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METHODOLOGY TO REDUCE NONCONFORMITIES IN AN INJECTION PROCESS: AN EMPIRICAL STUDY

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ABSTRACT

This study aimed to create a control methodology to avoid problems of nonconformities in an industry that is in the process of installation in the industrial hub of Manaus, in the Brazilian Amazon. These nonconformities appear as injection failures, injection burrs, lack of impact resistance, and lack of weight control of each injected pot. Reducing these nonconformities will allow the company to have quality products in the pots and lid injection process. The intention is that the control is based on tools from the RAMI 4.0 architecture so that you can parameterize and control all stages of the production process. The scientific-technological method was used in its second part, which aims to generate a technological product. The simulated results showed almost complete elimination of warping (991 to 7), injection failures (794 to 14), and injection burr (1,377 to 12) daily. The total number of failures dropped from 3,162 to just 33. The simulated results allowed the elaboration of a solution based on 1) the integration of the corporate control system, 2) the application of digital twin technology, and 3) the use of IoT for data collection, transmission, and analysis. The conclusion shows that the Rami 4.0 architecture is efficient and effective in dealing with these adversities in production processes.

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INTRODUCTION

A certain petrochemical industry produces petroleum-derived resins for thermoplastic processes for injecting plastic injections, extrusion of plastic laminates for yogurts and disposables, ethyl benzene, solvents for paints and styrene monomer located in the industrial hub of Manaus. It is expanding its product portfolio and entering the ice cream packaging industry. For this, it changed the structure of the factory and adapted machines for the injection of ice cream pots. The company wants to guarantee its customers the highest quality products by starting the ice cream pot injection process. The entire injection process will have a strict quality system to ensure that your customer is always satisfied and also that they are increasingly loyal. With the production startup, there were some problems in the production process. Among them, some are related to the quality of the product. According to the data collected, some issues were detected that could have been avoided if there was a specific control in the process, such as burrs, injection failure, weight control, impact resistance, and warping that causes the lid to fail to lock. These occurrences have been delaying production and generating raw material losses. As it is a food storage product, it cannot be used for recycling after the process. Injection burrs are a problem in the Injection process caused by excess material inside the mold. These injection burrs cause aesthetic issues and waste of material. Injection failures are a lack of material inside the mold, where all the space the material should fill is not being served. During the Injection process, the weight of each part must be controlled after it is ready, so you will have better control over the Injection flow to know what the material flow is inside each cavity to avoid failures during the process. The impact resistance and lid locking failures are measured to ensure that the injected part does not break if there is a fall during the handling of the pot by the end customer. The RAMI 4.0 architecture is a benchmark for transforming Industry 3.0 into Industry 4.0. Industry 4.0 is an era of artificial intelligence, where mechanisms can be implemented that can be controlled by artificial poverty, thus reducing failures in production processes. Control tools work by installing sensors, scanners, scales, and cameras to monitor all parts produced and allow faults to be corrected instantly. This study aimed to create a control methodology to avoid problems of nonconformities in an industry that is in the process of installation in the industrial hub of Manaus, in the Brazilian Amazon. These nonconformities appear as injection failures, injection burrs, lack of impact resistance, and lack of weight control of each injected pot.Reducing these nonconformities will allow the company to have quality products in the pots and lid injection process. The intention is that this control is based on tools from the RAMI 4.0 architecture so that it can parameterize and control all stages of the production process. The expected results are the reduction of interference from failures due to a lack of unsuccessful execution and the temperature of the sector's environment. The scientific-technological method was used in its second part to generate a technological product (Nascimento-e-Silva, 2020; 2021a; 2021b; 2021c). Two are the significant contributions of this study to the management practice of production processes following the Rami 4.0 architecture. The first is the substantial increase in productivity with stability through reducing rejection rates. Rejection will result from stopping during the production process to correct faults, significantly contributing to the system's efficiency. With the increase in productivity and stability in the process, the workforce that today spends a lot of time-solving problems and working on the causes of each issue will be available to work on other problems. It means that hiring more workforce to work in different stages of the process will no longer be necessary. The improvement in the efficiency and stability of the process will be reflected in the reduction of raw material consumption. The second contribution is the reduction of environmental impacts by reducing waste generated by process failures. The reduced waste will allow a smaller volume of raw material to be purchased. This natural material is particular because it is a container that will serve food storage and, therefore, cannot be reused in the process again, being discarded for other types of the injection process. Thus, companies that buy this waste will be forced to seek new sources of waste supply for injection of material that does not require high-end destruction and will open up opportunities for recycling many plastic products, which today are abundant. Their disposal is made incorrectly in nature.

