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SCRAP REDUCTION IN A PLASTIC INJECTION MOLDING COMPANY THROUGH FMEA AND LEAN MANUFACTURING TOOLS

Carlos Fernando Díaz-Serrano, José Israel Hernández-Vázquez * and José Omar Hernández-Vázquez

Department of Industrial Engineering Tecnológico Nacional de México/Instituto Tecnológico de León, León Guanajuato, México.

* Corresponding Author

ORCID Details

Carlos Fernando Díaz-Serrano: <https://orcid.org/0009-0004-1424-3879>

José Israel Hernández-Vázquez: <https://orcid.org/0000-0003-1332-8243>

José Omar Hernández-Vázquez: <https://orcid.org/0000-0002-0022-7614>

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ABSTRACT

The FMEA methodology has been progressively adopted in recent years by organizations across various industrial sectors with the aim of strengthening their competitiveness in an increasingly demanding environment. Complementarily, companies have incorporated Lean Manufacturing tools, such as the Overall Equipment Effectiveness (OEE) indicator, which leads to significant improvements in operational efficiency. This article presents the adaptation of these methodologies and their application in a sector of great impact both in Mexico and worldwide, the plastic injection molding industry, with the purpose of reducing scrap.

Keywords FMEA, OEE, Lean Manufacturing, Scrap, Injection molding.

1 INTRODUCTION

The plastics manufacturing industry is one of the most dynamic and strategic sectors in Mexico, with applications ranging from mass consumer goods to specialized manufacturing. However, plastic injection molding processes face a recurring challenge: the high amount of scrap generated during manufacturing, which directly affects production costs and business competitiveness.

In this context, the Failure Mode and Effects Analysis (FMEA) methodology has become established as an effective tool for identifying potential risks in production processes, making it possible to prioritize corrective actions according to the activities and workload involved. In 2019, the FMEA methodology was updated through a joint effort between the AIAG (Automotive Industry Action Group) and the VDA (Verband der Automobilindustrie), with the purpose of harmonizing criteria and strengthening the application of the tool in a global context. This update introduced significant

changes in how risks are assessed, how actions are prioritized, and how the analysis is documented, which has enabled greater precision in identifying potential failures and in quality management.

In parallel, the Overall Equipment Effectiveness (OEE) indicator has become an international benchmark for evaluating operational efficiency, as it integrates availability, performance, and quality factors and thus reflects the real capacity to produce without defects (Hernández-Vázquez J. I. et al., 2024; Hernández-Vázquez J. O. et al., 2024; Hernández-Vázquez. et al., 2025).

The combination of FMEA and OEE offers a robust methodological framework for process optimization in the plastics industry. The objective of this article is to implement FMEA in the plastic injection molding process of a Mexican company in order to significantly reduce scrap and improve the plant's overall performance. This proposal seeks to contribute to continuous improvement and to the consolidation of competitiveness in an increasingly demanding market.

2 METHODOLOGY

To determine the levels of scrap generated, three injection molding machines, identified as 1000B, 850C, and 1700A, were studied. These machines operate in three eight-hour shifts, six days a week, with a maximum permitted limit of defective parts equal to 1.5% of the total daily output. Based on these conditions, data were systematically collected over a 30-day period, recording the number of scrap parts generated each working day. Subsequently, the data were analyzed using a mean and range ($\bar{X}$ -R) control chart, as described by Pulido and De la Vara Salazar (2013), in order to identify the variation in scrap throughout the production process and to assess the stability of the system under statistical criteria.

The results obtained from the control chart analysis showed that, although the injection process exhibits a level of stability on most of the days evaluated, critical periods were identified in which scrap increased significantly, exceeding the established permitted limit.

