Advancing Multi-Level Production Defect Detection Using Quality Tools and Maintenance Optimisation

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Abstract

This study aims to advance the detection of production defects at three levels - part, material, and machine - through the application of a few quality tools with a view to proposing solutions. The research focuses on identifying and addressing the most prevalent and critical anomalies observed in the workshop. Despite existing quality control measures, production often falls short of meeting customer specifications due to machine malfunctions, inadequate operator vigilance, and inefficiencies in the maintenance processes. These challenges underscore the need for a systematic approach to visualise and address production system issues. By applying targeted quality tools, this paper seeks to optimise maintenance strategies and improve overall production performance, contributing to enhanced operational efficiency and product quality.

Keywords: production defects, quality tools, maintenance, operational efficiency, performance, Ishikawa approaches.

JEL Classification: O32; L86; C88.

Introduction

The literature dealing with pre-failure maintenance is grouped into 3 main policies: scheduled maintenance called "time-based" (Geurtsen et al., 2023), predictive maintenance called "data-based" (Nunes et al., 2023) and so-called "condition-based" maintenance (Li et al., 2022). The general idea is to study equipment from different points of view (operating time, sensor data, health status) in order to determine the optimal time at which a preventive replacement should be carried out (before the equipment fails) breakdown). Performing too many replacements represents a high cost for businesses (in time and spare parts) and doing too few increases the likelihood of having a failure. In addition, scheduled maintenance can be perceived as antagonistic to production, i.e., the shutdowns required by the various replacements as part of scheduled maintenance could negatively impact production. The problems linked to maintenance in a general framework of production are also found in the particular case of geographically distributed production sites.

In the particular case of distributed maintenance, several production sites, and therefore several geographically distributed pieces of equipment, must be taken into account simultaneously. In addition to the constraints specific to maintenance (allocation of resources and planning of operations) are added the distances which separate the different production sites. There are two main logistics approaches in the context of distributed maintenance: decentralization (Allaham & Dalalah, 2022a, 2022b) and centralization (Manco et al., 2022). In the first, each production site has an integrated maintenance workshop. The second approach consists of pooling maintenance resources in a single central workshop. A priori, the choice of a logistics architecture (centralized or decentralized) has an impact on the performance of distributed maintenance, since the flow of equipment within the multisite structure is no longer the same.

Performance in maintenance can be evaluated through three key dimensions: maintenance costs, availability of production sites, and environmental impact. Maintenance costs encompass both direct and indirect expenses, including labour, materials, and equipment downtime. Minimizing these costs while maintaining operational efficiency is crucial for organizations.

The availability of production sites refers to the operational uptime of production facilities, where effective maintenance strategies aim to reduce equipment downtime, ensuring that production schedules are met and overall productivity remains high. Additionally, maintenance practices have significant environmental implications, including energy consumption, waste generation, and the disposal of replaced components. By adopting environmentally friendly maintenance practices, organizations can enhance sustainability and ensure compliance with environmental regulations.

Maintenance policies are generally classified into three types:

- Corrective maintenance;
- Preventive maintenance;
- Predictive maintenance.

Each maintenance policy offers distinct advantages and challenges, and their effectiveness can vary based on the specific needs and constraints of a production system. Selecting the appropriate maintenance approach—or combining elements of each - can significantly enhance operational efficiency, reduce costs, and support sustainable production practices.

Corrective maintenance is initiated after detection of a failure (Pandey et al., 2010). Then comes the diagnosis which makes it possible to identify and locate the origin of the fault. The main methods used are, on the one hand, the analysis of failure modes, their effects and their criticalities (FMEA) (Lee et al., 2011) and, on the other hand, the failure tree (Klos & Patalas-Maliszewska, 2013). An intervention order mobilizes the necessary resources for the rehabilitation of the equipment (Ding & Kamaruddin, 2015). Interventions can either be handled by the maintenance department or be subcontracted to an external company (Ruschel et al., 2017). As soon as resources are available, interventions begin, immobilizing the production equipment concerned until the repairs are completed. There are several levels of maintenance linked to the nature of the failure, ranging from a simple repair by component replacement to a complete renovation (Ettaye et al., 2016).