Nonconformities in the Production Process: The literature review showed that conformity and nonconformity are two aspects of the same quality as a *continuum*. At one extreme, there is conformity; in another, nonconformity. Between these two extremes, several gradations are verified so that a product or service considered of quality presents nonconformities that do not affect the expected performance. In this way, a quality product or service is not synonymous with perfection or the absence of flaws but conformity or nonconformity with something. As the data in table 1 show, conformity has multiple interpretive possibilities (Leite,Maia eSantos, 2019). It means that what is seen as conforming in a given organization or society can be perceived inversely in another. No fact or phenomenon in the world can be taken as conforming or not conforming by itself. A reference is always needed.It specifies a particular area, as in teaching, where grade 10 represents the most excellent possible conformity between what has been taught and what has been learned. Also, it specifiesa context, such as giving up or not giving up a seat on a bus or subway). by a young person to an older adult or person with special needs. It is the starting point for understanding nonconformities. The study by Efendi et al. (2021) shows the application of conformityin a particular area, which has been called gamification. In this specific, conformityis linked to the needs of every individual or group of individuals who will use the games produced. And also, specifically, two things need to be taken into account by game developers and game planners: content and design. It means that the games' conformityor nonconformity depends on whether or not they meet the needs of all those who will use them. It implies, therefore, the requirement to know users' needs in these two aspects so that the possibility of nonconformity is reduced as much as possible. The studies by Puteri and Zagloel (2022) and Knop (2021) show that nonconformity can be a failure. And failure means that something that was expected did not happen. In technical terms, what was planned did not generate the intended results. When there is a difference between what was planned and what happened, it is considered a failure, a mismatch.And failures happen precisely in fulfilling a specific requirement, a word that, technically, is replaced by a condition. A requirement is a requirement, an obligation, that needs to be fulfilled for what is expected to happen effectively. And the process of precisely defining what is expected and how it needs to be done is called standardization. As a result, nonconformity (and conformity) can only be gauged bycomparing what was produced with the previously defined standard. It is why the studies by Dagnaisser et al. (2020) and David (2021) consider nonconformity to be any deviation from what is expected or projected. But it's not just any deviation. This deviation needs to be accentuated. It may be the complete deviation, as we can see in the studies by Dagnaisser et al. (2022) and David (2021), in which the requirements were not being met, or in the gradation of these deviations, as measured in the study by David (2021). Let's look at an example of the latter case. Imagine that the circumference of a given piece has a lower limit of 1.5 cm and an upper limit of 2.0 cm. A production batch submitted to quality measurement showed 2.01 cm in this requirement. See that the condition was worked on but not met in the specificity of the standard. For this reason, the entire batch was discarded. It is what we call the gradation of conformity.

Table 1. What is conformity?

References	What is conformity (and nonconformity)
Leite, Maia& Santos (2019)	Conformity can be defined in several ways; the concept will depend directly on the area and context that will be used
Efendi et al. (2021)	Conformity can be defined as the way in which the content and design of the game can be properly adapted to the user's needs.
Puteri&Zagloel (2022)	Nonconformity is defined as a failure to meet specifications or standards
Knop (2021)	A nonconformity is any failure to meet a requirement.
Dagnaisser et al. (2022)	Nonconformity is the term used to indicate that some standard requirement is not being met in the forest management unit
David (2021)	Nonconformity is defined as the deviation or absence of one or more of the quality characteristics or elements of the quality system from the requirements
Hebbar&Geymonat (2021)	Nonconformity is the denotation of a nonconformity of a mandatory requirement for the entire dataset

Source: data collected by the authors.

In general, a nonconformity is simply nonconformity with a specific requirement (Hebbar & Geymonat, 2021). It is the interpretive sense used in this work. It doesn't matter enough that the condition has been worked out. It is necessary that the result of this work, of all the effort expended, is within the specifications of the previously defined standard. As the metaphor goes, it's not enough to kick the ball toward the post; the goal must be scored. It is because what wins the game is not the number of shots toward the destination but the number of times the ball crosses the goal line. Thus, crossing the goal line is the requirement of the football game, not the number of shots on goal or playing nice.Table 1 summarizes this theoretical scope.