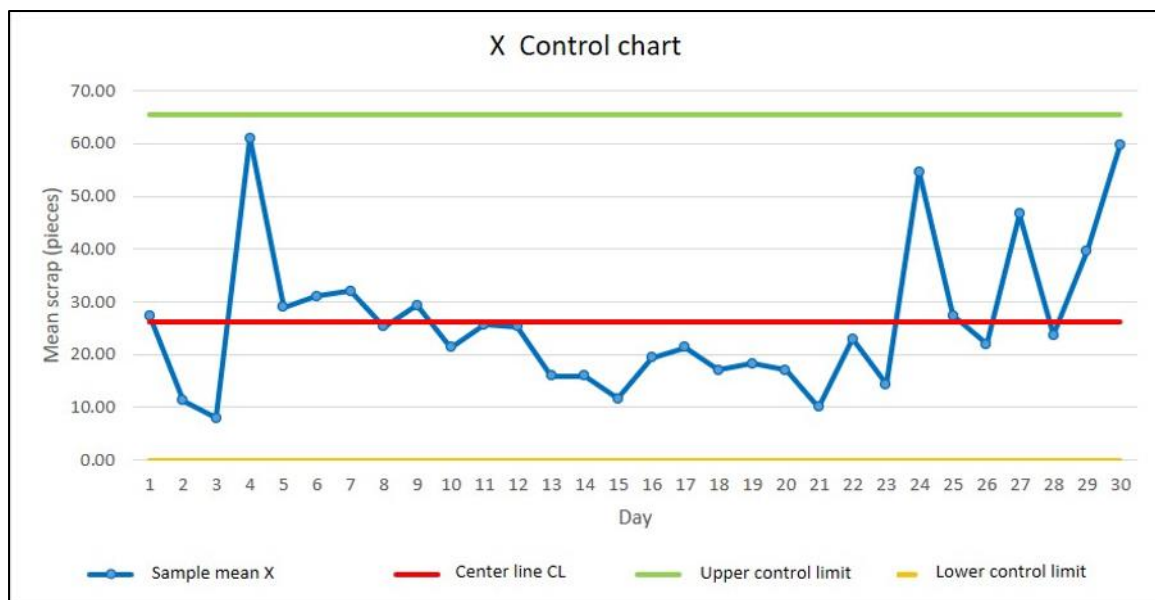


Figure 1: $\bar{X}$ control chart before implementation

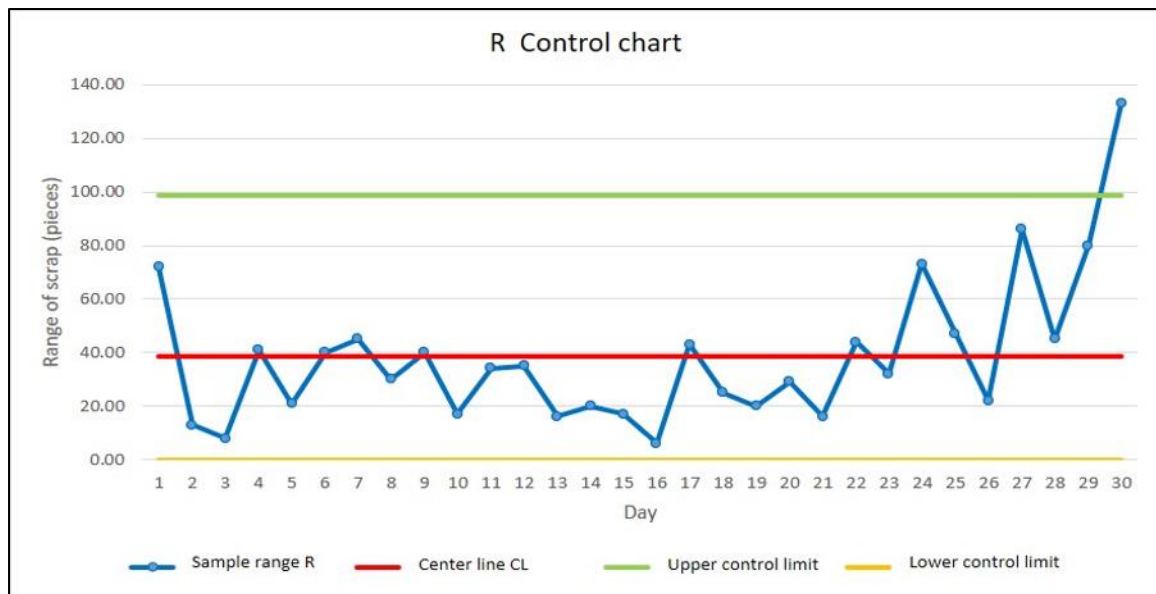


Figure 2: R control chart before implementation

Once the amounts of scrap produced, presented in Figures 1 and 2, had been established as a baseline, the OEE indicator was developed in order to comprehensively evaluate the availability, performance, and quality of each of the injection molding machines included in the study. This analysis provided a more complete view of operational performance, linking scrap levels to actual production capacity and process stability.

The corresponding calculations were carried out as described by Socconini, (2019). Accordingly, the following results were obtained:

Table 1: Initial OEE percentages

Machine	Availability	Performance	Quality	Overall OEE
1000B	73.91%	95.64%	97.07%	68.61%
850C	69.56%	92.24%	94.72%	60.77%
1700A	78.26%	96.07%	98.51%	74.06%

As shown in Table 1, machine 1700A achieves the best overall OEE at 74.06%, followed by machine 1000B at 68.61% and, finally, machine 850C at 60.77%. In all cases, availability is identified as the weakest factor, while performance and quality remain at acceptable levels. This finding directs improvement actions toward reducing unproductive time, with the aim of raising the plant's overall OEE.

Following the diagnosis carried out to understand the status of the production process, considering both the variation in scrap levels and the overall performance of the equipment, the FMEA methodology was applied. In its most recent version, it establishes a structured approach consisting of seven fundamental steps, which are shown in Figure 3. These steps range from initial planning to the documentation and communication of results. This methodological framework ensures greater accuracy in identifying failures and prioritizing corrective actions, thereby strengthening the reliability of production processes (AIAG & VDA, 2019).