Preventative maintenance relies on scheduled inspections, cleaning, and replacement of parts based on predefined time intervals or usage metrics. Its goal is to reduce the likelihood of failures and extend equipment lifespan, although it may involve shutting down equipment for maintenance, which can impact production. The resources are similar from corrective to preventive. But the intervention order is initiated by a maintenance schedule deadline. The deadlines correspond to dates separated by regular, predetermined time intervals (Ierace & Cavalieri, 2013). Operations consist of inspecting, cleaning/replacing and testing equipment (Hadidi et al., 2012). Interventions are based either on the manufacturer's recommendations, or on the distribution model of the number of equipment failures over time (Poisson, Weibull, normal law, etc.) (Hwang & Samat, 2019). The goal is to reduce the likelihood of system failure.

Predictive maintenance aims to be more intelligent in planning operations. Sensors make it possible to collect and collect data from equipment during operation (Cheng et al., 2022). The most used method consists of implementing machine learning algorithms to predict the remaining life of equipment or “Remaining Useful Life” (RUL) in English (Leukel et al., 2021).

1. Follow-up Approach in the SOTUPLAST Maintenance Department: Corrective Maintenance and Defect Detection

In our research, we aim to emphasize the importance of corrective maintenance, with a particular focus on defect detection using the Ishikawa quality method. Corrective maintenance is a proactive approach to addressing faults and inefficiencies in the production process by identifying underlying causes and implementing targeted solutions. Through this study, we have developed a systematic approach to identify, analyse, and resolve defects in the production processes at SOTUPLAST, using a structured methodology.

Our practical study follows a clear, step-by-step process consisting of three key phases: problem detection, application of methods, and proposal of solutions. This structured approach ensures that all issues are thoroughly investigated, potential causes are identified, and effective corrective actions are implemented.

Troubleshooting

At SOTUPLAST, non-compliance with customer quality requirements has led to a series of quality issues that needed to be addressed. The company sought to understand the root causes of these issues in order to improve the overall product quality. Through a comprehensive troubleshooting process, we identified three primary problems that contributed to product defects:

- Part defects. These defects arise when machines are not operated according to the recommended settings, such as speed, temperature, and pressure. When machine settings are not properly calibrated, two types of non-compliant products may result: deformed parts and parts with holes. For example, improper mould closure can lead to structural issues that cause defects such as warping, misalignment, and dimensional inconsistencies. These types of defects are detrimental to product quality and customer satisfaction, as they render the products unfit for use.
- Raw material defects. In an effort to optimise costs and minimize waste, SOTUPLAST occasionally uses recycled materials in the production process. While recycled materials can offer certain advantages, such as reducing material costs and minimizing waste, they may also lead to quality issues. Raw materials, such as virgin plastics, have superior properties like ease of processing, excellent electrical conductivity, and flexibility. In contrast, recycled materials may have inconsistent quality and may not meet the same performance standards as fresh materials, leading to defects in the final product. This trade-off between cost savings and product quality needs careful consideration to minimize the occurrence of defects.

Through careful detection and analysis, these two primary sources of defects were identified as critical areas for improvement in SOTUPLAST's production process. Addressing these issues effectively required a structured approach to quality management and maintenance practices.

Resolution Method

To resolve the problems identified in the SOTUPLAST production process, we applied appropriate quality methods to minimize the frequency of defects and improve overall product quality. A core tool used in our analysis was the Ishikawa diagram (also known as the Fishbone diagram), a well-established quality management tool that helps visualise the potential causes of defects and organize them into categories for further investigation.

