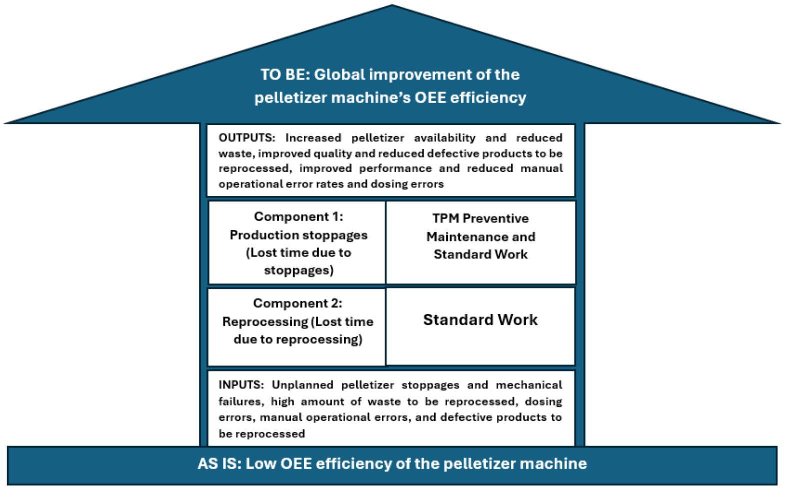


Figure 2. Conceptual Model

1.1 Objectives

1.1.1 General Objective

Increase the efficiency of the pelletizing machine in the animal feed production line through the implementation of Preventive Maintenance and Standard Work.

1.1.2 Specific Objectives

- Implement a preventive maintenance plan for the pelletizing machine under the TPM methodology in order to reduce unplanned stoppages caused by mechanical failures.
- Reduce the amount of waste (corn dust) to be reprocessed that comes out of the pelletizer, through the optimization of waste control and the implementation of preventive maintenance on the pelletizing machine.
- Minimize the rate of dosing errors by standardizing operating parameters and constantly verifying the dosed quantities, ensuring a uniform and continuous mixture.
- Minimize manual operational errors by standardizing the tasks of operating personnel and establishing clear procedures for cleaning, assembly, and operation of the machine.
- Reduce the generation of defective products and reprocessing during pelletizing by standardizing each activity of the process and controlling pellet quality.

2. Literature Review

Recent literature highlights that efficiency losses in industrial operations—particularly those associated with availability, performance, and quality—can be effectively addressed through preventive maintenance methodologies and structured Standard Work, both of which have demonstrated measurable improvements across various manufacturing sectors.

Several studies have shown that preventive maintenance under the TPM framework is one of the most effective strategies for improving equipment reliability in continuous production environments. Lozada et al. (2021) reported increases of 27.8% in machine availability, 39.7% in performance, and 29.9% in overall OEE following TPM implementation. These findings align with Pinto et al. (2020), who documented a reduction in failures between 23% and 38% and a 5% improvement in OEE in CNC machining cells. In the Peruvian context, Pinto-Zegarra and García (2024) demonstrated that adopting TPM increased OEE from 64.9% to 81.2% and reduced cycle time by nearly seven hours, significantly improving daily production scheduling. Likewise, Herrera-Uribe et al. (2024) reported a 14.97% increase in OEE in a palm oil plant after applying preventive maintenance, reinforcing the evidence that TPM contributes directly to production stability and the reduction of unplanned interruptions.

Regarding Standard Work, the literature consistently identifies it as a key approach for reducing operational variability, human error, and reprocessing. García-Torres et al. (2024) found that the absence of standardized protocols results in significant losses of time and resources, while Islam and Ahmed (2024) emphasized that documenting optimal methods and sequences helps reduce operational errors and improve workforce efficiency. Realyvásquez-Vargas et al. (2020) demonstrated a 25% increase in process efficiency after implementing Standard Work practices, and García et al. (2023) showed that using checklists and operating instructions reduces variability by at least 25%, improving workflow consistency. Concerning waste reduction, Wang et al. (2024) found that standardizing the handling of fine materials can decrease dust waste generation by up to 30%, increasing raw material utilization and reducing associated reprocessing.