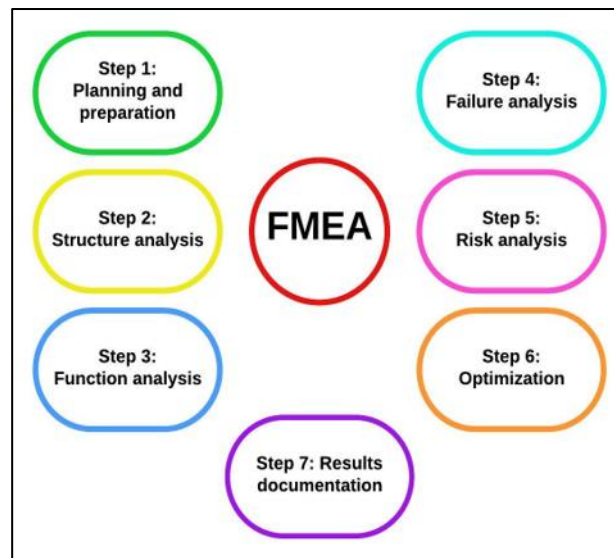


Figure 3: The seven fundamental steps of the AIAG-VDA FMEA

2.1 Step 1: Planning and Preparation

fundamental aspects must be considered: the voice of the customer, the project plan (5Ts document), and the designation of the table header. These elements form the basis for giving meaning and direction to the analysis, ensuring that the process is oriented toward the stated objectives and that the resulting actions remain consistent with the expected results (AIAG & VDA, 2019).

Table 2: Voice of client

Product name _____		Client _____		Revision _____	
Customer Requirement	Product characteristic	Customer expectation	Type of defect observed	Perceived impact	Preventive / corrective action
Uniform aesthetic appearance	Uniform color with no stains	Pieces without tone variations	Pieces out of tone or burnt	Visual dissatisfaction, batch rejection	Temperature control and pigment mixing
Full functionality	Pieces without deformations or missing parts	Correct assembly with no interference	Incomplete or misshapen pieces	Assembly failure or loss of function	Review of injection and pressure parameters
Product safety	Surface free of burrs or contaminants	Safe and risk-free handling	Parts with excess burr or contaminated	Risk of injury or contamination	Visual inspection and maintenance of molds
Durability	Material within specifications	Adequate mechanical strength	Burnt pieces or pieces with material variation	Shortened lifespan	Temperature control and raw material quality
Process reliability	Stable and traceable production	Standards compliance	Variability in scrap or recurring defects	Loss of customer trust	Implementation of OEE and FMEA indicators

Table 3: 5ts document

Product: <u>Pallet 130, Chicken and bird cage, Automotive box</u>		FMEA: _____	Reason: <u>Changes in the injection procedure</u>
Client: _____		Leader: _____	
FMEA TEAM			
Position	Responsibilities	Signature	
Manager	1. Direct support in the review whenever a change occurs in the FMEA. 2. Decision-making for the correct identification of risks. 3. Definition of responsibilities among the collaborators involved. 4. Ensuring the correct execution of the FMEA process at all of its stages.		
Boss			
Maintenance Supervisor			
Maintenance Technician			
Process Engineer	1. Gathering information 2. Defining functions, elements, and requirements 3. Setting goals 4. Holding team meetings 5. Obtaining documents and information 6. Incorporating lessons learned		
Injection Supervisor	1. Organization and execution of workflows, ensuring order and continuity in operations. 2. Problem-solving, effectively addressing incidents that may arise. 3. Active participation in team building, fostering collaboration and collective performance. 4. Preparation of documents to record, standardize, and track the activities carried out.		
Injection Technician			
Staff leader			
Operator	1. Support in the detection of defects and failures 2. Support in the analysis		
Intention		Timing	
Identify, evaluate, and prioritize possible failures in the process in order to prevent them or minimize their effects before they happen.		Start _____	End _____
		Tools	
		>Operation process diagram >Previous FMEA	
Tasks			
Identified risks	Actions taken	Observations	

Table 4: FMEA Table header

Planning and Preparation (Step 1)					
Company Name:		Subject:	Scrap reduction	PFMEA ID Number:	INYKN-001
Manufacturing Location:	León GTO.	PFMEA Start Date:		Process Responsibility:	GJSTIMO
Customer Name:		PFMEA Revision Date:		Confidentiality level:	Confidential
Model year(s) / Program(s):	2026	Cross Functional Team:	GJSTIMO		

Tables 2–4 present all the essential project information, including the item identification, customer, reference code, reason for the analysis, team members, and execution dates. This section ensures the traceability of the document and establishes the frame of reference for the development of the analysis, so that the conclusions and corrective actions are aligned with the project objectives and customer expectations (AIAG & VDA, 2019).

2.2 Step 2: Structure Analysis

As the second step of the methodology, one reference element and three analysis components are considered.