The Ishikawa diagram was used to analyse the production process of plastic products at SOTUPLAST, pinpointing the main sources of defects and their contributing factors. This method allowed us to systematically assess each aspect of the production process and identify the most significant causes of quality issues. The diagram divides potential causes into five main categories, known as the 5 Ms:

- Machine: This category encompasses all the machinery and equipment involved in the production process. The goal of the machines is to produce finished plastic products efficiently and accurately. However, defects may arise if the machines are not properly maintained, calibrated, or operated. Issues such as wear and tear, mechanical failures, or incorrect settings (e.g., temperature, pressure) can result in faulty products. Regular maintenance and machine upgrades are crucial to ensuring the machines operate at optimal performance levels.
- Method: This category refers to the procedures and methods used during the production process. Each step in the manufacturing process, from material handling to moulding and finishing, requires clear instructions and standardized procedures to ensure product quality. Any deviation from these established methods can lead to defects. For example, inconsistent application of production techniques

or failure to follow quality control procedures can result in defects such as deformed or non-dimensionally accurate parts. Proper training and adherence to best practices are critical to maintaining high-quality standards.

- Labour: Workers play a significant role in ensuring the quality of the final product. Labour-related issues can impact product quality if workers are not properly trained, motivated, or supervised. Additionally, inadequate safety protocols or poor working conditions can lead to errors in the production process, compromising the quality of the product. It is essential for SOTUPLAST to implement robust training programs, establish clear performance standards, and maintain a strong focus on workplace safety to ensure the quality of the products produced.
- Environment: The working environment has a direct influence on the production process and the quality of the products. Factors such as temperature, humidity, and cleanliness in the production area can affect the materials and machinery. For example, high humidity levels may cause certain materials to degrade, or temperature fluctuations may impact the curing or moulding processes. Moreover, ergonomic considerations and the overall comfort and safety of workers should be addressed to minimize human errors and increase productivity. SOTUPLAST must ensure that the work environment supports optimal conditions for both workers and production equipment.
- Materials: The materials used in the production process are central to ensuring the quality of the final product. As previously mentioned, SOTUPLAST uses both raw materials and recycled materials. While raw materials offer consistency and superior properties, recycled materials may introduce variability in product quality. This category also includes the proper storage and handling of materials, as improper storage can lead to material degradation or contamination. Careful selection of high-quality materials, along with proper handling and storage practices, is necessary to prevent defects related to material quality.

Applying the Ishikawa diagram to the production process, we were able to identify and categorize the key factors contributing to defects at SOTUPLAST. The findings from this analysis provided valuable insights into potential areas for improvement and informed the development of targeted solutions aimed at reducing defects and improving overall production efficiency.

2. Analysis of Defects in SOTUPLAST Production: Part, Material, and Machine Issues Using the Ishikawa Diagram

During the production process at SOTUPLAST, several issues arise that compromise the quality of the finished products. These issues, which are systematically analysed using the Ishikawa diagram, are categorized into three primary areas: part defects, material defects, and machine-related faults. Each category includes specific, recurring problems that have been identified as contributing factors to overall production inefficiencies and product non-conformities. Below, we detail the most frequent issues observed in each of these categories.