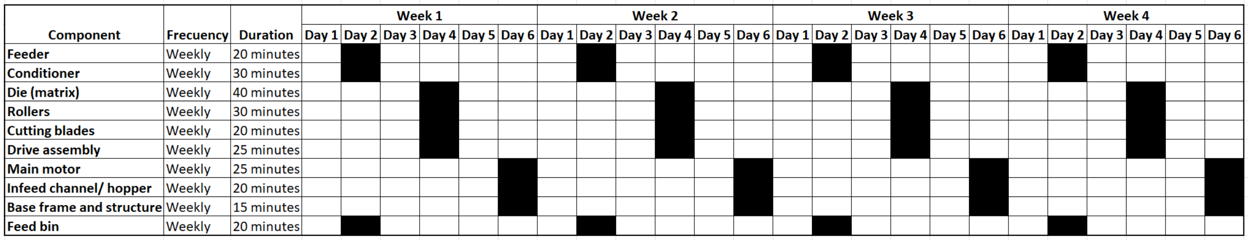
Overall, the available evidence suggests that integrating TPM with Standard Work provides a robust and well-supported strategy for improving global efficiency, reducing failures, and minimizing reprocessing in production lines similar to the one analyzed in this study.

3. Methods

This study follows the research onion framework proposed by Saunders et al. (2023), adopting a pragmatic research philosophy with a deductive approach. A single-case study strategy was employed, focusing on the pelletizing line of an animal feed production company. The research design is predominantly quantitative, based on operational data analysis and discrete-event simulation, complemented by qualitative inputs obtained from operator observations and maintenance staff interviews.

The study was conducted in three stages: diagnosis, solution design, and validation. First, operational records of the pelletizer were analyzed to identify the main causes affecting efficiency, including mechanical failures, unplanned stoppages, reprocessed waste, and operational errors. Based on these findings, a preventive maintenance plan following TPM principles was developed, along with standardized work procedures for critical tasks such as dosing, cleaning, assembly, and machine operation (Table 1). Finally, the proposed improvements were evaluated through a discrete-event simulation model in Arena, comparing the current scenario with an improved scenario to estimate the overall impact on equipment efficiency (Figure 3- Figure 7).

