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Implementation of Industrial Traceability Systems: A Case Study of a Luxury Metal Pieces Manufacturing Company

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Abstract: Technological advances have shown an accentuated growth trend, which is directly proportional to the quality of life in today's society. As a result, the business market is becoming increasingly competitive and customers are becoming more demanding, forcing companies to look for new tools and adopt new work methodologies to improve their flexibility, effectiveness and efficiency, ensuring a better response to market needs. In this context, the tools for tracking objects, totally or partially automatic, are considered essential technologies to all kinds of analysis and the treatment of business data, providing several benefits to companies, including waste reduction, identification of bottlenecks, cost reduction, improvement of product quality and the entire flow of business information. A case study of an industrial company specializing in machining, polishing and galvanoplasty of metallic alloys, small size pieces to be incorporated in luxury fashion accessories, is presented. Derived from the difficulties underlying the implementation of a traceability system supported by identification technologies and obtaining data in an automatic way, the focus of the study is based on the identification of a base model, with sequential steps, which allows any industrial company to adapt these types of technological tools and systems. Based on the pillars of knowledge acquired through a bibliographic review on the subject, as well as on the recognition of the whole production flow, this work makes use of an implementation model already developed, studied and tested, supported by a project viability analysis measuring the benefits obtained with the results found after the respective implementation. Production performance increased with the implementation of a traceability system, as the time worked throughout the flow decreased. Production performance prior to implementation was around 98.6%. Applying a Kaizen (continuous improvement) strategy and based on the times collected in the pilot test, this indicator rose by 0.5%, obtaining a production performance of 99.1%, corresponding to an annual increase of 99 pieces. The integration of a robust and simple traceability system supported by automatic identification and data capture (AIDC) technologies in this industrial environment allowed for automated data collection and processing. In addition to the financial and productive benefits, this Industry 4.0 implementation encompasses a huge medium- to long-term impact in functional and monitoring terms, providing enormous aid to the management of production flows.

Keywords: traceability; barcode; RFID; AIDC technologies; Kaizen; Industry 4.0; business technology development

Citation: Fortuna, G.; Gaspar, P.D. Implementation of Industrial Traceability Systems: A Case Study of a Luxury Metal Pieces Manufacturing Company. *Processes* **2022**, *10*, 2444. https://doi.org/10.3390/pr10112444

Academic Editors: Yan Wang, Zhigang Jiang and Wei Cai

Received: 18 October 2022
Accepted: 16 November 2022
Published: 18 November 2022

1. Introduction

The technological development observed in recent years has shown an accelerated growth trend, contributing to a significant improvement in the quality of life in today's society. The technologies known today are an integral part of the world of people and, consequently, of companies, which are considered to be an engine of evolution. Today, we live in a world highly dependent on telecommunication, whose aim is to obtain better and more modern means of communication, with greater quality and capacity, differentiating factors in the business world. In this sense, the global market has become more and more competitive, and investment in technological innovation represents success and maintenance for organizations [1,2].

In corporate industry, the greatest difficulty involves the constant increase in customer satisfaction, with constant productive costs or with a tendency to decrease. In this way, technology and innovation can become allies in this issue, as mentioned above; however, it is necessary that they are used in an intelligent and judicious manner. Over the last few years, several solutions have been made available to the various sectors, some of which can be applied almost immediately and others that require more rigorous feasibility studies. In this context, automatic identification systems have been gaining more emphasis in various applications, such as monitoring goods or managing the flow of products [3,4].

In terms of industrial traceability, new tools have been developed, including automated technological systems that greatly assist entities in their information flows, organization, and planning. In addition, these tools cooperate in terms of control and production, saving time. Innumerable other advantages have also been determined. However, it is important to consider that implementation of these systems presents difficulties, namely in the integration phase conducted by companies [1,4].

Traceability within an organization can be automatically or manually conducted. Normally, small companies manually carry out the management of objects, location of products, and entry and exit movements. In these cases, the probability of error is high, since it is associated with human factors. However, for some companies, and due to their size, the integration of automatic traceability systems is not justified, since evaluations of profits associated with implementation are difficult to measure. In the case of larger companies, it is essential to have real-time control, without error rates and obtaining automated data, and thus, saving time. Generally, these organizations are part of supply chains characterized by large quantities of raw materials, products in the manufacturing or assembly phase and the finished product [5,6].

The integration of traceability systems presents difficulties that frequently limit the growth of the company itself, where the main problem is high complexity. Due to this, many companies wrongly adopt these systems, but the purpose of traceability tools is precisely the opposite [7].

From this perspective, and highlighting the industrial manufacturing sector, traceability systems are essential for the proper functioning of an organization. However, before implementing this technology, it is necessary to investigate the existing market, i.e., which tools are available to assist in the traceability and registration of information on the company's existing flows, as well as to carry out a cost/benefit analysis of the identified problems.

The main objective of this study is to analyse studies that have been focused on these technologies, which support better information traceability of the existing operational flows inside an industrial company. In this investigation, it is intended to find a simple and robust way of integrating a traceability system that automatically collects and processes data, including methods of feasibility analysis and implementation that may be useful for the problem in question.

This article is organized into five sections. In Section 1, the introduction is presented and the subject under study is outlined, as well as the respective framework, the main objectives of the study, the research methodology used and the organization of the document. Section 2 presents the current state of the subject, where a bibliographic review is carried out regarding traceability systems, existing support technologies for automatic identification and data capture (AIDC), i.e., the tools that support the traceability of objects, information about the options currently most used at industrial level and an implementation model. This chapter also provides a literature analysis conducted in terms of the viability of investments in the industry. In Section 3, the company of the case study is presented and characterized, as well as a description of the article that served as analysis to the study and its respective production flow. Section 4 identifies the current technological status of the company, in terms of traceability, and describes the implementation model used. Furthermore, a quantitative and qualitative analysis of the results obtained with the implementation of a traceability system supported by AIDC technologies is performed. Section 5 presents the conclusions drawn from the study carried out and the proposals for future work.

2. Literature Review

This section presents a theoretical review of the concepts related to the study under analysis, traceability, providing various notions and methodologies adopted by organizations. It will also characterize the main tools used in the industrial sector that help with the tracking of objects. It will also outline a generalized model for enterprise implementations of a traceability system supported on AIDC technologies, elaborated by Ngai et al. [8]. Finally, there will be a sub-point related to the analysis of the viability of this type of project, analysing in a quantitative and qualitative way the possible gains from the investment associated with the implementation.

In this work, deductive methods are applied and supported by exploratory research to focus on a quantitative and qualitative approach, offering a mixed perspective. The objective of the literature review is to identify traceability tools currently available on the market, and which best adapt to the needs of industrial companies, and to identify the implementation models and feasibility analysis of these types of projects, and to then draw conclusions. In this way, through generalist theories, particular conclusions are deduced, i.e., the deductive method [9,10]. As for the type of research used, already existing theories were used to serve as a basis for elaboration. Thus, this research is categorized as exploratory [9]. As for the study approach, since the purpose of the study is to explore traceability systems, from those available in the market to their design and implementation in an industrial environment of luxury metal articles manufacturing, the mixed approach was determined to fit best. This is justified because the formulation of the implementation proposal is supported by quantitative and qualitative factors, where the former focuses on metrics to obtain conclusions and the latter is built through the interaction between the researcher and the study phenomenon [10].