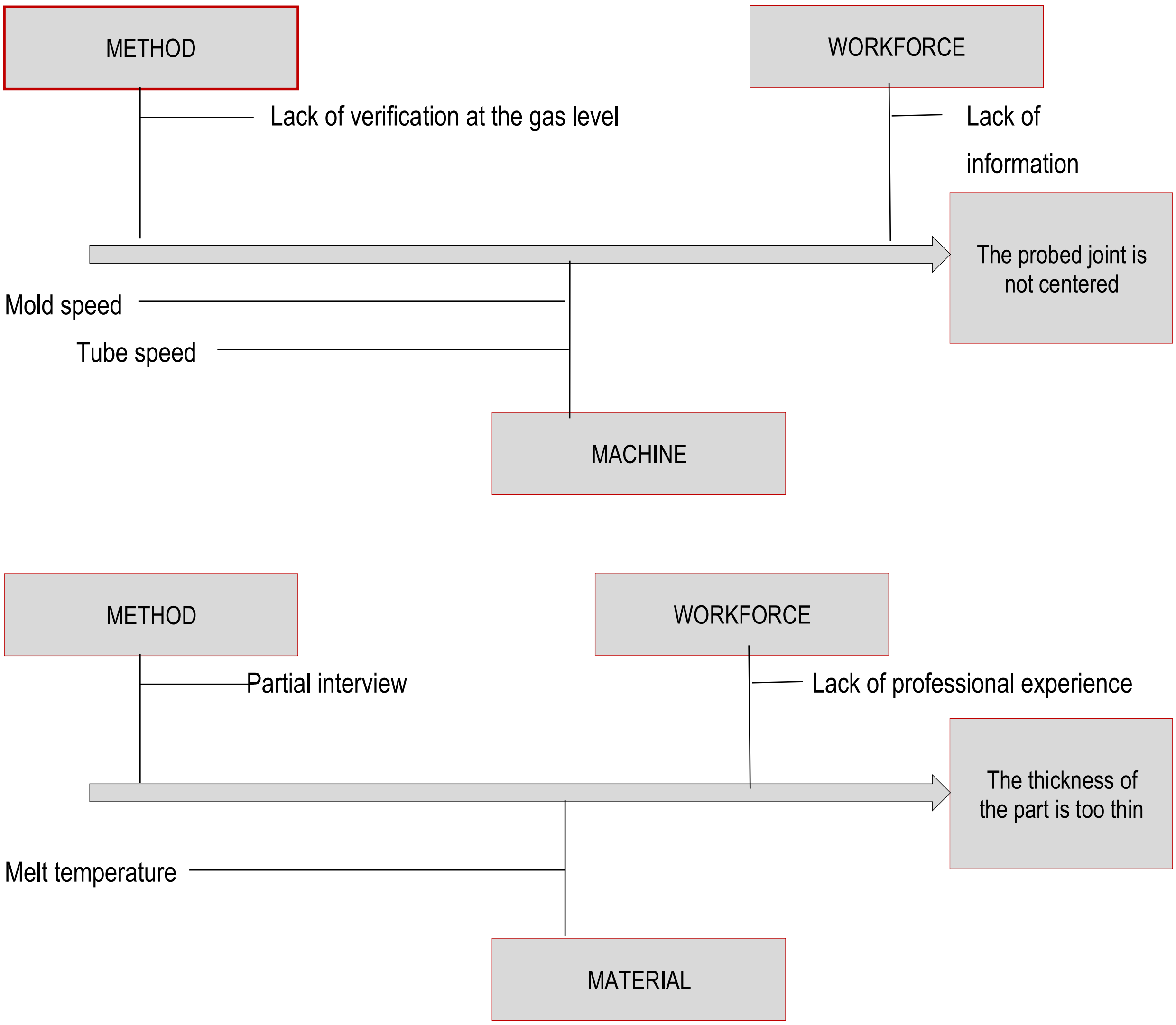
First Issue: Part Defects

Part defects are a critical concern in the production process at SOTUPLAST. These defects manifest as a result of various operational factors, and the most common issues identified include:

- Misalignment of probed joints: This issue occurs when the probed joints are not properly centred during the moulding process, leading to misfit components.
- Uneven side welds: Inconsistent welds along the sides of the product contribute to structural weaknesses and poor aesthetic quality.
- Excessive thinness of the part: Parts produced with insufficient material thickness fail to meet quality standards, compromising their durability and functionality.

- Incomplete parts: This issue arises when the mould fails to fully capture the required shape of the part, leading to incomplete or partially formed products.
- Excessive exit from the sector: This refers to parts that fail to remain within the designated production specifications, leading to inefficiencies and waste. Other less frequent but significant part defects have also been identified, contributing to the overall need for corrective action to ensure higher product quality.