3.1 TPM application formats for preventive maintenance of the pellet mill

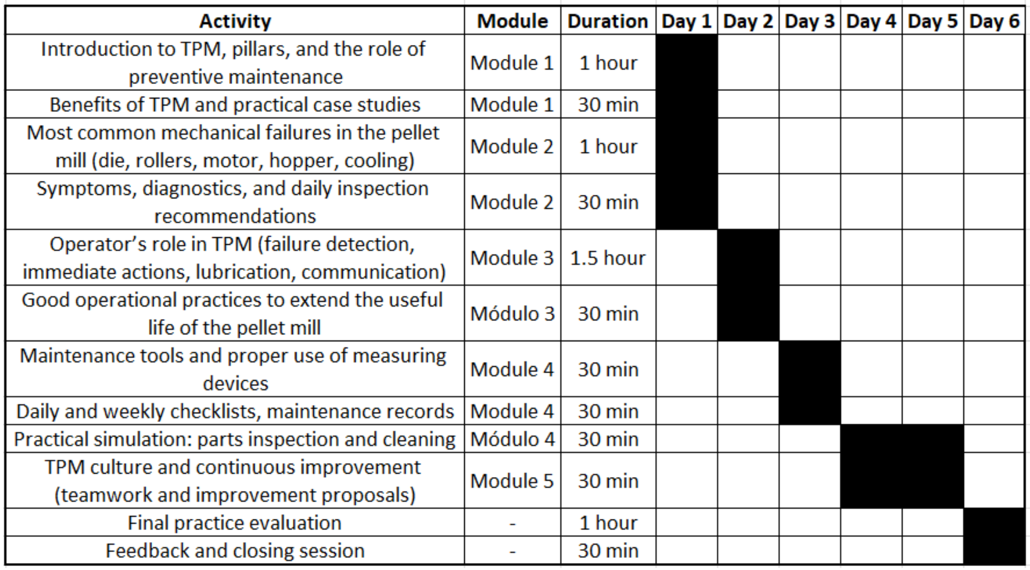


			Week 1						Week 2						Week 3						Week 4					
Component	**Frecuency**	**Duration**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
Feeder	Weekly	20 minutes		■						■						■						■				
Conditioner	Weekly	30 minutes		■						■						■						■				
Die (matrix)	Weekly	40 minutes				■						■						■						■		
Rollers	Weekly	30 minutes				■						■						■						■		
Cutting blades	Weekly	20 minutes				■						■						■						■		
Drive assembly	Weekly	25 minutes				■						■						■						■		
Main motor	Weekly	25 minutes						■						■						■						■
Infeed channel/ hopper	Weekly	20 minutes						■						■						■						■
Base frame and structure	Weekly	15 minutes						■						■						■						■
Feed bin	Weekly	20 minutes		■						■						■						■				

Figure 3. Preventive Maintenance Schedule – Pellet Mill

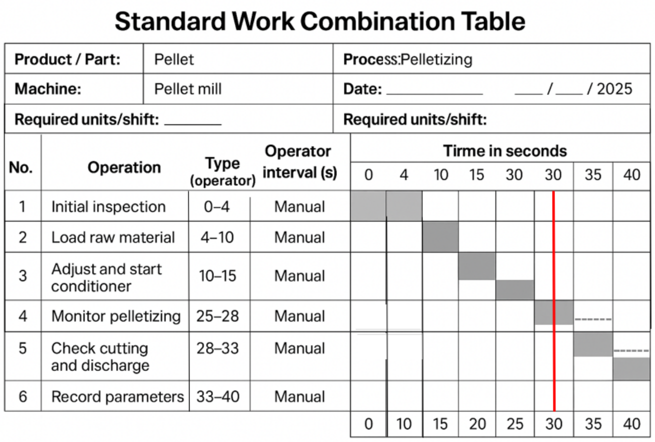
Table 1. Maintenance Activities for Pellet Mill Components

Component	**Maintenance activities**
Feeder	Cleaning of feeder, checking for blockages, adjustment of gates, inspection of inlet flow
Conditioner (dosing screw / conditioner)	Internal cleaning, inspection of screw wear, verification of pressure and temperature, lubrication of bearings
Die	Deep cleaning of channels, removal of incrustations, inspection of wear, adjustment or replacement according to condition
Rollers	Wear inspection, verification of pressure against die, surface cleaning, bolt adjustment
Cutting knives	Knife sharpening, inspection of wear, adjustment of distance with respect to the die, cleaning and fastening
Mechanical drive group (couplings / transmission)	Alignment check, bolt adjustment, vibration inspection, coupling lubrication
Main motor	Vibration and temperature inspection, verification of amperage, shaft lubrication, external cleaning
Inlet channel / hopper	Internal cleaning, removal of material build-up, inspection of gates and sensors
Base frame and structure	Vibration inspection, adjustment of supports and bolts, levelness verification
Feed bin	Internal cleaning, removal of dust and residues, inspection of falling-flow, blockage check



Activity	Module	Duration	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Introduction to TPM, pillars, and the role of preventive maintenance	Module 1	1 hour	■					
Benefits of TPM and practical case studies	Module 1	30 min	■					
Most common mechanical failures in the pellet mill (die, rollers, motor, hopper, cooling)	Module 2	1 hour	■					
Symptoms, diagnostics, and daily inspection recommendations	Module 2	30 min	■					
Operator's role in TPM (failure detection, immediate actions, lubrication, communication)	Module 3	1.5 hour		■				
Good operational practices to extend the useful life of the pellet mill	Módulo 3	30 min		■				
Maintenance tools and proper use of measuring devices	Module 4	30 min			■			
Daily and weekly checklists, maintenance records	Module 4	30 min			■			
Practical simulation: parts inspection and cleaning	Módulo 4	30 min				■	■	
TPM culture and continuous improvement (teamwork and improvement proposals)	Module 5	30 min				■	■	
Final practice evaluation	-	1 hour						■
Feedback and closing session	-	30 min						■