The reference element consists of identifying in detail all the activities that make up the production process. For this purpose, the development of an operation process diagram is recommended, which provides greater organization and structure to the system, facilitates the identification of each stage, and contributes to a clearer and more orderly understanding of the workflow (AIAG & VDA, 2019).

Table 5: Plastic injection process operations

Injection Procedure						
Operation number	Operations					Activities
						Observations
1	D	○	△	⇒	■	Verify the customer order
2	D	●	△	⇒	□	Mount the mold on the machine
3	D	○	△	⇒	□	Request raw material from the warehouse
4	D	○	△	⇒	■	Move the raw material container next to the machine
5	D	●	△	⇒	□	Connect the loading hose to the container
6	D	●	△	⇒	□	Turn on hydraulic oil temperature control
7	D	●	△	⇒	□	Turn on the hydraulic pump
8	D	○	△	⇒	■	Verify overall hydraulic temperature
9	D	●	△	⇒	□	Turn on mold temperature control
10	D	●	△	⇒	□	Turn on barrel temperature control
11	D	●	△	⇒	□	Enter temperature profiles for the mold
12	D	●	△	⇒	□	Enter temperature profiles for the barrel
13	D	○	△	⇒	■	Verify zone temperatures (mold and barrel)
14	D	○	△	⇒	■	Verify hot runner temperature
15	D	●	△	⇒	□	Heat the nozzle
16	D	●	△	⇒	□	Set mold clamping force
17	D	●	△	⇒	□	Adjust mold thickness
18	D	●	△	⇒	□	Adjust mold safety
19	D	●	△	⇒	□	Adjust closing speed
20	D	○	△	⇒	■	Verify the physical condition of the mold
21	D	●	△	⇒	□	Adjust mold opening position
22	D	●	△	⇒	□	Adjust opening speed
23	D	●	△	⇒	□	Adjust opening stroke or delay
24	D	●	△	⇒	□	Set zero point on central ejection
25	D	○	△	⇒	■	Verify core signals
26	D	●	△	⇒	□	Set core cycles
27	D	●	△	⇒	□	Adjust ejector stroke
28	D	●	△	⇒	□	Adjust number of ejector strokes
29	D	●	△	⇒	□	Adjust ejection stroke or delay
30	D	○	△	⇒	■	Verify masterbatch pigment
31	D	●	△	⇒	□	Clean the doser
32	D	●	△	⇒	□	Fill the doser hopper
33	D	●	△	⇒	□	Perform masterbatch test
34	D	○	△	⇒	■	Check doser cables and power-on
35	D	●	△	⇒	□	Adjust filling phase
36	D	●	△	⇒	□	Adjust injection cushion
37	D	●	△	⇒	□	Adjust metering position
38	D	●	△	⇒	□	Adjust switchover point
39	D	●	△	⇒	□	Adjust filling time
40	D	●	△	⇒	□	Adjust filling speed
41	D	●	△	⇒	□	Enter injection profiles
42	D	●	△	⇒	□	Adjust holding pressure
43	D	●	△	⇒	□	Adjust holding time
44	D	●	△	⇒	□	Adjust decompression
45	D	●	△	⇒	□	Adjust screw speed
46	D	●	△	⇒	□	Adjust hydraulic clamp time
47	D	●	△	⇒	□	Adjust screw back pressure
48	D	●	△	⇒	□	Adjust cooling time
49	D	●	△	⇒	□	Set alarms for maximum injection time
50	D	●	△	⇒	□	Set alarms for maximum cycle time
51	D	●	△	⇒	□	Set alarms for maximum metering time
52	D	●	△	⇒	□	Inject the part
53	D	○	△	⇒	■	Inspect part quality
54	D	○	△	⇒	■	Validate parts for release

The analysis components consist of:

- Process item system: describes the specific activity performed within the plant.
- Station number and element name: corresponds to the operation number indicated in the flow diagram, together with the identification of the element.
- Process work element type: selected based on one of the 4 Ms: Manpower, Machinery, Material, or Method.

For the reference element, an operation process diagram was developed, which can be seen in Table 5, in order to identify in detail all the activities that make up the injection procedure. This procedure is uniform for all the machines considered, so the operations are carried out following the previously established order, ensuring consistency and control in the production sequence.

2.3 Step 3: Function Analysis

This section is divided into three parts:

- Function of the process item: records the function it fulfills within the plant, for the customer, and for the end user.
- Function of the process step and product characteristic: documents the step corresponding to the operation described in the flow diagram, together with the associated product characteristic.
- Function of the process work element and process characteristic: records the function linked to the previously selected "M" (Manpower, Machinery, Material, or Method), together with the process characteristic.

2.4 Step 4: Failure Analysis

This section considers the following FMEA elements:

- Failure effects: records the possible consequence that could arise at the plant, at the customer, and for the end user.
- Severity: the severity rating is determined based on the tables established in the FMEA handbook. This value cannot be modified unless the company changes its business model or undergoes a reengineering process, since it represents the impact caused by the failure.
- Failure mode (FM) of the process step: documents the failure mode identified in the corresponding operation.
- Failure cause (FC) of the work element: records the cause associated with the failure mode, in order to verify the existence of prevention and detection controls.