Figure 1: Ishikawa diagram of defects linked to the part

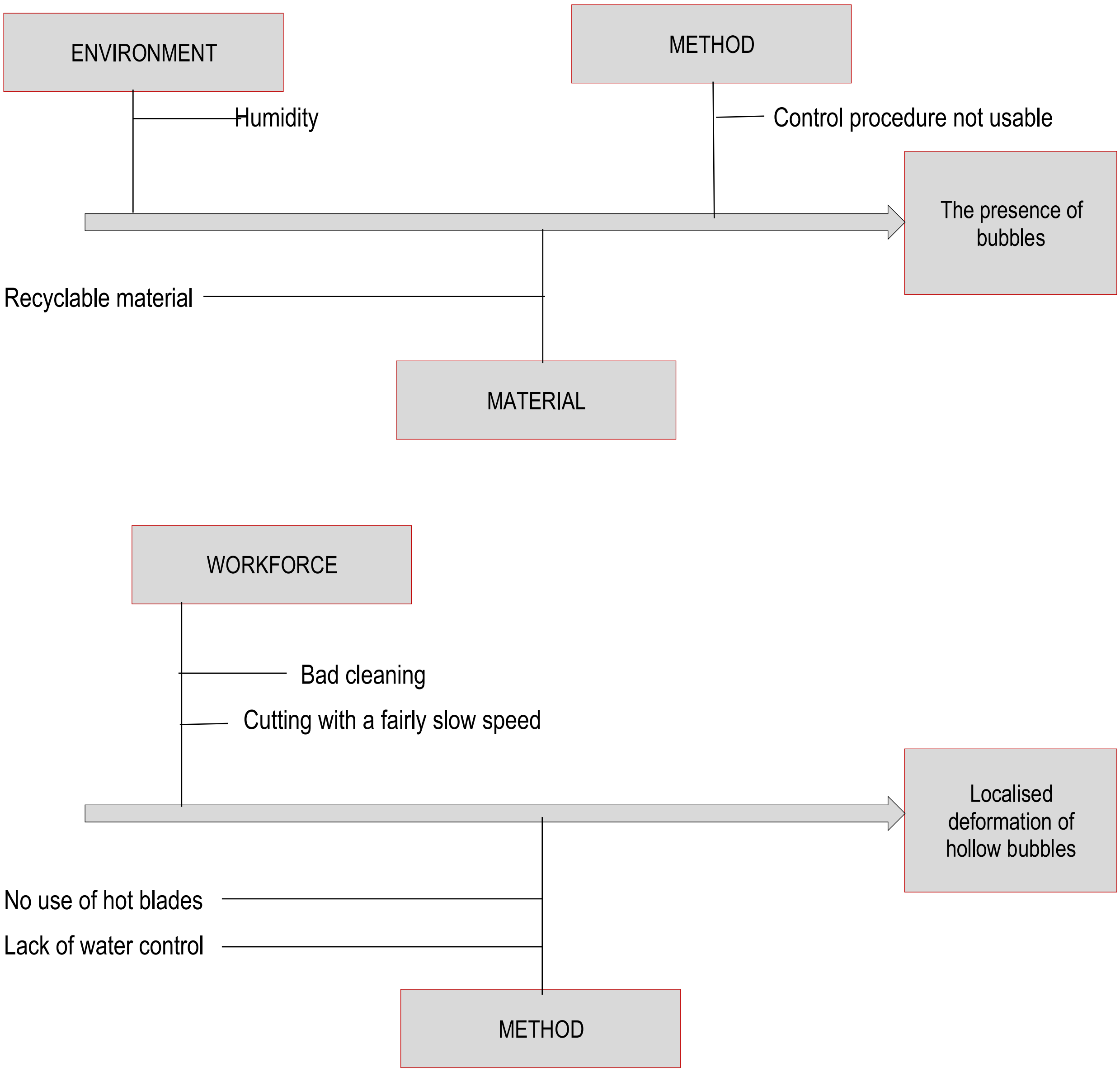


Second Issue: Material Defects

Material-related issues are another significant source of production defects. These problems typically arise during the material handling and moulding stages, and the most frequent material defects include:

- Presence of Bubbles: The formation of air bubbles within the material can lead to imperfections in the final product, affecting both its strength and appearance.
- Localized Deformation of Hollow Bodies: This occurs when certain areas of hollow parts experience deformation, compromising the integrity and usability of the product.
- Parison Closure Issues: In the moulding process, improper closure of the parison can cause the material to collapse inward or expand outward, leading to inconsistent product shapes and defects. Additional material defects have been noted, all of which highlight the importance of stringent material control to ensure product consistency and quality.

Figure 2: Ishikawa diagram of defects related to material



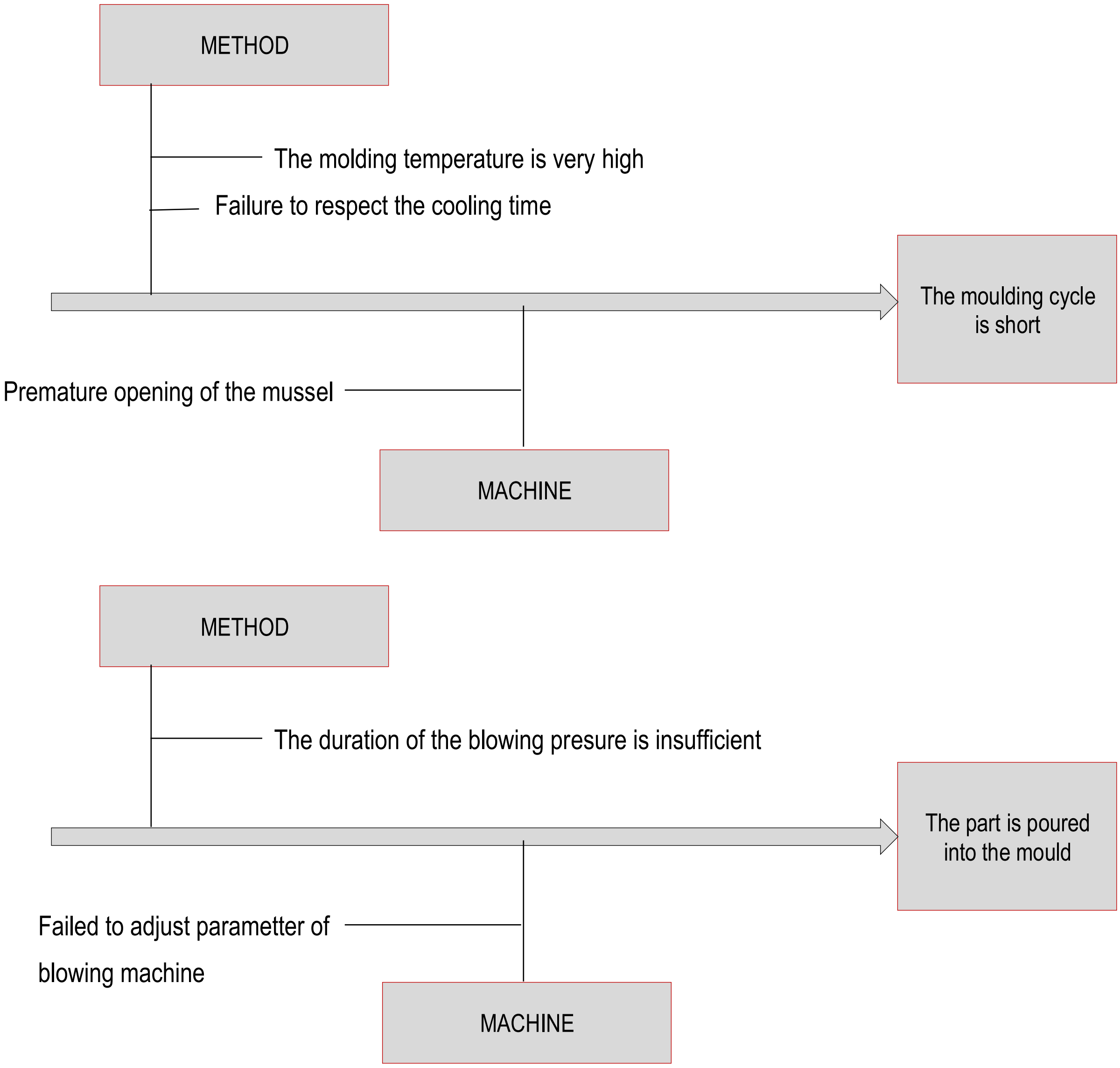
Third Issue: Machine Defects

Finally, machine-related faults play a crucial role in the production of finished products at SOTUPLAST. These defects typically arise from issues with machinery settings, maintenance, or operational procedures, and the most common machine-related defects include:

- Improper part pouring into the mould: This occurs when the material is not properly introduced into the mould, resulting in incomplete or deformed products.
- Short moulding cycle: A cycle that is too brief may not allow for proper material setting, leading to weak or poorly formed products. Other machine-related faults, though less frequent, also contribute to the overall defect rate and underscore the need for continuous machine maintenance and calibration.

In conclusion, the analysis of part, material, and machine defects through the Ishikawa diagram has allowed for a comprehensive understanding of the root causes of quality issues at SOTUPLAST. This structured approach to defect detection helps identify areas for improvement, guiding the development of corrective measures to enhance the overall quality of the production process.

Figure 3. Ishikawa diagram of faults connected to the machine



3. Proposed Solutions for Corrective Maintenance

In this section, we outline the most frequent defects identified through the application of the Ishikawa diagram and propose corrective solutions specifically related to the maintenance function, with an emphasis on corrective maintenance. The proposed remedies focus on resolving issues concerning part defects, parison defects, and operational faults.

First Issue: Correction of Part Defects