Figure 4. Training schedule on the Application of Preventive Maintenance to the Pellet Mill

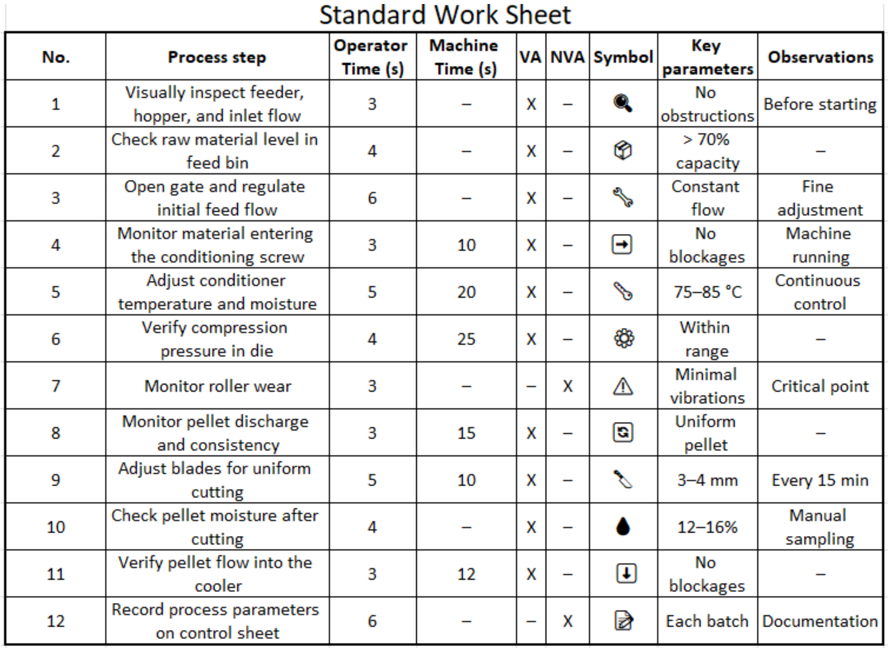


Standard Work Combination Table

Product / Part:	Pellet	**Process:**Pelletizing	
Machine:	Pellet mill	**Date:** ____________	___ / ___ / 2025
Required units/shift: _______		**Required units/shift:**	

No.	**Operation**	**Type (operator)**	**Operator interval (s)**	**Tirme in seconds**							
				0	4	10	15	30	30	35	40
1	Initial inspection	0–4	Manual	▨	▨						
2	Load raw material	4–10	Manual			▨					
3	Adjust and start conditioner	10–15	Manual				▨	▨			
4	Monitor pelletizing	25–28	Manual						▨	------	
5	Check cutting and discharge	28–33	Manual							▨	------ ▨
6	Record parameters	33–40	Manual								
				0	10	15	20	25	30	35	40

Figure 5. Standard Work Combination Table for the Pelletizing Process



Standard Work Sheet

No.	**Process step**	**Operator Time (s)**	**Machine Time (s)**	**VA**	**NVA**	**Symbol**	**Key parameters**	**Observations**
1	Visually inspect feeder, hopper, and inlet flow	3	–	X	–	🔍	No obstructions	Before starting
2	Check raw material level in feed bin	4	–	X	–	📦	> 70% capacity	–
3	Open gate and regulate initial feed flow	6	–	X	–	🔧	Constant flow	Fine adjustment
4	Monitor material entering the conditioning screw	3	10	X	–	➡	No blockages	Machine running
5	Adjust conditioner temperature and moisture	5	20	X	–	🌡	75–85 °C	Continuous control
6	Verify compression pressure in die	4	25	X	–	⚙	Within range	–
7	Monitor roller wear	3	–	–	X	⚠	Minimal vibrations	Critical point
8	Monitor pellet discharge and consistency	3	15	X	–	🔄	Uniform pellet	–
9	Adjust blades for uniform cutting	5	10	X	–	🔪	3–4 mm	Every 15 min
10	Check pellet moisture after cutting	4	–	X	–	💧	12–16%	Manual sampling
11	Verify pellet flow into the cooler	3	12	X	–	⬇	No blockages	–
12	Record process parameters on control sheet	6	–	–	X	📝	Each batch	Documentation