Practical Case

The Causes of Problems: We present the causes of the problem with the Ishikawa graph. This representation allows one to accurately understand the relationship between a problem with its causes and causes of reasons, as can be seen from studies by Priebe (2022), Santos et al. (2022), Rodríguez, Canga and Gallegos (2021) and Santos and Okada (2021). This diagram describes complex situations thatare difficult to describe and interpret by words alone. From a defined list of possible causes, the most likely ones are identified and selected for better analysis. For the best detailing of the objective of this study, the 6M method will be the main one to be used in the analysis and discovery of the problematic root of the lack of impact resistance, injection failures, and injection burrs in the injected pots.

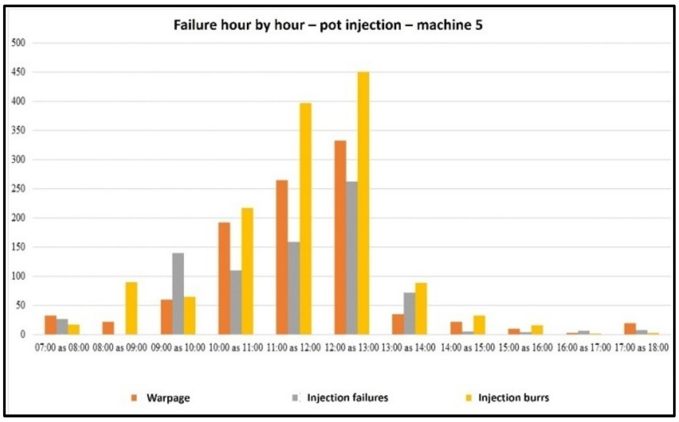
The Ishikawa Diagram is also known as the Cause and Effect Diagram. This representation has significantly improvedcompanies' quality of products and processes worldwide. The Ishikawa Diagram made it accessible and straightforwardas a potent cause analysis tool that could be used by "non-specialists" in the field. This problem-solving process tool is considered one of the pillars of Quality Management. The high rejection rate in the injection of ice cream pots, from 9:00 am to 3:00 pm, is due to the waste suffered by the production process during this period. More precisely, these rejects are warping, injection failures, and burrs due to the temperature variation in the environment and the water that circulates inside the mold. The water temperature has an acceptable deviation of ± two °C to stabilize the process. Table 2 shows the number of failures by type of tailings.

Table 2. Rejection data in the jar sector

Time	Warpage	Injection Failures	Injection Burrs	Total
07:00 às 08:00	32	27	17	76
08:00 às 09:00	22	0	90	112
09:00 às 10:00	60	140	65	265
10:00 às 11:00	192	110	217	519
11:00 às 12:00	264	159	396	819
12:00 às 13:00	332	262	450	1044
13:00 às 14:00	35	72	89	196
14:00 às 15:00	22	5	32	59
15:00 às 16:00	10	4	16	30
16:00 às 17:00	3	7	2	12
17:00 às 18:00	19	8	3	30
Total	991	794	1.377	3.162

Source: data collected by the authors.

As shown in Table 2, we have a high rate of defective parts. These data were collected during a production week, from Monday to Friday, from 07:00 to 17:00. They are the records of the 5-day production tailings. If added to the average production of 25 working days, these values rise to 15,810 pieces per month. Estimated losses during a year can reach an unacceptable 189,720 parts rejected. It is a very high rate, even for producing 4,032,000 pieces per year per machine, because it has representativeness of 4.70% of waste, a rate considered high for the Pot injection process. It is also worth considering that the maximum acceptable rejection target is 0.50% of the total produced.

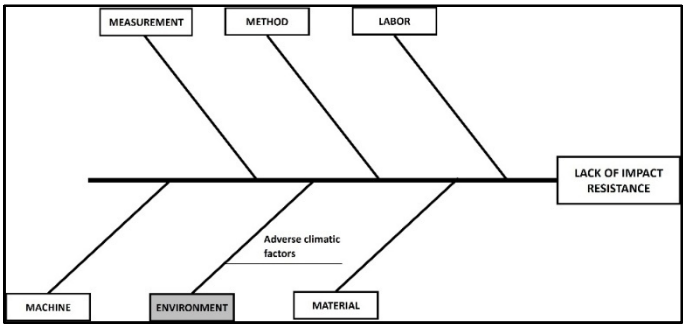


Source: data collected by the authors.

Graph 1. Disapproval of Pots hour-by-hour: machine 5

Graph 1 shows the amount of rejected parts during the working day and data collected during the week. In the data analysis in the graph, a very sharp rise in the number of pieces rejected in the process can be seen from 9:00 am, reaching a maximum between 11:00 am and 1:00 pm. This high part rejection rate coincides with the maximum temperature peak hours in the environment. After this time, the rejection rate drops abruptly, returning to the average level after 15:00 hours. The process always happens due to the variation in ambient temperature. Consequently, there isan increase in the temperature of the water that circulates in the cooling system of the injected parts still inside the injection mold. Let's take a closer look at these causes.