Table 1 presents the most common defects observed in the plastic parts produced by SOTUPLAST, along with their corresponding causes and corrective measures. These defects specifically pertain to issues in the moulded plastic parts that arise during production. For instance, the defect of the probed joint not being centred occurs when the mould is not properly adjusted, causing the part's joint to be misaligned during production. To correct this, two remedies can be applied: first, the blower head should be positioned appropriately to ensure the moulding process is carried out correctly; second, the mould must be adjusted relative to the die to ensure proper alignment and achieve a centred joint.

Another common issue is the thickness of the part being too thin, which results from the parison (the preliminary tube of plastic) not being sized correctly, leading to uneven thickness in the moulded part. To address this, the parison size should be increased to meet the required thickness specifications. Additionally, reducing the pellet temperature can help control the material flow, ensuring even distribution and uniform thickness in the final product.

Table 1: Correction of part defects

Defect	Cause	Remedies
The probed joint is not centred	Poor mould adjustment	- Position the blower head appropriately
		- Correct the mould adjustment relative to the die
The thickness of the part is too thin	Inadequate parison size	- Enlarge the parison size
		- Reduce the pellet temperature to ensure proper material flow

Second Issue: Correction of Parison Defects

A parison is a preliminary form of a plastic product, typically a tube or hollow shape, created during processes like blow moulding or extrusion. The parison is heated to a specific temperature before being placed in a mould, where it is further shaped to form the final product. Defects in the parison, such as improper size or deformation, can affect the quality of the finished product.

One common defect is when the parison closes in on itself, which is often caused by the die temperature being too low. When the temperature is insufficient, the material does not flow correctly, causing the parison to collapse. To correct this, it is necessary to select the appropriate temperature for the die to ensure proper material flow. Additionally, ensuring proper assembly of the sector to avoid misalignment can prevent the parison from closing improperly.