This bibliographic review was carried out using several scientific works obtained through using the search engines Science Direct, Web of Science, Research Gate, documents published by entities directly linked to traceability systems, books available online and institutional websites.

2.1. Traceability

In the context of this study, the word traceability is defined as the ability to follow an object from its beginning, as a raw material, to its conclusion, when it becomes unusable. This action consists of the identification of a certain product in order to assist in the management, quality control and detection of possible anomalies in the processes inherent to its conception [11]. The definition of traceability presents two different approaches [12]:

- Tracking: The ability to locate or follow the path of a given object downstream, i.e., through subsequent observations. It is therefore defined as the ability to follow a product from the raw material stage to the point of consumption;
- Tracing: The ability to identify the origin and characteristics or history of a certain upstream object. Therefore, it is characterised by the ability to verify the past state of a product through its references and historical records.

Figure 1 illustrates the supply chain with the orientations of the information flows of the aforementioned concepts:

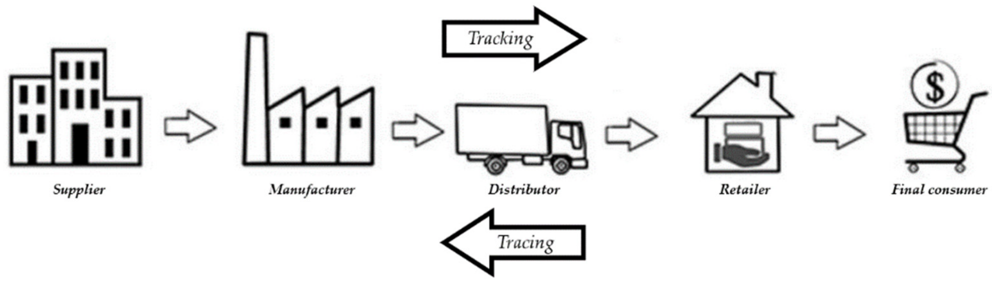

Figure 1. Representation of the tracking and tracing approach (GS1, 2017).

In this context, there are two distinct types of traceability applicability: the internal level and the supply chain level. The first applies only to activities in the company's own domain, where there is no need to relate external information on the product to the other members of the supply chain. The second follows the life cycle of the article, where there is the need to share information and resources among the various stages of the product in the supply chain [12,13].

2.1.1. Supply Chain

A supply chain is a network composed of different participants in which both either directly and indirectly contribute to the accomplishment of the demands from the final client. This concept is based on value formation along the chain, which is generated through the interaction between individual organizations cooperating with each other to maximize their competitiveness and profit, enhancing the profitability of the respective supply chain, as well as the attaining the satisfaction of the final customer [14,15]. In this way, the strategies adopted by companies directly impact the performance and dynamism of the supply chain, specifically on the following factors [15]:

- Inventory: Designates all raw and subsidiary materials in stock, the products in the production units and finished product in the warehouse. The changes around stock management policies may not only affect the efficiency, but also the responsiveness of a supply chain;
- Facilities: In this context, these are the locations in which the inventory is stored (warehouse), manufactured or assembled (production);
- Transport: Defines the movement of articles from a certain location to another in the respective chain. For this purpose, there are several services available in the market, and each company is responsible for acquiring them, usually according to its needs;
- Information systems: Essential property for the proper functioning of a supply chain, responsible for communication between the various stages in which its performance is directly correlated with this factor, and the others are conditioned by it. A supply chain with a complete and precise flow of information enables greater responsiveness and efficiency, and traceability is a key element for its success.

Within the scope of industrial traceability systems, the most important elements are inventory and information systems, since this type of system is mainly designated by the combination of these two areas of work. For any industrial manager, information is potentially the most important driver of success, insofar as it assists his decision-making in terms of market demand, products in stock and monitoring of factory production and the respective customer demands. An essential contribution is made here by traceability systems, since they facilitate the collection of this type of information [1,15].

2.1.2. The Importance of Traceability

Traceability comes from the need to respond to market demand with efficiency and to obtain greater profits for the companies. Generally, its purpose is to carry out factory control of a certain article, register the various stages included in its production cycle, as well as to guarantee better quality, improve visibility in the supply chain and, consequently, increase safety, as it brings with it a reduction in the rate of disappearance, extraversion and loss of products [1,2]. According to the Global Traceability Standard (GS1) [12], in order to comply with traceability procedures, the respective systems must include features that make it possible to identify the product, its historical data and the respective interconnection between these factors, as follows:

- Identification of the origin: Information regarding the source of raw materials, which are used in the production processes;
- Destination identification: Information relating to product tracking (records location dates);
- Data relating to the handling of product processing: Knowledge of production operations;
- Control information: Information about control results carried out during production.

Through this collection of information, it is possible to identify the entire route of a determined object in a supply chain [12].

Several advantages are associated with the use of traceability systems, but there are also challenges to be overcome when implementing this type of application [5]. A high degree of sophistication in a traceability system translates into a loss of productivity, since there may be wasted time associated with aspects that do not increase value for the company, as well as the tendency for the company to adapt to the system itself [7]. The initial investment and resistance to change are factors that also condition the implementation of a traceability system. Regarding the first, currently, the vast majority of traceability systems are supported by AIDC technologies, which requires investment in hardware and the training of employees. As for resistance to change, in any situation, changing the mentalities of workers, and sometimes of top management, is a huge business challenge. In addition to the challenges addressed, one can also list the complexity of compatibility of a system of this type with others already existing in the organization [16].

A quality traceability system requires the use of automatic identification technologies. In the industrial context, Automatic Identification and Data Capture (AIDC) technologies play an especially important role in terms of traceability. Over time, these have shown technological growth capable of making traceability operations automatic, thus reducing the costs associated with obtaining data [5]. Currently there are several support technologies available, and the choice of which one to adopt should respond to the needs of the amount of information required for its implementation [7].

2.2. Technologies for Automatic Identification and Data Capture

The acronym AIDC brings together all the technologies that enable the identification of objects and people through automatic data capture, i.e., the direct input of data into a microprocessor-controlled device, where many of these tools do not require any human involvement [17,18]. As mentioned above, the alternative to automatic data collection is manual data collection. For this, it is normally necessary to have a worker register the information on paper and, later, to enter it into a computer; e.g., by means of a keyboard. This situation has several inconveniences not only in terms of the data collection operation, but also in terms of data entry, such as [5,17]:

- The average error rate when typing on a keyboard is one error per three hundred characters, or 0.33%;
- Manual methods are intrinsically more time-consuming than automated methods. However, when manual practices are used, there is a time lag between the activities taking place and their introduction in the respective software, i.e., the information is not available in real time;
- Labour costs are associated with the time spent by workers on this type of action.

These drawbacks become practically non-existent when operating supported by AIDC tools [5]. According to Groover [17], practically all automatic identification technologies aggregate three main components: data encoder, reader and data decoder. The first is responsible for creating codes. A code is designated by a set of symbols or signs that normally represent alphanumeric characters. When a codification is carried out, the characters are translated into a code, readable by the respective complementary machines of the traceability system, and is in the form of a label attached to the items to be traced. The reader is the device used for reading the coded data. Finally, the data decoder is the component that transforms the data read by the reader into digital data, so that the information contained in the code returns to its initial phase; i.e., it is presented in alphanumeric characters.