The lack of impact resistance: The raw material used for the production of food packaging, such as ice cream, which is frozen at shallow temperatures, must have good impact resistance because it is frozen products and transported by several distributors. Packages must maintain impact resistance, even when dropped from a height of up to 90 cm from the ground, stipulated based on the average size of the hands of a person who carries out the work of transport and replacement in the freezers. It is necessary to guarantee the same temperature conditions to maintain the texture and consistency of the ice cream. Keeping control of the temperature and unit of the injection sector and controlling the temperature of the chilled water that circulates inside the mold implies a better result in the process. Figure 1 shows this cause-and-effect scheme.

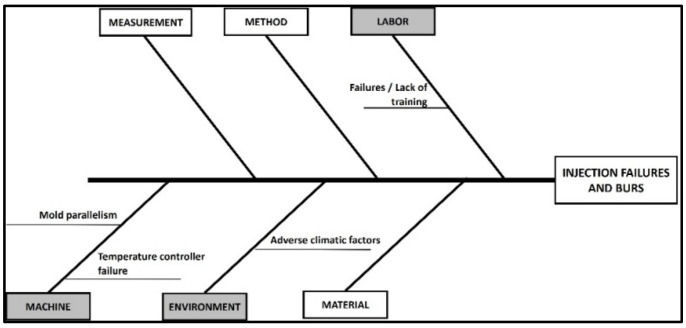


Source: data collected by the authors.

Figure 1. Causes of lack of impact resistance

Ice cream packaging needs impact resistance for drops up to 90 cm high. This requirement is because it will remain with the frozen product, where any failure in handling and falling of the package with the cooled product inside can cause the package to break and the lid to unlock. It can cause dirt and contamination of other containers in the same box during transport between their distributors. Thus, the control of impact resistance and lid locking is significant during the injection process of ice cream pots. The impact resistance test must be done with the pot full of product and cooled.

Injection failure and injection burrs: The lack of mold parallelism has caused considerable losses due to variations in the injection process. The consequence is a high rejection rate due to injection failure and burrs. This injection failure and burr problems occur due to several factors, such as lack of parallelism in the mold, operators with little knowledge of the pot injection process, and temperature variations. These two problems have a significant impact on the bounce rate. In addition to losses in rejecting defective parts, they occupy a lot of time for operators to review the material and technicians to solve the problem to keep the machine running. In the injection process, generally, there is a rework in each injected part. This process finishes the part where the injection burrs must be removed. The food product injection process has strict procedures to avoid contact with the injected parts and to avoid contamination of the product during the injection process. Thus, the piece cannot be finished, and articles with burrs must be rejected and crushed to be used in injection processes other than food products. As this material cannot return to the reprocessing of injected food, there is a loss in the value of the crushed material, which will be sold for the production of other injectable processes with values far below the value of the raw material purchased exclusively for the procedure. Figure 2 shows the causes of this type of failure. The operators and technicians of the injection processes are workforces transferred from other areas. Previously they worked with the injection process but with different types of resins and other models of parts. For this reason, they need more training to understand the pot injection process better.

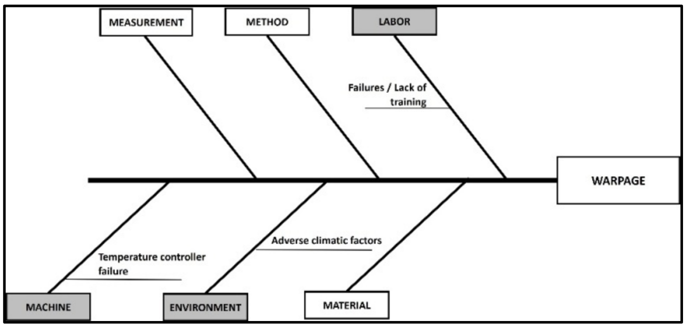


Source: data collected by the authors.

Figure 2. Causes of injection failures and injection burrs

It means that technicians and operators in the pot sector need specific training to work with pot injection, mainly because the resin is so precise that any change in the process can cause many rejections. In addition to all this, specific care is required for the handling of containers intended for food. Injection failures and burrs occurred a lot between 10:00 and 15:00 hours. The reason was a significant increase in temperature and humidity in the sector. The failures were caused by the variation of the ambient temperature and, consequently, the variation of the temperature of the water that circulates in the cooling process.The variation in temperature and humidity are very unfavorable factors for the injection process because they cause problems in the material. With that, the adverse effects of the injection process arise.