2.5 Step 5: Risk Analysis

This section considers the following FMEA elements:

- Current prevention control (PC) of the failure cause (FC): records the documents registered in the system, such as forms, work instructions, visual aids, and procedures, which makes it possible to identify the prevention controls established for the failure cause.
- Occurrence (O) of the failure cause (FC): the rating is determined based on the tables in the FMEA handbook. This is the only value that can change over time, since it reflects the frequency with which the failure occurs.
- Current detection controls (DC) of the cause (FC) or the failure mode (FM): records the documents registered in the system, such as forms, work instructions, visual aids, and procedures, in order to identify the existing detection controls.
- Detection (D) of FC/FM: the rating is determined based on the tables in the FMEA handbook. This value depends on the type of detection used, whether by machine or by human visual inspection, and makes it possible to evaluate the effectiveness of the detection method.
- PFMEA AP: corresponds to the combined rating of severity, occurrence, and detection. This value helps determine whether additional actions need to be implemented to reduce the level of risk. It is classified into three priorities: High (H): highest priority for review. Medium (M): intermediate priority; the team must identify actions to improve prevention and/or detection controls. Low (L): lower priority for review and action.
- Special characteristics: those special characteristics defined by the team will be marked with a specific symbol.

Risk assessment in Failure Mode and Effects Analysis is carried out using three criteria: severity, occurrence, and detection. Severity corresponds to the assessment of the level of impact that the failure has on the system, process, or end user; occurrence estimates the frequency with which the cause of the failure appears; and detection evaluates the ability of the current controls to identify the causes or failure modes before the effect materializes (Mendoza et al., 2020). Having covered the application of the first five steps established in the handbook, it is advisable to carry out a detailed analysis of all process activities in order to identify those considered critical, that is, those that generate significant problems during their execution. In the particular case of this project, it was decided to include only these critical activities in the FMEA. Seven were identified, which can be seen in Table 6. In accordance with the methodological guidelines, each of these activities was assigned severity, occurrence, and detection ratings according to the evaluation tables established by AIAG and VDA (20)

Table 6: FMEA Document

Problem	Structure analysis (Step 2)			Function Analysis (Step 3)			Failure Analysis (Step 4)			Risk Analysis (Step 5)						
	Upper level	Focus element	Lower level	Upper level	Focus element	Lower level	Upper level	Severity (S) of FE	Focus element	Lower level	Current prevention control (PC) or (FC)	Occurrence (O)	Current detection controls (DC) of (FC) or (FM)	Detection (D) of FCFM	Action priority (AP)	Special characteristics
1. Process item system, subsystem, part element or name of process	2. Process step station No. And name of focus element	3. Process work element 4M type	1. Function of the process item/function of system, part element or process	2. Function of the process step and product characteristic	3. Function of the process work element and process characteristic	1. Failure effects (FE) to the next higher level element	2. Failure mode (FM) of the focus element		3. Failure cause (FC) of the work element							
1	Plastic injection process	Request raw material from the warehouse	Materials	I = Start production or monitor it C = Know the order status U = Product assurance	To start production or continue producing during the process	Move the container using a hydraulic pallet jack or a forklift	The machine does not start or stops during production, and defective parts are generated upon restart	7	Material is not delivered or is delivered late	Ineffective communication between the forklift operator and the technician or machine operator	...	10	Hopper and material container gauges	6	H	
2	Plastic injection process	Prepare the raw material	Method	I = Start production or monitor it C = Know the order status U = Product assurance	To prepare the machine with the material required by the part	Connect the hopper suction hose to the material container	Defective parts are generated due to contaminated material or inadequate properties	7	Producing with contaminated or incorrect material for the parts	Error in material assignment by the materials department	...	6	Manual inspection	8	H	
3	Plastic injection process	Machine setup	Method	I = Start production or monitor it C = Know the order status U = Product assurance	To start production of the parts	Follow the setup procedure document	The machine does not start or defective parts are generated, so the machine must be stopped	3	Unintentional oversight or omission of one or more machine setup steps	Unclear setup procedure instructions	...	5	Manual inspection by injection technicians	5	L	
4	Plastic injection process	Mold setup	Method	I = Start production or monitor it C = Know the order status U = Product assurance	To adjust the mold functions and systems at start-up or during production	Follow the instructions in the setup procedure document	The mold condition generates defective parts; the machine does not start or stops during production, and defective parts are generated upon restart	8	The mold cannot be adjusted for start-up or during production	Failure of one of the mold's systems or components	Preventive maintenance	8	Manual inspection by mold shop technicians	6	H	
5	Plastic injection process	Masterbatch pigment preparation	Materials	I = Start production or monitor it C = Know the order status U =	To prepare the machine with the pigment required by the part	Load the doser hopper with the required pigment	Defective parts are generated due to faded pigment or incorrect shades	5	Injecting with incorrect pigments or dark pigments before light pigments	Pigment programming error or lack of verification by the injection technician	Verification through the injection program	9	Manual inspection by injection technicians	6	H	
6	Plastic injection process	Enter injection parameters	Method	I = Start production or monitor it C = Know the order status U =	To adjust the machine parameters at start-up or during production	Enter the controlled values established in the parameter sheets	Defective parts are generated during production	5	Variation in the adjustment of injection parameters during production	Improper adjustment by the technician or misadjusted parameters due to natural process variation	...	9	Verification using the parameter sheets	8	H	
7	Plastic injection process	Machine start-up or restart	Method	I = Start production or monitor it C = Know the order status U = Product assurance	To start production or continue producing during the process	Follow the setup procedure document	The machine does not start or stops during production, and defective parts are generated upon restart	8	The machine cannot be adjusted for start-up or during production	Failure of one of the machine's systems or components	Preventive maintenance	8	Manual inspection by maintenance technicians	6	H	