Figure 6. Standard Work Sheet - Instructions and Key Control Points for the Pellet Mill

4. Data Collection

The data for this study were obtained from the operational records of the pelletizing line provided by the company. The dataset included information on equipment stoppages, failure reports, waste generation, dosing deviations, defective products, and operational incidents. These records were sourced from production reports, maintenance logs, and quality control documents from the regular operating period. Additionally, qualitative observations were collected through consultations with operators and maintenance personnel to understand task execution, recurrent sources of error, and process limitations. All this information was used to characterize the current performance of the pelletizer and to define the parameters and inputs required for the simulation model (Figure 7).

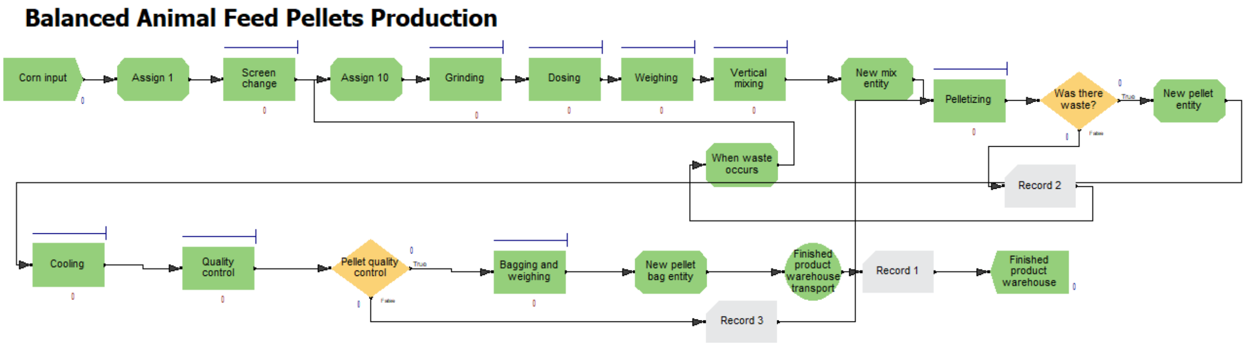


Figure 7. Process simulation in the Arena program

5. Results and Discussion

Table 2 presents the validation of the simulation model before implementing the improvement (As-Is) in Arena, through a comparison between the data obtained from the company and the results of the model's As-Is scenario. Four key process indicators are evaluated—number of waste reprocessing events, defective bags, total bags produced, and total cycle time—to assess the proximity between the simulated values and the actual measurements. In all cases, the relative error between the simulation outputs and the plant data remains below 5%, a threshold established in the methodology as the minimum acceptance criterion. This confirms that the model was adequately calibrated and that its results reasonably represent the current behavior of the system, thereby enabling its use as a reliable basis for the analysis of the improvement scenarios developed in the subsequent section.

Table 2. Validation of the Arena Simulation Model for the As-Is Scenario

Indicator	**Company Data**	**Model Simulation results (As-Is)**	**Error**
Number of waste reprocessing events	11.5	11.4	0.88%
Defective bags	0.9	0.867	3.80%
Total bags produced	360	368	2.17%
Total cycle time (h)	2.20	2.29	3.93%

Table 3 presents the validation of the Arena simulation model for the As-Is scenario by comparing the model outputs with the actual operational data provided by the company. Four key performance indicators were evaluated: number of waste reprocessing events, defective bags, total production, and total cycle time. In all cases, the relative error between simulated and real data remained below 5%, which confirms that the model adequately represents the current behavior of the pelletizing process. This validation supports the use of the simulation model as a reliable tool to evaluate the impact of the proposed improvement scenarios.