Warpage: Injected packages with warpage cause failure to lock the lid. Warpage occurs due to mold cooling failures and several consecutive machine stops with variations in ambient temperature and variations in the chilled water that circulates inside the mold. With these occurrences, there is a strong tendency for the parts to be warped. Aesthetically, in appearance, they look good, but when doing the conformity test, the lid does not lock. Failure to close the cover can cause the packaging inside the freezer to break, and impurities will contaminate the ice cream. These factors also occur due to the lack of training of operators and technicians in pot injection, as shown in the data in Figure 3.



Source: data collected by the authors.

Figure 3. Causes of warpage failure

Figure 3 shows that we have problems with the lack of training of employees as one of the causes for the warping of the injected parts. Employees in the injection area need more specific training for the injection area so that they can have greater perception and can detect the root of the problems for immediate action. Another point that may be causing the warping in the parts is the climatic factors, which suffer a significant temperature variation. The issue of temperature variation becomes the leading cause of the problems in the process, mainly the warping of the parts.

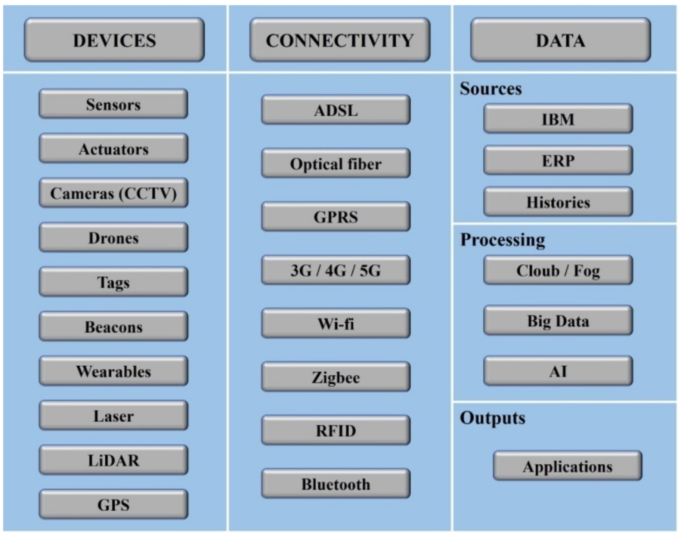
Solution of problems with the implementation of rami 4.0: Deploying the RAMI 4.0 architecture in the process will help resolve issues quickly. According to the study carried out in the process, it is evident that the root problem of the high rejection rates in the process is the temperature variation in the environment. Temperature sensors were installed at the water inlet of each machine so that the variation could be detected in real-time. The data collected by the sensors were sent to the controllers. This procedure was intended to solve the problem of temperature variation in the period from 9 am to 3 pm and stabilize the ambient temperature throughout this period. Data will be collected and converted from analog data to digital data. After converting the data, all water temperature data will be monitored every 30 seconds and shown on the dashboard for decision-making regarding temperature so that the technical team will have information about everything in real-time.

Integration of the corporate control system: Integrating the system for administrative control can bring a series of advantages to the business, among them the optimization of processes, reduction of rework, reduction of errors, and management of metrics and indicators. IEC 62264 is an ANSI/ISA-95-based standard that defines terms and models between enterprise business and shop floor control systems. It is an interactive standard for integrating corporate control systems. The pattern can reduce the effort associated with implementing new product offerings. The goal is to have enterprise and control systems that interact and integrate easily. Industrial process measurement and control encompasses the data structures and catalog elements of process equipment. IEC 61987, directly linked to industrial process control measurement, defines a standard to facilitate understanding of process measurement and control equipment descriptions when transferred from one party to another.