2.6 Step 6: Optimization

In this penultimate step of the methodology, prevention controls, detection controls, and the pertinent corrective actions are established to mitigate the associated risks. The suggested actions must be specific, measurable, and feasible, leaving aside those that prove impracticable. In addition, they must be distinguished from the tasks already included in the detection and prevention controls, since these are part of the primary analysis. Each action must have an assigned owner and a defined deadline for completion.

Among the benefits identified for FMEA as a risk analysis tool, its usefulness for managing manufacturing process risks and for ensuring traceability among the elements of the analysis was highlighted: from failure modes and their effects, through the established controls, to the residual risk of each evaluated element. It was also noted that FMEA offers a structured and methodical approach that engineers are familiar with and comfortable applying (Nolan & McDermott, 2025).

3 RESULTS AND DISCUSSION

3.1 Step 7: Results Documentation

Once all corrective and optimization actions had been implemented, a comparison of results was carried out between the initial diagnosis and the data obtained after the application of the established controls. This analysis made it possible to objectively evaluate the impact of the implemented measures on the production process. The results of this comparison were obtained during the first week after the implementation and are presented below.

Regarding the variability identified through the mean and range control charts, after the implementation of the corrective actions, the results showed that the $\bar{X}$ chart, which can be seen in Figure 4, indicates that the process is under statistical control. The daily averages remain within the control limits and close to the center line, with no out-of-control points or anomalous trends. This demonstrates that the corrective actions applied managed to reduce variability and stabilize the process, directly contributing to the reduction of scrap and the strengthening of the reliability of the production system.

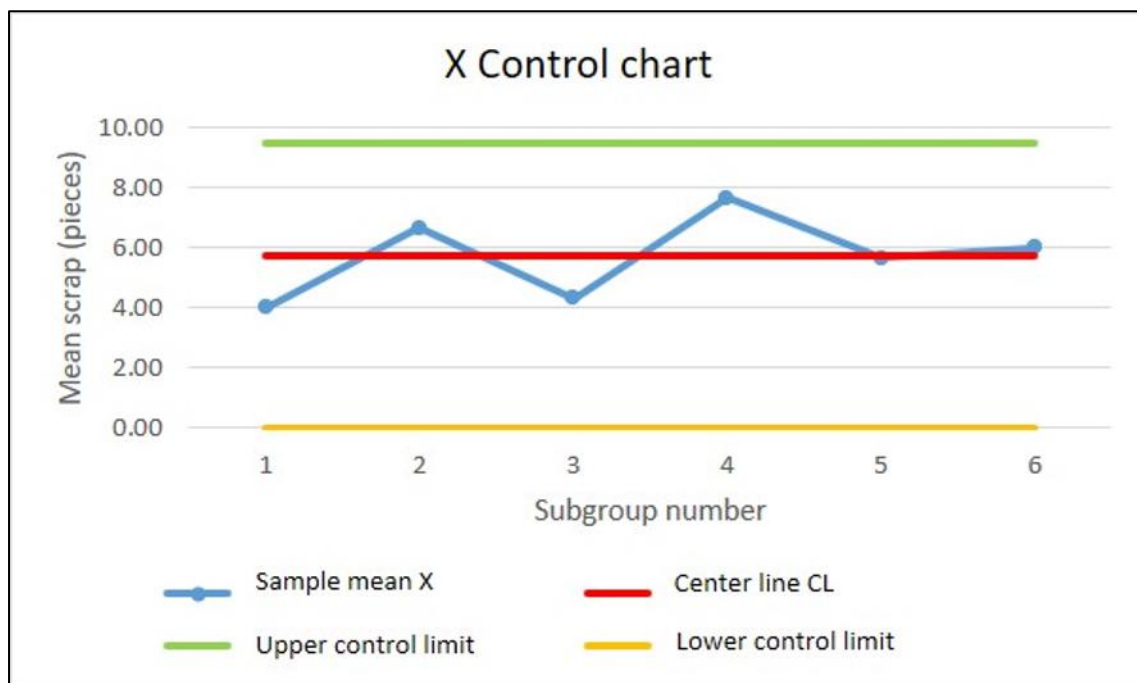


Figure 4: X chart after implementation

The R chart, which can be seen in Figure 5, shows that after the implementation of the proposed method, the variability of the process is under statistical control. The daily ranges remain within the control limits and close to the center value, with no out-of-control points or anomalous patterns. This shows that the corrective actions applied managed to stabilize the dispersion of the process, reducing the risk of scrap and strengthening the reliability of production.