The AIDC technologies most frequently used in production and respective distribution are the barcode and Radio Frequency Identification (RFID). At the industrial level, their most common operational applications are in goods receipt and dispatch, finished product storage, work in process (WIP), assembly and quality control, among others [18]. In several applications of these technologies, it is necessary to have operatives in the data collection process, usually to operate the identification equipment. Therefore, these techniques that require human intervention are called semi-automatic or partially automatic, rather than fully automatic; i.e., when the participation of employees in the process is not necessary [5].

2.2.1. Barcode

Barcode technology, despite its five decades of existence, remains a promising technology of high universal use [19]. It is defined as a legible electronic label that accompanies the respective products, providing information on origin, destination, type of product and associated documents, such as invoices or bills of lading, among other information [7,20].

The main hardware components of a barcode system are a barcode reader, printers and their printing labels [5]. Regarding software, this is usually directly linked to the company's Enterprise Resource Planning (ERP), where it is responsible for storing and providing data for further analysis on the collected data; i.e., object movements, consumption, waste and locations, among others [20].

This technology consists of the reading carried out by optical readers, through the emission of laser beams to the respective codes. When they are used on a barcode, they are absorbed by the black bars or reflected by the white spaces, where the sequence made up of bars, some narrower and others wider, represents the information contained in the code. This can be read by means of the rebound effect, or reflection, of the laser rays to the reader, which contains a photocell capable of converting light into electric current, obtaining an analogue signal that gives rise to a binary code (which uses the combination of digits "0" and "1" for the representation and transmission of information) [5].

There are different barcode layouts. The main differences are the type of characters (i.e., numbers or alphanumeric), the amount of data, the length of the bars and representations of the information, i.e., in one-dimensional (linear) or two-dimensional (2D) structure. The choice of the type of code to be used is directly related to the need for its application [20]. Table 1 lists the main characteristics of the most commonly used code typologies currently in use [21,22].

Table 1. Differences between the main barcode layouts.

European Article Number (EAN)	Stock Keeping Unit (SKU)
Set of coding standards enabling efficient management of global and multi-sector value chains	Variable length, no external standards defined, varying according to company needs
Universal code that accompanies the product throughout the supply chain	For internal (organization) use only; it may differ from company to company.
Made up of information that identifies manufacturers, companies, origin of production, among others	Reflects information about the product

Constant technological evolution and the growing need for companies to ensure that all data is included in the respective information flow, both externally (supply chain) and internally (organization), in order to operate efficiently and consequently gain competitive advantage in the market presents barriers in terms of the use of barcodes, since the storage of information can become quite limited [1,23]. Another barrier to the application of this technology is associated with when barcode labels become damaged, thus becoming illegible. Humidity, dust and high temperatures are generally characteristics of an industrial environment, which negatively affect the readability of the label. Other disadvantages that can affect the profitability of the operation include the fact that there must be no obstacle between the reader and the barcode, which can lead to an inability to perform multiple readings; i.e., the reading must be conducted label by label [5,7].

Despite its limitations, barcode technology is easy to apply, demonstrated by their persistent and long years of use worldwide, as well as low acquisition and integration costs. These factors may be decisive during decision-making about which AIDC support technology to implement [4,7].

2.2.2. Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a technology that enables communication, identification and collection of data without any physical contact, but through radio frequency waves. In the context of the study, this technology can perform important functions with high operational profitability and flexibility, meaning that it is able to identify and collect location data and information in real time without any human intervention [5,14].

In the same way as the technology discussed above, RFID can be used in various processes of the supply chain, presenting different impacts at each stage. According to Espinal et al. [7], the applications with more values within the supply circuit are as follows:

- Simplification of the monitoring of the industrial production flow and stock management, as this technology contributes to a better localisation of products, real-time updates and automation of operations, thus increasing confidence in decision-making related to supplies;
- In the logistics process, RFID can allow an increase in efficiency, due to speeding up the delivery of products or raw materials, automating goods receipt and dispatch operations and, in this way, it is possible to eliminate operations that do not generate value for the organisation, thus gaining time for employees to focus on activities that add relevance to the business;
- Regarding the end customer, this technology can provide visibility and product information at any point in the supply chain in an automatic and assertive manner, thus improving the reliability of the information flow.

An RFID system is mainly composed of one or more readers and tags. The first readers are responsible for reading the tags within their reading range. Both are information sending and receiving systems, and are categorised as transceivers. Table 2 lists the components of this technology, as well as brief descriptions [5,7].

The reader, besides its main function of detecting RFID tags and communicating with them in its interrogation zone, has a region/diameter where communication can be established between the reader and the tag. This is also responsible for the activation, power supply (if necessary) and the structuring of the communication sequence with the tag to establish the data transfer operation. The RFID tag is the simplest component of the system and can come in various shapes and dimensions. Its purpose is to identify the object on which it is placed, through its unique identification number (unique ID). It has in its constitution an integrated circuit (IC) and an antenna, which are physically connected to its chip. The IC is the tag's essential constituent, as it is responsible for transmitting information when it is activated. The reader is the most complex component, as it is responsible not only for reading the information transmitted by the tag(s), but also for communicating with external agents; i.e., for transmitting the received data to the respective servers [5].

Table 2. RFID components (adapted from [7]).

Readers	They detect products with RFID tags; They are devices that emit and receive radio frequency waves.	**Antennas**	They receive and send signals between the tag and the reader; Their range is directly dependent on the label used.
Tags	They identify the products that they accompany.	**Label Printer**	Allows printing of the information, in code form, on the label.
Software	Encodes and decodes data (information) on RFID tags; Translates the data captured by the reader and subsequently uses it to feed information systems that have planning, business process control and logistics functionality; i.e., communicate with an ERP.		

As previously mentioned, a system based on communication by radiofrequency waves has in its fundamental properties the respective frequency of operation. Regarding RFID technology, this fact is considered a barrier to implementation and operation, as there is no normative reference for the use of a single, standardised worldwide frequency [5,24]. The world's radio spectrum is divided into three geographical zones, as shown in Figure 2, each with specific terms and considerations for the use of radio waves. This division was carried out by the International Telecommunication Union Radiocommunication Sector (ITU-R), a departmental division within the International Telecommunication Union, which is responsible for radio communications worldwide. Region 1 comprises Europe, Africa, North Asia (former Soviet Union) and the Middle East. Region 2 comprises North and South America and, finally, region 3 consists of South Asia, Australia, and Oceania. The main reason for the use of different frequencies in the three regions stems from the existence of a wide variety of devices that also communicate through radio waves; e.g., televisions and mobile phones, among other applications [5].