Application of digital twins technology: Barricelli et al. (2001) define the digital twin as the mirroring of equipment or piece of equipment, giving a physical identity, a living prototype of this equipment, making it intelligent and progressive. It can be applied in different forms and life cycles. Itcan optimize, monitor, and control processes, investigate new rules, obtain other simulations and tests, and predict everything that may happen, such as failures and future defects. With this, you will have better control over the operation and maintenance of this equipment. For Akanmu et al. (2003), BIM is a modeling platform that contributes to the storage of equipment information, it is the starting point for the DG, and the CPS is a representation of the digital twin of the equipment, it is a prerequisite for the diffusion of the CPS, it has the one-to-one interaction. The CPS is the integration of the physical system as the digital twin through computational means; it has a one-to-many exchange. This feature is characterized by computational communication and the action of sensors. According to Jiang et al. (2014), BIM is considered a virtual model represented by the equipment's physical structure. It can mean something that does not exist or has not been molded; while the GD needs a virtual model of the physical equipment, it transfers data between the physical and virtual equipment in real-time. In the case of GPS, the virtual model is not necessary. It transfers data from the physical object to the computer system in realtime and has computers and integrated networks that can monitor and control the equipment in real-time. For Sacks et al. (2005), BIM encompasses workflows and technology for the digitally oriented construction of equipment, products, and processes. The GD uses data and intelligent monitoring that recognizes the flow of information in realtime and allows a closed-loop model of monitoring and control of the information. CPS makes it possible to digitally monitor the production chain in the process and analyze data. Creating common languages for industrial automation was necessary to facilitate the programming of systems and devices for automation to differentiate from the languages already used in the software. A common IEC data dictionary (IEC CDD) was created to establish a common language between systems and suppliers (supply chain). This dictionary is a common repository of concepts for all electrotechnical domains, based on the methodology and information model of the IEC 61360-4: 1998 series. Both electronic catalogs and engineering databases include not only component data, but also its own ontology. The main international standards for ontology in the field of industrial automation systems and integration are ISO 13584-511 and IEC 61360-4:1998. These standards provide a data exchange format for use in systems engineering and industrial automation. AutomationML (IEC 62714) describes production plants or plant components.

For the design of digital factories about measurement and automation control of industrial processes, the RAMI standard is based on the following standards: IEC 62832 of digital factory structure. This standard proposes a reference model for the representation of a digital factory that comprises an abstract description of all automation assets (machines, devices, and software) and structural and operational relationships. The bar provides a framework to build and maintain representations of production systems. It includes the elements, the relationships between those elements and the exchange of information between these elements. This standard seeks to reduce interoperability deficiencies for the exchange of information in production systems. IEC TR 62794 reference model for the representation of production facilities.

Collection, transmission, and analysis of data: IoT is a unique technology because it is related to different types of (hardware), such as sensors, actuators, RFID (Radio-frequency IDentification) tags, video cameras, lasers, and scanners. It is also related to information systems and software specifically developed to analyze the data collected. In addition, it is linked to data centralizers, which use simpler mathematical models, statistical analysis tools, and more sophisticated correlations. It also works with the most complex analysis algorithms, using AI concepts, which may contain different development guidelines or levels of complexity, such as artificial neural networks for the development of methods based on machine learning (ML-Machine learning). Figure 4 presents a representation of the different layers of technologies, hardware, and software, to provide better visualization of the interactions between the other elements that make up the concept of IoT. The systems and aspects of centralization and data analysis are also represented, reaching the concept of Digital Twins, that is, information outputs that enable actions and responses through the generation of a digital representation (or virtual model), of the physical elements., providing decision-making based on data and information.

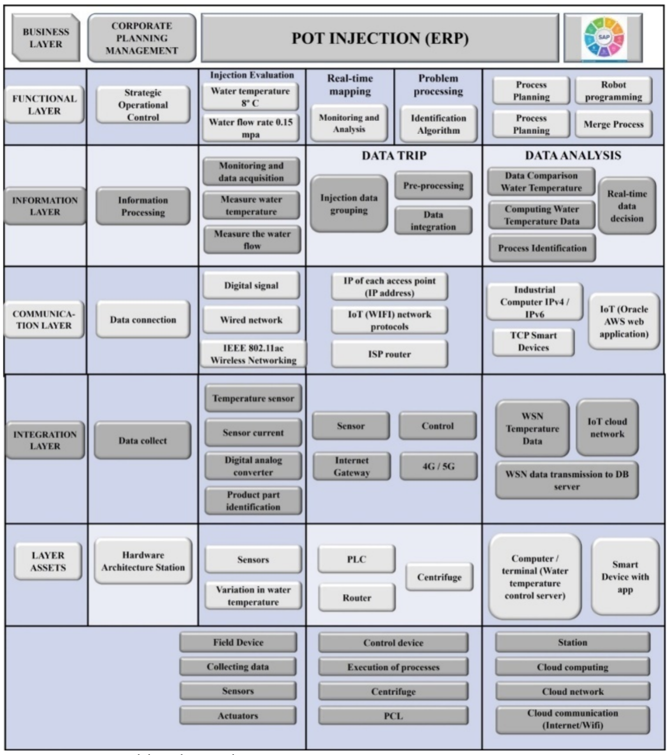


Source: prepared by the authors.