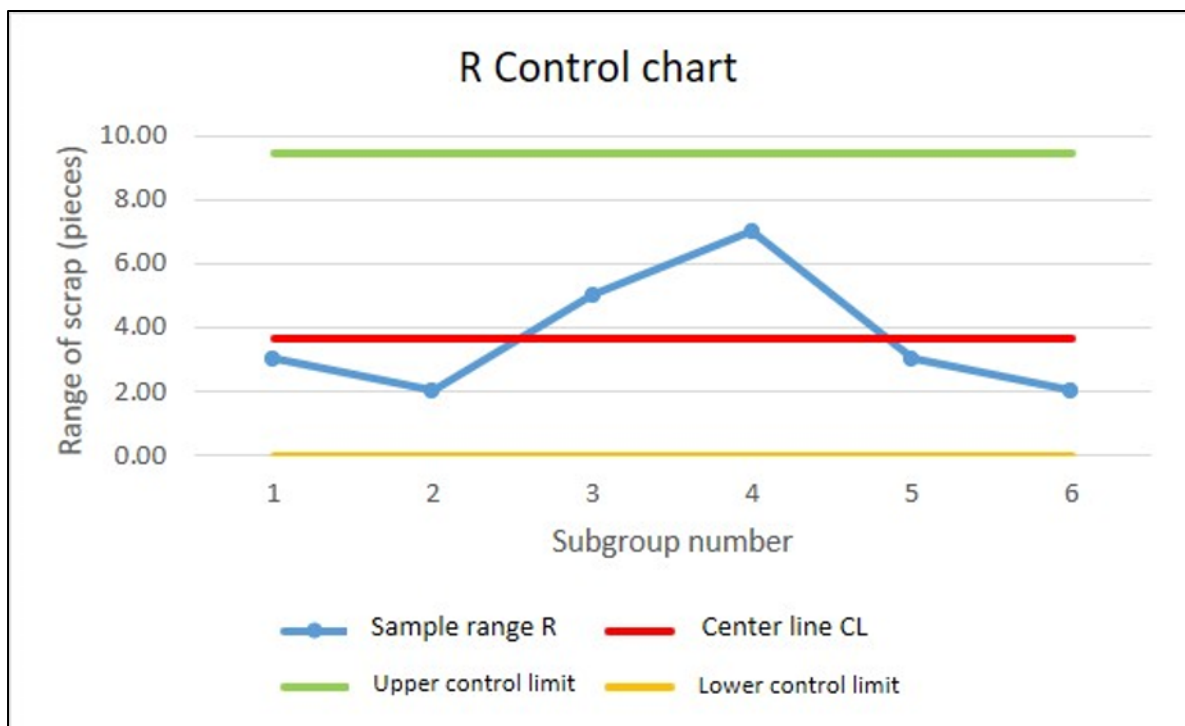


Figure 5: R chart after implementation

The comparison between the $\bar{X}$ -R charts before and after the implementation confirms the effectiveness of the corrective actions. In the initial state, the process showed high variability and the presence of special causes, which increased the risk of scrap. After the implementation, the charts show a process under statistical control, with centered averages and reduced ranges, and no out-of-control points. The results shown in Table 7 confirm that the methodology applied made it possible to stabilize the process and strengthen the reliability of production.

Table 7. Scrap reduction percentages

Machine	Before	After	Reduction
1000B (pcs)	35.1	7.3	79.20%
850C (pcs)	29.13	5.6	80.78%
1700A (pcs)	14.2	4.1	71.13%

The results show an overall scrap reduction of 78% after the implementation. Each machine showed improvements above 70%, with machine 850C standing out with a reduction of 80.8%. These data confirm that the corrective actions applied were highly effective, transforming an unstable process into a reliable one with minimal generation of defective parts.

The main motivation for implementing OEE lies in the fact that, by making it possible to identify the root causes of poor performance, it provides a useful frame of reference for detecting and prioritizing improvement opportunities, as well as for monitoring and comparing process performance. This indicator is considered particularly relevant in high-volume, process-oriented manufacturing environments with full or partial automation, where the utilization of installed capacity is critical and production losses imply high costs (Kiridena et al., 2022).