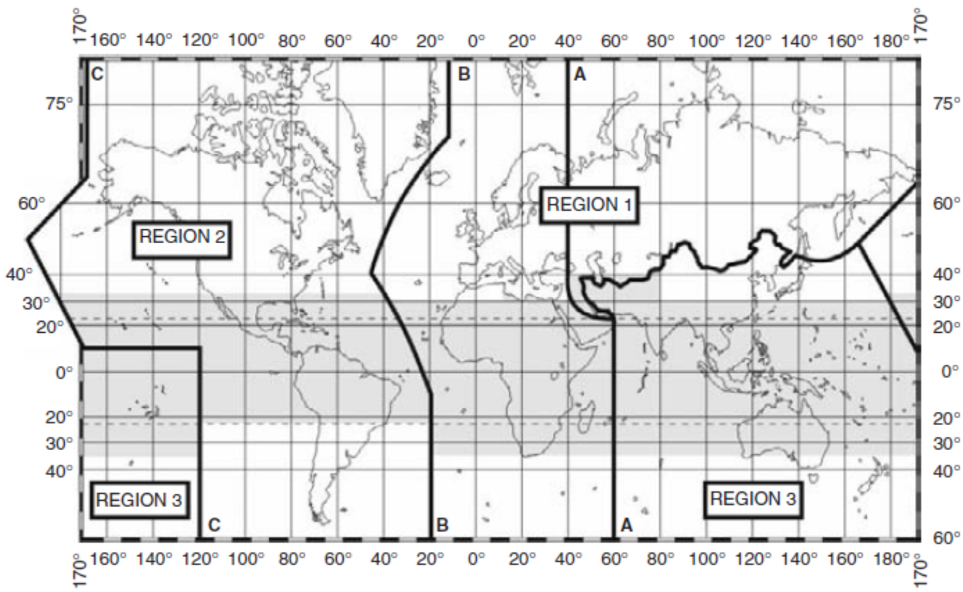

Figure 2. Division of the world into three geographical zones by ITU-R (Adapted from [5]).

The biggest barriers to this technology are the lack of legislation for its application and the fact that different operating frequencies are used in various parts of the world, which makes interconnection and compatibility between equipment very difficult [5,7].

The estimated cost for the implementation or design of any project is an important variable for any company when decision-making. RFID entails high costs compared with barcode technology. At the industrial level, the acquisition price of all the necessary hardware for the implementation of a tracking system based on RFID can reach several thousand euros. An economic cost/benefit balance is needed to assess the real applicability of the technology [7]. In addition to the limitations described, Finkenzeller [5] also points to the following features that could be developed and evolved:

- Electromagnetic interference: Automatic identification and data collection through RFID, for its success, also depends on the type of object in which the tag is inserted. Objects with metallic or liquid content absorb the radiofrequency energy emitted by the reader, which may cause shorter transmission ranges or even the non-identification of the product;
- Sustainability: Not recycling and reusing the labels may be a limitation to be considered. If they are integrated in the object to be identified, it may not be possible to use them again. The non-reuse of electronic waste is a serious risk to the environment and, consequently, to human health.

2.2.3. Comparison between Barcode and RFID Technology

To conclude the description of the most used technologies at the industrial level, this section offers a direct comparison of some of the most impactful characteristics for implementation of information traceability in a supply chain or industrial company.

RFID technology, regardless of the monetary costs involved, is the most attractive technology to adopt due to its extensive traceability capabilities in a fully automatic manner. However, according to the aforementioned, it is essential to carry out a review of existing traceability needs, as well as a cost/benefit ratio of the various hypotheses available. In this way, there is no risk of unconscious, hasty or inappropriate action, because although the barcode does not offer so many advantages when compared to RFID, it may be sufficient in view of the requirements of the purpose for which it is intended [7,20]. Table 3 provides a brief comparative summary of the main technologies supporting traceability systems, barcode and RFID, based on what has been previously described.

Table 3. Comparison between barcode and RFID (adapted from [7]).

Barcode	RFID
Definition	
Technology capable of capturing data and identifying products by reading barcodes.	Technology that uses radio waves to automatically identify objects.
Applications and impacts on the supply chain	
Inventory management; Identification of products in logistics processes; Transport management, enabling the identification and registration of mobilized loads.	Automatic product traceability and visibility; Inventory management, with real-time updates; Administration and control of transport activities without operational costs; Increased information flow in supply chains.
Advantages	
Technology with years of operation, providing greater confidence in the adoption decision; Lower implementation costs compared to RFID.	Greater information storage capacity compared to barcodes; The information contained in the labels can be varied and is continuously reusable; Capacity to identify several products simultaneously; Accuracy of the data collected, as well as its availability in real time.

Table 3. *Cont.*

Barcode	RFID
Disadvantages	
Limited identification characters, which restricts the amount of information that can be traced; Labels can easily become illegible; In most applications, the technology requires an operator to perform the scanning "picks", thus barcoding is not a fully automated tool (without human intervention).	High cost of implementation; Lack of standardization and legislation at a global level; Requires high levels of security from the user, since this type of technology is totally programmable by its software. For this reason, it becomes an "inviting" target for computer attacks that are prone to invasion of privacy and changes in the data contained in the tag.

2.2.4. Motivational Factors for Implementing Traceability Systems

The implementation of traceability systems aided by AIDC technologies are motivated by a set of factors oriented by perspectives of technology push (TP) and technology pull (NP). The first is directly related to top management, which is activated when there is a possibility of accessing a new technology in the market, bringing with it a priori positive features to the business, but are of an optional nature. The second is connected to the need to operationalize, i.e., a need to act in the search for and design of technological solutions; hence, the fact that this term is also called need pull [1,16]. Ngai et al. [16] define compatibility, complexity and extensibility as motivational drivers TP, and competition and attracting customers as the main reasons for implementing this type of system in NP terms.

The use of Lean practices is one factor driving the implementation of traceability systems supported by AIDC technologies. The Lean production work methodology aims to reduce or eliminate waste, generating value for the end customer [25]. Ohno [26] identified seven types of waste, these being the largest losses associated with the industry. The first waste identified was the transportation of raw materials and products in poorly structured layouts that increase production time and that are not even value producers for the product. This requires a layout analysis of the industrial field, from a structural perspective, in order to reduce the number of transport flows. The second waste identified was inventory, which states that keeping stocks increases costs and invested capital. Having less inventory will make it easier to detect and correct quality defects and prevent uselessness; it will also mean more space and better organization. Movement was associated with the displacement of workers that is useless and unnecessary for the process, e.g., looking for tools or moving materials, which was also correlated to transport waste. Waiting was another waste identified and defines the useless time periods associated with different phases of the production process: information, material, machines, and others. Overproduction, another waste, means producing excessive quantities of finished product. Lean advocates that production should flow only when there is customer demand. A sixth waste, overprocessing, was associated with waste through extra production operations, operator, or machine error. Lastly, defects or reworking were forms of waste associated with defects in products resulting from careless production, which, when detected, force a review of the work conducted. With the evolution of Lean thinking and the knowledge of production systems, there is another form of waste. The wasteful use of human potential, which is associated with the company's inability to identify human capital with superior skills, which could be producers of value for the company, but end up being allocated to basic tasks; the eighth waste [27].

According to Womack et al. [28], the Lean philosophy holds five principles: product value; product value stream; continuous value stream; pull production; and achievement of perfection. The value identified in the first principle is defined by the customer and can be defined through the characteristics of the product or service that attract the consumer, and has the power to define even the design objectives of the product [29]. The value stream of each product should consider the three critical management tasks, which naturally create value for the customer [29]:

- Problem solving: A concept that applies from design, through engineering, to the manufacturing and operational stages;
- Information management: Receiving orders through successful scheduling of information until the delivery of the product;
- Physical transformation: Raw materials that allow a finalisation of the product, in the hands of the customer.

Continuous value flow requires speed and continuity during the process. Regarding the pull production principle, it is associated with a manufacturing philosophy based on the definition of goals synchronised with customer demand to avoid inventory. In an ideal scenario, production is only activated by order. The last principle, the conquest of perfection, makes it necessary to repeat the other four primary principles defined in a continuous way [29].