Figure 4. Structure of data collection, transmission, and analysis

Data analysis and AI tools are fundamental for applying RAMI 4.0 in industries. Real-time data analysis facilitates the entire process, as it can improve analysis by the technical team and conformity with requirements. It provides new capabilities in other studies to streamline the production process and support the most automated learning system. In the same way, like the definition of collection technologies and transmission protocol, the techniques or analysis tools are related to the specific objectives of interpreting these data for the generation of information to add more excellent value to the processes. The definition of applications will consider the third column of Figure 4, which presents examples of input technologies and centralization of collected data, and legacy systems, which are data analysis tools for specific applications to consume the generated information.

ISO/PAS 17506 describes the COLLADA scheme. COLLADA is a collaborative design activity that defines an XML-based schema to allow 3D authoring applications to exchange digital assets without information loss freely. Furthermore, it combines multiple software packages into extremely powerful toolchains. The purpose of ISO/PAS 1755506 is to provide a specification for the COLLADA schema in sufficient detail to allow software developers to create tools to process COLLADA (COOLAborative Design Activity) resources - Standard for exporting and importing files.



Source: prepared by the authors.

Figure 5. Layermap

PLCopen is an independent organization that provides efficiency in industrial automation based on user needs. PLCopen members focus on technical specifications around IEC 61131-3, creating specifications and implementations to reduce industrial engineering costs. IEC61131-3 is an industrially accepted programming standard. Many industrial software and hardware companies offer products based on this standard that is ultimately used in many different types of machines and other application fields. Topology is the branch of mathematics that studies topological spaces and is considered an extension of geometry. AutomationML (AML) core is CAEX top-level data, a neutral data format according to IEC 62424. It interconnects established data formats for engineering aspects related to topology, geometry, kinematics, behavior, and sequencing. Therefore, a basic feature of AML is an inherent distributed document architecture focusing on the above engineering aspects.

A supplementary OPC UA specification and a DIN SPEC 16592 specification have been published, which defines the mapping of AutomationML models to an OPC UA information model. Model-driven engineering of an I4.0 component can be performed from an AutomationML model, expressing the properties and capabilities of an I4.0 component. This way, an OPC UA server can be generated and allowed to act as an interface for an AAS (Asset Administration Shell) implementation for the I4.0 component. The data controllers must be integrated with the indicators in the control of temperature and flow of chilled water. The temperature variations of the water inlet in the circulation flow of the molds, in the water inlet in the mold, will be monitored. For injection molding, the chilled water pressure should be 0.1~0.2mpa, which can meet the water flow requirements in the injection process. The water flow in the pipe inside 1/2" is 20 liters. The ideal temperature for the pot injection process should be 8° C, with a variation of ± 2° C, to maintain the operation with perfect stability. Implementing a sensor to measure the water temperature every 30 seconds in real time is necessary, as sending this data to the controllers. A valve must also be implemented to measure the flow of water in real-time to capture data every 60 seconds and send the data to the controller. These mechanisms will be installed at the machine's water inlet to demonstrate a vision of automation. This way, they will be filtered and go up to SCADA (Supervisory Control and Data Acquisition) control and supervision monitoring. The electrical area must be used, specifically the IEC 61850 standard, which is responsible for simplifying and enhancing controls in power electricity systems, which aims to upload data to the PLC (Programmable Logic Controller) regulatory control system.