Table 3. Comparison of Simulated To-Be Improvements with Theoretical Improvement Benchmarks

Indicator	**As-Is**	**To-Be (Simulated)**	**% Improvement (Simulated)**	**% Improvement (Theoretical)**
Number of waste reprocessing events	11.4	5.5	51.8 %	30 %
Defective bags	0.867	0.233	73.1 %	30 %
Total bags produced	368	464	26.1 %	25 %
Total cycle time (h)	2.29	1.82	20.5 %	20 %

The simulation results show that the implementation of the integrated TPM and Standard Work approach generates significant improvements across all evaluated performance indicators. The number of waste reprocessing events was reduced from 11.4 to 5.5 per production round, representing a 51.8% reduction. This improvement is mainly attributed to the TPM-based preventive maintenance activities, which reduced mechanical instability, material accumulation, and unplanned stoppages during pellet formation.

Similarly, defective bags decreased from 0.867 to 0.233 per round, corresponding to a 73.1% reduction. This result reflects the impact of Standard Work implementation, which reduced operational variability and manual errors by standardizing critical tasks such as dosing, cleaning, assembly, and equipment operation. These findings are consistent with previous studies that report significant reductions in defects after implementing standardized operating procedures.

In terms of productivity, total production increased from 368 to 464 bags per round, equivalent to a 26.1% improvement. This increase is primarily associated with higher equipment availability and more stable operating conditions resulting from reduced downtime and reprocessing. At the same time, total cycle time was reduced from 2.29 h to 1.82 h, representing a 20.5% decrease. This reduction indicates a more efficient and balanced process flow, which aligns with theoretical improvements reported in the literature.

Overall, the consistency between the simulated results and the theoretical improvement benchmarks supports the validity of the proposed solution. The integration of TPM and Standard Work not only closes the identified efficiency gap but also stabilizes the pelletizing process, enabling the system to reach an OEE of 85% and align with international performance standards.

6. Conclusion

This study set out to increase the efficiency of the pelletizing machine in an animal feed production line through the implementation of TPM-based preventive maintenance and Standard Work. The discrete-event simulation developed in Arena was first validated against plant data, showing relative errors below 5% for all key indicators (waste reprocessing events, defective bags, total bags produced, and total cycle time), confirming that the model represents the current (As-Is) system behavior with acceptable accuracy.

Regarding the general objective, the integrated TPM + Standard Work improvement scenario (To-Be) closed the performance gap by enabling the pelletizer to reach an OEE of 85%, moving from the current average level (≈80%) to the international benchmark used in this study. This improvement was supported by measurable changes in operational performance: waste reprocessing events decreased from 11.4 to 5.5 per round (–51.8%), defective output dropped from 0.867 to 0.233 bags (–73.1%), total production increased from 368 to 464 bags (+26.1%), and total cycle time was reduced from 2.29 h to 1.82 h (–20.5%).

With respect to specific objectives, the results support the following conclusions. (1) A TPM-based preventive maintenance plan was designed and incorporated into the improvement scenario to mitigate mechanical instability and unplanned interruptions; the resulting increase in throughput (+26.1%) and the reduction in total cycle time (–20.5%) are consistent with higher equipment availability and fewer disruption-driven delays in the pelletizing stage. (2) Waste (corn dust) reprocessing was substantially reduced, as evidenced by the decrease in reprocessing events from 11.4 to 5.5 per round (–51.8%). (3) Dosing-related deviations were addressed through Standard Work by defining operating parameters and verification routines; while dosing errors were not reported as a standalone metric, the marked reduction in reprocessing and defects indicates a more stable process and improved control of critical variables that affect pellet quality and consistency. (4) Manual operational errors were targeted through standardized procedures for cleaning, assembly, and operation; the significant reduction in defective bags (–73.1%) is consistent with reduced variability and fewer human-error-driven quality losses. (5) Defective products and reprocessing during pelletizing were minimized, directly confirmed by the drop in defective bags from 0.867 to 0.233 per round and the concurrent reduction in reprocessing events.

In summary, this research contributes a practical and replicable improvement approach that combines preventive maintenance (TPM) and Standard Work, supported by simulation-based validation, to enhance reliability, stabilize operations, and improve efficiency in pelletizing systems. Future work should complement simulation findings with post-implementation field measurements and include an economic evaluation (cost–benefit) and/or advanced maintenance strategies (e.g., predictive maintenance and real-time monitoring) to sustain and scale the achieved performance gains.

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Biographies

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