In this context, the time spent on human working time and the energy required for manual data processing are seen as resources incorrectly used by the company, since there are techniques that allow this operation to be conducted in a totally or partially automated way. This practice is in line with the Lean philosophy, identifying and reducing waste when it cannot be eliminated [6,25].

2.2.5. Implementation of Traceability Systems Based on AIDC Technologies

The process of implementing AIDC tools is highly complex, not only because of the technical features, but also due to prior knowledge of the potentialities and weaknesses that may emerge in the organisation. It is a path that may become lengthy, lasting years, but it is necessary to prevent any less favourable situations that may arise [16]. Figure 3 illustrates an implementation model designed by Ngai et al. [8], with proven application in the textile industry, which involves seven main steps.

The first stage is based on identifying gaps and problems, defining an objective and the scope of the need for a new project. In this context, investigating the feasibility of using a traceability system, supported by AIDC technologies, and ensuring top management support are the most important tasks in this planning phase. It is also important to complement this with a cost/benefit analysis. Whenever possible, for any large investment project, the rate of effort required to achieve various ends should be justified, looking at the return on investment (ROI). In this way, it can be verified if the possible implementations are aligned with the company's business plan [8,30].

Once the project has been approved, an implementation team should be formed to rigorously monitor the project; the second stage. At this stage, it is fundamental to be aware that the implementation is conducted and motivated by the results that it will bring, not prejudicing the change of daily routines [8]. Tseng et al. [31] defined a team, as described in Table 4, for the implementation of this type of system.

The third stage, current situation analysis, consists of the evaluation and analysis of the organization's current state. The success of a traceability system integration depends on an understanding of the current processes and information of the business and company [8]. Theoretically, the third stage comprises the following activities [8]:

- Research: Gathering relevant information and data on business process equipment, operations, activities, documents and models within the scope of their implementation;
- Information analysis: Based on the data collected, and after the gaps have been identified, the main points and bottlenecks should be determined, where the team will define where they want to spend more resources and control, ensuring that the changes that are envisaged to bridge the identified gaps.

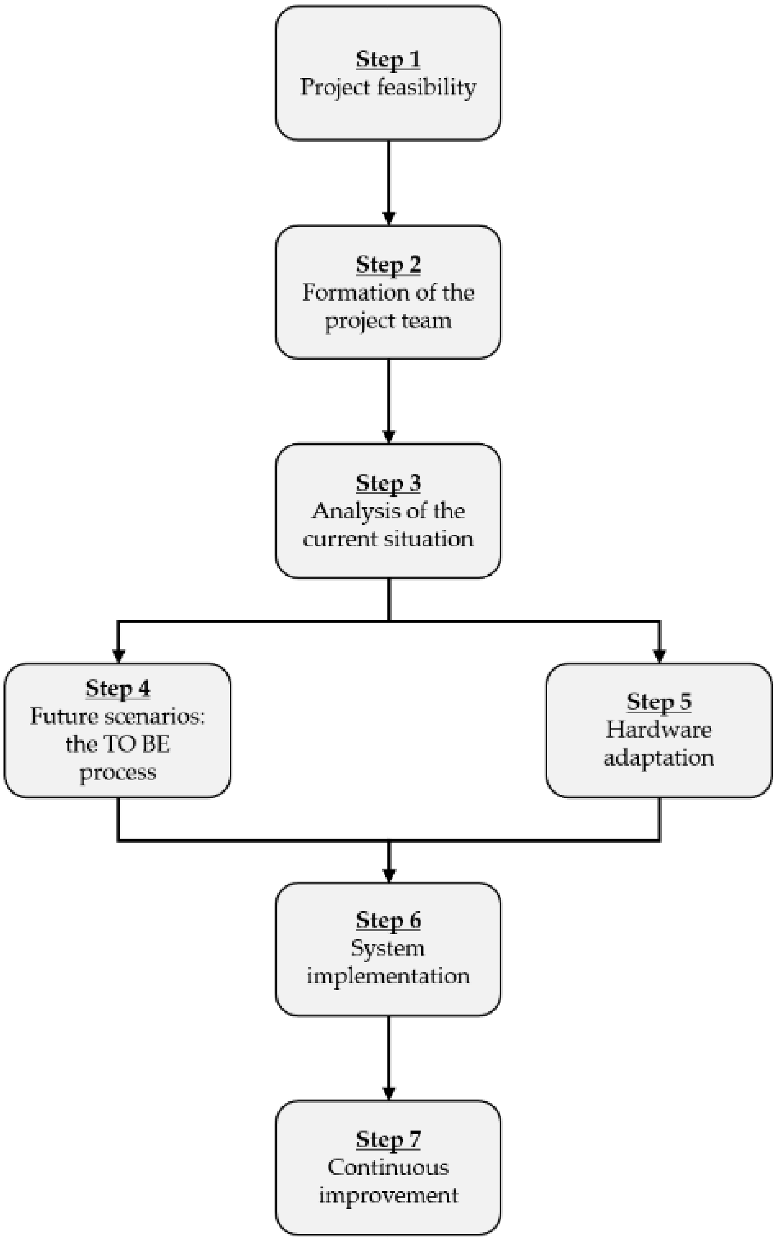

Figure 3. Model framework for implementing traceability systems based on AIDC technologies (adapted from [8]).

Table 4. Traceability systems implementation team (adapted from [31]).

Members	Associated Tasks
Project manager	Plans and controls the schedule; Determines the resources required; Communicates with the different parties, taking decisions when necessary.
Analyst	Gathers and analyses information on the requirements of the different parties; If necessary, redesigns processes based on the results of the investigation carried out.
AIDC specialist	Studies the needs exposed and recommends the most suitable traceability solutions in terms of hardware and software.
System designer	Responsible for the software development, integrating it into the various existing flows in the company.
Operations department	Provides information on business procedures and operations; Assists communication and integration of the new operating mode.

The fourth stage, the TO-BE process, is the implementation stage where reengineering of existing business processes is conducted. In addition to the technical developments, it is necessary to understand whether the planned changes are compatible with the company's ideals. This will allow the company to adopt this new system to make changes safely, in a planned and structured way [8,32].

During the fifth stage, hardware and software adaptation is composed of three phases. First, the traceability systems implementation analyst studies the infrastructure where the new technology will be adopted, determining characteristics, limitations of the environment and the needs exposed, to find the best AIDC solution for the success of the project. Second, the drawing up of a detailed plan for the integration of the software and hardware, as well as creating a budget for their acquisition and installation. Finally, it is advisable to carry out a small-scale test to ensure that the proposed solution is ready to be deployed according to the plan made in stage four [8,17].

The sixth stage, system implementation, is of extreme importance and is a key responsibility for the success of the project. The team designed to carry out the project will have to ensure that everything is put in place according to plan, so that the desired functionalities of the project are obtained. Naturally, some deviations from what was planned may arise during implementation and will have to be reviewed in detail. Some crucial points of this stage are as follows [8,17]:

- Installation: After placing all physical equipment, it is recommended to test it immediately, since positions, angles or modes of operation may influence information reading rates. In parallel, the information systems should check if the data passage is operating correctly, as intended;
- Formation: Employees usually have no knowledge or are unfamiliar with this type of technology. Therefore, the project team should first explain to them the benefits and the importance of the need for change, followed by training in the use of the equipment. Nevertheless, it is important to safeguard against resistance to change as it can be a serious problem; employees need to adapt and spend time and effort in order to learn new ways of working;
- Technical and operational support: Whenever necessary, a support team shall intervene for the system users to solve technical problems, such as bugs and defects in the system, and also help them adapt to the use of the new functionalities.