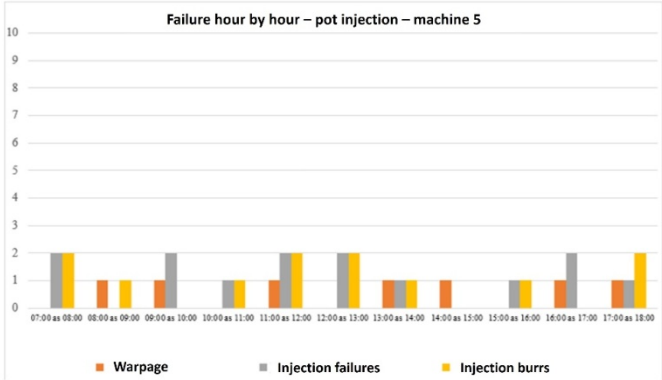
Results achieved with the implementation of rami 4.0: The RAMI 4.0 architecture brings a vast opportunity for improvements in the production process by implementing self-adjusting technologies. Thus, methods have emerged of incredible ways to stabilize the process and prevent the emergence of new unwanted failures. It brings spectacular competitiveness to the business, with the market of suppliers of industrialized products, and excellent productivity because it increases the financial return, improves the quality of life at work, and improves the quality and guarantee of the product. In addition to all this, it brings products beyond their expectations to customers and reduces the amount of waste generated by industries. The desired results with the implementation of RAMI 4.0 in the injection process will bring the company promising growth. With the quality of the products supplied, there are more opportunities for quality assurance for your current customers and the chance to win new customers for your high-quality products. Thus, the following results can be listed with the deployment of Rami 4.0. The implementation of sensors at the water inlet aimed to collect and send data to the controllers and make them available on the dashboard. There it will be viewed every 30 seconds by the technical team to keep real-time control of the water inlet temperature.The monitoring of temperature variations of the water inlet in the circulation flow of the molds, at the water inlet in mold, is maintaining the ideal temperature for the pot injection process, standardized and stabilized at 8° C, with a variation of ± 2° C within the perfect standard for the injection process. Installation of the valve to control water flow stabilized chilled water pressure of 0.1~0.2mpa, meeting the water flow requirements in the injection process. For this, data are collected every 60 seconds, sent to the controllers, made available on the dashboard, and viewed by the technical team.

Table 3. Data after the implementation of RAMI 4.0 in the Potes sector

Time	Warpage	Injection Failures	Injection Burrs	Total
07:00 às 08:00	0	2	2	4
08:00 às 09:00	1	0	1	2
09:00 às 10:00	1	2	0	3
10:00 às 11:00	0	1	1	2
11:00 às 12:00	1	2	2	5
12:00 às 13:00	0	2	2	4
13:00 às 14:00	1	1	1	3
14:00 às 15:00	1	0	0	1
15:00 às 16:00	0	1	1	2
16:00 às 17:00	1	2	0	3
17:00 às 18:00	1	1	2	4
Total	7	14	12	33

Source: data collected by the authors.

As shown in the data in table 3, the pot injection process was stable from 9:00 am to 3:00 pm. During this period, the entire injection process was compromised. There was a high rejection rate due to injection failure, injection burrs, and warping of the injected parts. After the implementation of RAMI 4.0, the result was very gradual. There was a total reduction of all variations in the pot injection process, a gradual increase in productivity, a reduction in the rates of rejects, and a reduction in machine downtime to adjust processes by the technical team. A reduction in unnecessary process adjustments was also found to contain process variations. It happened due to variations in the temperature of the water inside the mold during the cooling of the injection process.



Source: data collected by the authors.

Graph 2. Data after the implementation of RAMI 4.0 in the Pots sector

The reduction in rejection rates in the pot injection process leads to a 4.20% increase in productivity and a 4.20% reduction in the generation of non-conforming waste. It is considered an excellent environmental responsibility, aiming to reduce the amount of trash available for disposal. Considering this rejection elimination, previously rejected parts are now added to the approved production. Today the quantity is 4,032,00 parts approved annually per machine and will increase to 4,201,344 pieces per year per machine. It results in 169,344 more approved parts that will be available for sale. There wasa gain in productivitydue to the reduction of rejects, which is also a financial gain, as each rejected part becomes an approved part. The impact of this can be seen in Graph 2. There is stability at all times. After the RAMI 4.0 architecture and stabilization of the process, the scenario of tailings rates changes completely. It leaves a harmonic behavior, as shown in graph 2. It shows that an entire process monitored in real time instantly leads to an action and resolution of process failures, which changes the perception that losses can be resolved. All injection processes have a stabilization period. It is due to the start of the process and the return of some unscheduled stops. When we reduce this unscheduled downtime, we permanently reduce failure rates. Comparing the graph before and after the implementation of Rami 4.0, it is noted that there was a very significant gain in the production process.There was an improvement in productivity levels and a guarantee of stability in the quality of the parts.

CONCLUSION

This study showed a methodology to deal with nonconformities in the injection of ice cream pots from an empirical point of view, using the Rami 4.0 architecture as a reference. The application of the methodology was able to reduce a total of 3,162 daily failures to just 33. For this, it reduced the concentration of losses from 9 am to 4 pm, whose peak production of faults occurred between 11 am and 1 pm, with almost 2,000. The simulation performed was able to establish and control parameters by eliminating the causes of the problem. These empirical tests, therefore, attested to the efficiency and effectiveness of the Rami 4.0 architecture in dealing with these adversities of production processes.

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