Another frequent issue is the parison exiting the sector incorrectly, which typically occurs when the extrusion of the melt is too slow. Slow extrusion leads to inconsistent material flow, causing the parison to exit the sector in an undesired manner. The solution to this is to increase the extrusion speed, allowing the material to flow consistently. Reducing the pellet temperature can also help improve material flow, ensuring that the parison maintains the correct size and consistency throughout the extrusion process. These corrective actions aim to resolve the common parison defects, improving the quality and consistency of the finished plastic products (see Table 2).

Table 2: Correction of parison defects

Defect	Cause	Remedies
The parison closes in on itself	Die temperature too low	- Select the appropriate temperature for the die
		- Ensure proper assembly of the sector to avoid misalignment
Exit from the sector	Extrusion of melt too slow	- Increase the extrusion speed to achieve a consistent flow of material

Third Issue: Correction of Operational Faults

Table 3 addresses common operational faults that can occur during the production process of plastic parts, along with their causes and suggested remedies. One issue is when the deviated parison is not pierced, which typically results from insufficient blowing pressure. This can prevent the material from being distributed properly and cause the parison to deviate from the intended shape. To resolve this, the air gap should be minimized, which can improve the efficiency of the piercing process. Additionally, adjusting the blowing pressure ensures a more uniform material distribution, allowing for better control over the parison and its final shape.

Another issue is when the part sticks in the mould, often caused by improper mould opening. When the mould is not opening correctly, it can create resistance, causing the moulded part to remain stuck. The remedy for this problem is to slightly reduce the mould temperature, which helps the part release more smoothly, reducing the likelihood of sticking. These corrective measures aim to optimise the operational processes, ensuring smoother production and higher quality moulded parts.

Table 3. Correction of operational Faults

Defect	Cause	Remedies
The deviated parison is not pierced	Insufficient blowing pressure	- Minimize the air gap to improve the efficiency of the piercing process
		- Adjust the blowing pressure to achieve uniform material distribution
The part sticks in the mould	Improper mould opening	- Slightly reduce the mould temperature to facilitate smoother part release

These proposed solutions aim to address the root causes of defects identified during the production process. By implementing these corrective maintenance strategies, SOTUPLAST can enhance product quality, minimize downtime, and improve overall production efficiency.

Conclusion

In the context of distributed maintenance, two key elements are essential for categorizing the various approaches: the perspective (logistics, information systems, or communication networks) and the selection of the type of maintenance workshop (centralised or integrated). This paper specifically focused on the logistical perspective, which is a common challenge across all maintenance policies. The primary goal in this context is to ensure the efficient transport and provision of maintenance resources.

Maintenance plays an important role in the optimal functioning of production systems, and addressing maintenance issues directly impacts the quality of production outputs. The problem examined in this study is centered on minimizing product non-conformity defects, a key objective for the SOTUPLAST company. By aligning our approach with the company's maintenance service goals, the proposed improvements are expected to have a positive influence on both productivity and product quality. Ultimately, these enhancements will contribute to strengthening the company's brand image and market competitiveness, demonstrating the critical interplay between maintenance optimisation and quality control.

However, the study has some limitations. Firstly, the scope of the research was confined to the SOTUPLAST company, meaning the findings and proposed solutions may not be fully generalizable to other industries or companies with different production systems. Additionally, while the study focused on corrective maintenance and defect detection using specific quality tools, other maintenance strategies, such as preventive or predictive maintenance, were not explored in depth.

Further research could expand the scope by investigating the integration of various maintenance strategies within different industrial settings. Additionally, exploring the role of digital technologies, such as IoT and machine learning, in predictive maintenance could provide valuable insights for optimising production processes and minimizing defects. Future studies could also consider the long-term impact of these maintenance optimisations on sustainability and cost-efficiency, areas that were not addressed in this research.

Credit Authorship Contribution Statement:

The sole author, Fadwa, E. is responsible for all aspects of the paper including conceptualization, methodology, data collection, analysis, writing, and final approval of the manuscript.

Conflict of Interest Statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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