The seventh and last stage, continuous improvement, has an infinite duration because improvement must be a continuous process and never negligible. After implementing the new traceability system, it is important to review the implemented metrics and collect feedback from users, to determine technical and operational problems and solve them by adjusting, if necessary, the predetermined processes. After the new working methodology is strengthened, this task should be proactively conducted, preventing any problems with the new business processes that may arise after implementation, as well as always working towards optimizing operations [8,32].

2.3. Feasibility Analysis of Investments in Industry

With any implementation there is, generally, a monetary and time effort correlated investment. This is understood as the act of applying resources, normally scarce, with the expectation of achieving future benefits that compensate the application made [33]. Soares et al. [34] defined the following five variables for project analysis/evaluation:

- Financial evaluation: Verifies if the results that are expected from the investment of capital in the project in question are interesting for the respective entity and its investors;
- Technical evaluation: Evaluates the process engineering and design of the installations and equipment;
- Commercial evaluation: Essentially based on market studies and marketing;
- Economic and social evaluation: Analysis carried out focusing on the effects that the project presents to society, with economic effects for a certain region or country;

- Environmental assessment: Level of impact that the change will bring to the physical environment, which may be positive or negative.

In accordance with the implementation proposal in question, traceability systems based on AIDC technologies, the evaluations with the greatest weight will be financial and technical.

2.3.1. Financial Evaluation

The feasibility study, in financial terms, of such an implementation is directly related to the operating methods. At this point, it is important to compare the current procedural practices, as well as the times associated with them, with the results that are obtained with the adoption of the new practices. In this way, it is verified not only if there is a saving in the duration of operations, but also an increase in productivity with the same need for resources; factors that generate wealth and value for any company [15]. In this sense, production indicators or process performance measures can help in terms of decisions made regarding the implementation of projects that directly influence the operation. Some common metrics identified by Chase et al. [15] are listed below:

- Productivity: Ratio between what the company produces, output, and what it consumes, input, as expressed by Equation (1). Therefore, an increase in productivity should contemplate cost reduction or production increase measures, while maintaining the quality levels required by customers.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \tag{1}$$

- Efficiency: Ratio between the output generated with the new implementation and the standard output; i.e., before the change. This is expressed by the following Equation (2).

$$\text{Efficiency} = \frac{\text{Output after implementation}}{\text{Standard Output}} \tag{2}$$

- Production performance: Evaluates the speed of production, i.e., the ratio between the time dedicated only to production and the total time worked, which is the sum of all activity times, and may include, in addition to the duration of production, downtime due to maintenance, failures, information recording and transport movements, among others. This is calculated using the following Equation (3).

$$\text{Productive performance} = \frac{\text{Productive time}}{\text{Time worked}} \times 100 \tag{3}$$

- Profitability: Expresses the return generated by the increase in productivity that is profitable, in relation to the projected investment. Its calculation is made based on the net profit obtained during a certain period, e.g., monthly, over the initial investment. Equations (4) and (5) show the formulas for calculating net profit and profitability:

$$\text{Net profit} = \text{Receipts} - \text{Variable costs} - \text{Fixed costs} \tag{4}$$

$$\text{Profitability} = \frac{\text{Net profit}}{\text{Amount invested}} \times 100 \tag{5}$$

It is important to note that the higher the values obtained from the equations described above, the more beneficial the implementation project designed for the respective company will be [15].

2.3.2. Technical Evaluation

In technical terms, the adoption of a traceability system based on AIDC technologies may require changes to processes, factory layouts and systems already in place. From this perspective, it will be important to evaluate if the acquisition of new tools, equipment and software are compatible with the company, thus assessing its implementation viability or unfeasibility [8,16]. Due to the flexibility and ease of tracking all the productive information, allowed by the use of AIDC systems, it is possible to extract numerous points of improvement [35]:

- Identification of bottlenecks: By recording temporal information (time and date) of all movements, it is possible to discover the exact point along the entire production flow that is causing blockages, thus helping to solve them;
- Long waiting times: Following the same registration basis as in the previous point, the system is able to identify times wasted due to delays or failures, i.e., blocked flow due to breakdowns, layout problems or delays in deliveries from suppliers;
- Transportation: Transportation within the factory floor cannot be eliminated, but it can be reduced to the bare minimum. The information provided by the AIDC system can help the company make decisions regarding the acquisition of specialized manufacturing cells at the end of each production unit, or the hiring of operators and the acquisition of flexible equipment;
- Inventory levels: AIDC systems, as already mentioned, provide tools for easy stock accounting. Through this, it is possible to analyse whether inventory levels are reasonable, high or low compared to the current requirements.

It can be concluded from the above that, in a short period of time, the acquisition of an AIDC system will enable several decisions to be made on changes at the level of production and operation, in order to reduce waste [25,35].

Considering the objective of this article, through this literature review, it was possible to understand traceability and identify the main support tools existing in the market. In this context, it was important to identify the motivational factors for adopting traceability systems based on AIDC technologies, as well as a model proposal that sets out, in a procedural manner, the path to follow; i.e., a basis of support for future implementations. Finally, important aspects of feasibility analysis to be considered when implementing these projects were described.

However, this type of study should be conducted on an individual basis, since it takes into consideration the characteristics of the company, its operations, human resources and operational and industrial management, among others.

3. Case Study

The application of research to business practice is one of the mechanisms of theoretical development. Therefore, a Portuguese industrial company, which was in the process of implementing a traceability system supported by an AIDC technology, was used in order to ascertain the results obtained within the scope of the adopted integration methodology, as well as the feasibility and benefits that it offers to the entity. The industrial company specializes in machining, polishing and galvanoplasty of metal alloys, small parts to be incorporated into luxury fashion accessories. It was founded in 2013, with only 50 employees, and was exclusively dedicated to polishing. Today, the company is in constant evolution and expansion, offering jobs to around 350 employees, which significantly contributes to the development of the region where it is located.

Due to the complexity of the operation in the factory, the focus of the analysis was on a single feature. The feature encompasses the company's organization and all the operations of its production flow, from the arrival of raw material to shipping to the customer. Internally, the piece is referred to, for confidentiality reasons, as the "ring", where the product is to be placed into a fashion accessory, in this case, a wallet. This feature is designated as the "ring" that serves as a connecting link of the wallet to the respective handles.

Production Flow

The production process of the feature studied is described. Being one of the most complex features that the company uses, it interacts with six different operational departments: logistics; machining; tribofinition; galvanoplasty; assembly; finance.

The process begins with the customer placing a production order. As soon as the production is properly planned, an order is placed with the respective raw material supplier so that they can provide the quantities to be worked on at the factory on the agreed date. After the supplier sends the raw parts, which are circular in shape and made up of a copper and zinc metal alloy called brass, logistics is then responsible for receiving the material and registering the entry of the goods in Pro Concept (PCO), the company's ERP, where information, such as quantities, document number and date, are noted. This information is visible to all employees who have access to the ERP and indicates that a certain quantity has been received and is in a controlled status. Subsequently, a technical control reception is carried out (TCR) of all pieces, thus ascertaining the real quantities delivered, in order to compare them with what is described in the supplier's document and other visual aspects, i.e., if there is no damaged material or the dimensions, diameter and thickness of the raw material is in accordance with the customer's requirements. Once the entire quantity received has been checked by the controllers, information about the number of conforming and non-conforming parts is passed on to logistics, as well as the respective reasons for rejecting the material, if applicable. If there is non-conform material to integrate into production, it is returned to the supplier, removing the defective quantity from the ERP by issuing a debit note, and the financial department is notified to claim a credit note from the supplier. At this point, logistics will confirm the "OK" quantities of the goods receipt previously made, thus creating a Reception Note (RN) report.