Based on our initial analysis of the OEE calculation, availability was identified as a critical factor in all the injection molding machines. When evaluating through both on-site observation and theoretical analysis, it was observed that the pre-startup and equipment preparation procedures generated recurrent and prolonged stoppages, accumulating between 4 and 8 hours of downtime per day per machine. However, after the implementation of the improvements, the calculations showed a significant reduction in downtime, since the causes of the equipment stoppages were corrected. As a result, availability increased notably, strengthening the overall efficiency of the production process. Likewise, the new calculations were carried out following the same methodology applied in our initial diagnosis, as explained by Socconini, (2019).

Table 8: OEE comparison

Machine	Before				After			
	Availability	Performance	Quality	Overall OEE	Availability	Performance	Quality	Overall OEE
1000B	73.91%	95.64%	97.07%	68.61%	86.95%	98.91%	99.00%	85.14%
850C	69.56%	92.24%	94.72%	60.77%	82.60%	97.45%	99.17%	79.82%
1700A	78.26%	96.07%	98.51%	74.06%	91.30%	97.99%	99.63%	89.13%

The OEE analysis after the implementation of the improvements shows a substantial change in the plant's performance. Availability was strengthened by reducing unproductive time, performance remained at optimal levels, and quality improved as scrap decreased. As a result, the overall OEE increased significantly, as can be seen in Table 8. This demonstrates that the corrective actions applied not only stabilized the process but also transformed it into a reliable and competitive system. This finding confirms that the methodology implemented has a real and sustainable impact on productivity and cost reduction.

4 CONCLUSION

The integrated implementation of $\bar{X}$ -R control charts, the OEE indicator, and FMEA made it possible to address the scrap problem from three complementary perspectives. The control charts enabled the monitoring of the initial and final amount of defects generated in the process; OEE determined the actual OEE percentage of each machine before and after the improvements; and FMEA identified and prioritized the failure causes, which led to an overall scrap reduction of 78%, with reductions above 70% on each machine. These results show that the corrective actions applied were highly effective, transforming an unstable process into a reliable one under statistical control.

It is worth noting that the result is not due to an isolated tool, but to their combined use: the control charts detected the variability, OEE quantified its impact on the performance of each machine, and FMEA directed the actions toward the highest-risk causes. This combination constitutes a replicable methodology for other manufacturing processes with similar characteristics. Likewise, the reduction in scrap translates into less material waste, greater utilization of installed capacity, and a decrease in the costs associated with poor quality.

Future work should focus on maintaining periodic monitoring of the control charts to ensure that the improvements are sustained over time, updating the FMEA as new failure modes are identified, and extending the methodology to other lines or processes in the plant.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

REFERENCES

- [1] AIAG (Automotive Industry Action Group) & VDA (Verband der Automobilindustrie). (2019). *AIAG & VDA FMEA handbook: Failure mode and effects analysis* (1st ed.). AIAG.
- [2] Hernández-Vázquez, J. I., Hernández-Vázquez, J. O., Hernández-González, S., & Olivares-Vera, D. A. (2024). Optimization of the OEE Indicator Through Meta-Models' Simulation in the Buffer Allocation Problem. *Journal of Industrial Engineering and Management*, 17(1), 275–291. DOI: <https://doi.org/10.3926/jiem.6572>
- [3] Hernández-Vázquez, J. I., Hernández-Vázquez, J. O., Hernández-González, S., & Martínez-González, A. (2025). Multi-Objective Optimization of the Buffer Allocation Problem Considering the Overall Equipment Effectiveness Indicator. *International Journal of Industrial Engineering: Theory Applications and Practice*, 32(5), 1331–1341. <https://doi.org/10.23055/ijietap.2025.32.5.11019>
- [4] Hernández-Vázquez, J. O., Hernández-Vázquez, J. I., Hernández-González, S., & Olivares-Vera, D. A. (2024). Solution of the Buffer Allocation Problem Using the Overall Equipment Effectiveness Indicator in a Serial

Production Line. *International Journal Industrial Engineering: Theory, Applications and Practice*, 31(1), 170–183.
DOI: <https://doi.org/10.23055/ijietap.2024.31.1.9695>

- [5] Kiridena, S., Li, W., & Dwight, R. (2022). Development and validation of an overall equipment efficiency measurement model for supporting operational excellence. *IFAC-PapersOnLine*, 55(10), 3076-3081.
- [6] Mendoza, J. P. T., Mendoza, A. G., & Barrera, J. D. E. (2020). Metodología AMEF en el área de moldes en una empresa proveedora para la industria automotriz y línea blanca.
- [7] Nolan, N., & McDermott, O. (2025). Failure mode effect analysis use and limitations in medical device risk management. *Journal of Open Innovation: Technology, Market, and Complexity*, 11(1), 100439.
- [8] Pulido, H. G., & De la Vara Salazar, R. (2013). *Control estadístico de la calidad y Seis Sigma*. McGraw-Hill Interamericana.
- [9] Socconini, L. (2019). *Lean manufacturing. Paso a paso*. Marge books.