Once the goods have been received and the respective entry controls have been carried out, they are labelled, transported and delivered to the "work stock" of the next sector, i.e., to the place where the machining department stores the material to be processed. In the machining department, as soon as the production planning determines that the production of the "ring" is to begin, a manufacturing order (MO) is created by them in the ERP. Depending on the quantity to be produced, the system will inform which batches are to be manufactured and RNs are made available for work by the logistics department, always with a first in, first out (FIFO) approach. In operative terms, the first production step in the machining department is to perform a symmetrical cut of the piece, dividing it into two equal halves using a conventional milling machine, as shown in Figure 4.

Figure 4. Conventional milling machine.

As the cutting is carried out, the employee creates batches of 300 half units of the cut halves of the "ring"; this being the minimum capacity required for the next stage, as well as the ideal quantity for monitoring anomalies during the production machining process. After the end of the first operation, the pieces are sent to the mechanical-chemical polishing (tribofinition) department of the company's industrial plant to be pre-polished to remove the burrs caused by the milling machine's cut. This department contains a unique process that enables the surface condition and edges of metal parts to be modified by immersing them in an abrasive mixture, essentially composed of ceramics and chemical liquids, placed in an oscillating or rotating movement in an open or closed tank. Results such as cleaning, pickling, deburring, polishing, and matt effect are obtained through friction between the pieces and the abrasive mixture. When the pre-polishing process is finished, the production batch goes back to the machining department, where they will perform the third operation, drilling the edges of the pieces. This step is carried out using a computerized numerical control (CNC) machine, which allows the simultaneous control of several axes, through a list of movements written in a specific code. Figure 5 shows the equipment used for this operation, as well as the piece after being machined by the respective CNC.

Figure 5. CNC machine and its machined piece—reference "ring".

After machining, the batches of 300 $\frac{1}{2}$ units of the "ring" are complete, they are then checked in their entirety by the machining controllers. Parameters such as hole diameter, centring and depth are measured. A visual check is also performed to verify that there are no marks on the workpieces. After total verification of the batch produced, the person responsible for machining closes the MO, where not only the quantity of pieces that conform to the production flow is registered in the ERP, but also those that were rejected by the controllers. These ones are then analysed to see if they can repeat some type of correction operation or if they will be directly recorded as losses (destruction). As soon as an OF is closed, the logistics department receives information on the quantity of pieces available to be worked on by the next production department, and is responsible for moving, in this case, the stock of finished product from machining to the stock of unworked materials for the tribofinition.

In this department, once the production planning has the capacity to integrate new pieces, with a minimum of 750 and a maximum of 1200 required to proceed with production, the procedural logic in the ERP is identical to the previous one: opening of the MO with a certain quantity to manufacture. Once the tribofinition equipment, as shown in Figure 6, has been prepared, the pieces are deposited for a more rigorous polishing, leaving them in a totally shiny and clean state. When the machine cycle time is over, a visual control is performed by sampling, i.e., 10% of the total amount of the MO quantity is compared with a compliant standard piece. At the end of the visual control, the person responsible for tribofinition will declare the MO closed in the respective ERP, informing how many compliant, non-compliant or correct parts there are in the respective production batch. At this point, logistics operators will have to physically move the WIP stock to the next department in the production flow, galvanoplasty.

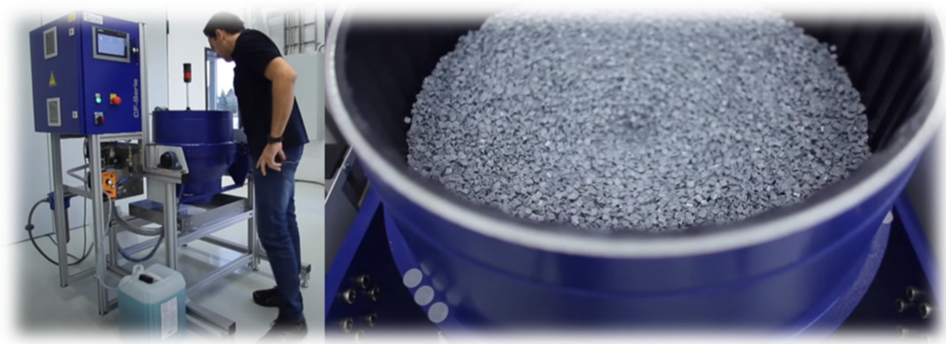

Figure 6. Tribofinition equipment.

In the galvanoplasty sector, as in the previous operational departments, when there is the capacity to produce the batches awaiting recall in working stock, a galvanoplasty MO is created, in which the "ring" may be coated with one of two treatments, i.e., gold with varnish coating or only palladium. The first operational stage that follows in the galvanic production process is the assembly of expositors, a section where the various operators place the pieces on the structures that will serve as transport during the production flow. Figure 7 illustrates a half-piece expositor of the "ring" waiting to be worked on.

Figure 7. Galvanoplasty expositor — "ring".

The second stage encompasses all the galvanic operations, from degreasing the pieces by immersing the expositor in electrolytic baths, rinsing it between moves from basin to basin, to the stage of depositing the exhibits in immersions containing precious metals that are transferred to the pieces through electrodeposition. It should be noted that the purpose of these treatments, besides the aesthetic aspect it gives to the piece, also has an important function in preventing corrosion. To finish the galvanic process, the expositor is placed in a drying vat. At the end of the second stage, all the pieces are subjected to quality control. This will evaluate the quantity of precious metals present in the pieces, through equipment incorporated with non-destructive X-rays, measuring in microns the quantities deposited, analysing not only if there is a lack of them in relation to what is required by the customer, but whether there is an excess deposition of these metals, which, in the latter case, easily generates losses. In addition to this technical control, a visual check is also carried out to identify any holes or reliefs, among others. The next phase, after production control, depends on the type of treatment that is being carried out on the production batch. If it is gold with varnish coating, the pieces are assembled again in a specific expositor, with the capacity to resist the downstream treatment, which will take place next. Once finished, the pieces will be checked again. In the case of palladium, it is not necessary to go back to the galvanic baths, since the varnish, in the case of gold, serves mainly to increase the anti-corrosion indices, a characteristic that palladium possesses to a high degree; hence, it is not common to perform a varnish treatment after the galvanization of palladium in the pieces. To complete the galvanic process, once the total control of the pieces in the batch has been completed, the MO is closed, registering at this stage the quantities correctly or incorrectly produced and those that need to be repeated in the galvanic production cycle.

The next department is assembly, which will start its work when it has the production lot on hold, supplied by logistics, and has production capacity availability. In the assembly phase, the various components that make up the final product are joined together. The end product consists of two halves cut from the "ring", one of which is called a male and the other a female. Components will be added to each part to enable the parts to be joined, once they have been placed in the final product (an operation that the customer will perform). Figure 8 demonstrates the components that make up each part, as well as the final product ready to be "tightened".

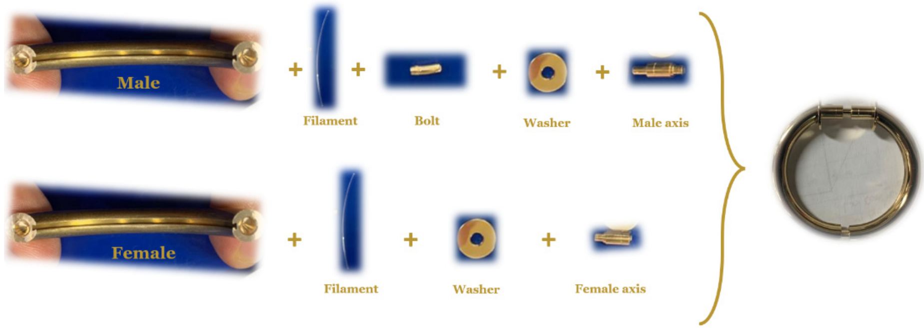

Figure 8. Components required for the final product — "ring".

The assembly department is also responsible for partially packaging the material. Therefore, it is necessary to have packaging material in stock. In terms of process, the assembly cycle begins with the creation of an MO. The procedure can only be carried out if there is enough material in working stock to pack a complete box, corresponding to a minimum quantity of 192 units of the "ring". The pieces are joined using tools, such as automatic and manual presses, where each manufacturing batch of assembly is subject to a check of 16% of the total pieces. Once the defect analysis operation has been completed, packaging is carried out, and when this is complete, the MO is closed, registering the parts that conform to dispatch, those that do not conform and those that need to be rectified. Finally, logistics is responsible for collecting the boxes ready for shipment to the customer in the assembly, completing the packaging process, i.e., closing the boxes completely, placing the respective delivery note (DN) and all the documentation that will accompany the shipment on one of the outer sides of the volume. This procedure is transversal to all the articles worked on by the company, as shown in Figure 9.

Finally, to complete this whole production circuit, the total quantity of parts sent to the customer is invoiced by the company's financial department.

In summary, the main purpose of this section is to present the object of study, for a better understanding of the type of industry being investigated, as well as the intrinsic productive and procedural operations. With this data, it is possible to acquire the necessary knowledge for the development of a case study focused on the implementation of AIDC technologies that promote the progress of operations with a view to their profitability, a consequence of the reduction of operation times, as well as the guarantee of a high assertiveness rate of the data collected throughout the manufacturing operation.

Figure 9. Final packaging.

Figure 10 represents a flowchart of the respective production cycle described above.

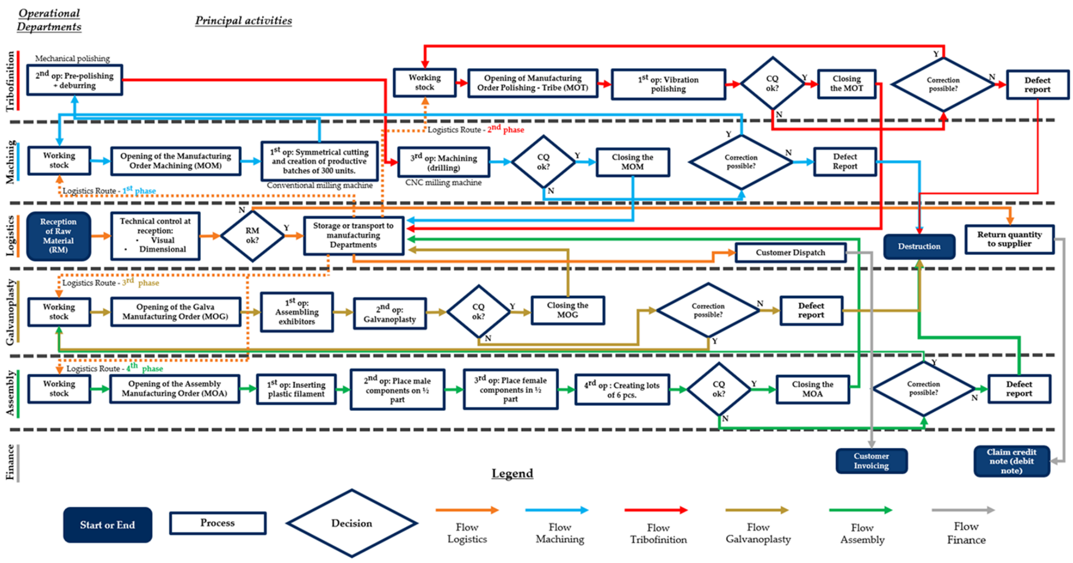

Figure 10. Representative flowchart of the "ring" production cycle.

4. Discussion

Before any implementation is carried out, it is necessary to go into detail what is practiced prior to the change, studying which points need to be focused on and which need to be improved.

A status report was made on the current state of the technologies used for the traceability of production flows, and the company was in a state of transition of operating methods for registering information. This transition is because the entity has a contracted license for an ERP, PCO. Prior to the acquisition of this new software, all information registration was carried out through Microsoft Office files, where the use of Excel spreadsheets predominated. This data shows that top management is aligned with the fact that there is a need to make a change to improve traceability performance and the respective internal communication, naturally, with an associated monetary effort. During interviews with top management, as well as throughout the physical production follow-up, gaps were identified. Table 5 lists the various motivations that led the company to act.

From this perspective, a traceability system will help throughout the production flow and in many ways to automate and mechanize operations, providing resources to the operatives to better perform production monitoring and procedurally simplify the respective information registration operations.

Table 5. Traceability gaps in the production flow.

Main Problems	Motives
Lack of credibility of information	As mentioned in subchapter 2.2, the average error rate when typing on a keyboard is 0.33% per 300 characters; Information may be out of date.
Procedural problems	At a procedural level, it can be complex, as the uniformity standards of certain operations can be broken; Excel files tend to be modified by the users themselves, running the risk of forgetting the purpose of their creation.
Waste and losses	Difficult to monitor the mill orders in progress in the flow, which makes it prone to information loss; The time required to register, investigate and detect anomalies is quite high, as well as being a meticulous task. These follow-up actions and analysis of possible bottlenecks are a key point for the company in the study of the profitability of its production.
Functional limitations	Ideologies such as FIFO are impossible to practice on a large portion of the raw materials entering the facility; Difficulty in locating working stocks, both in the warehouse and in the operative flow; Traceability of the activity is very detailed and with imprecise information.
Technologically outdated company	In today's business landscape, the organization with the highest technological indices gains ground on its competitors, as it carries various tools that facilitate business interactions in all aspects; With the success that the company was achieving, going digital was a strong necessity.

As mentioned above, the company was undergoing a transition process, and had a department entirely dedicated to the implementation of a traceability system, namely ERP, made up of two employees with professional experience in the respective area and hired to focus on this project. The tasks of these two people in charge were essentially planning and controlling the deadlines set for each implementation phase, measuring the tangible and intangible resources needed for the project and communicating with the different parties involved in the implementation. In addition, these roles included the study of possible improvements to be made, based on observations of the current situation, as well as the drafting of the outline of the new operating methods, i.e., the TO-BE process, to carry out a successful implementation; one that achieves the greatest number of benefits, together with minimal risk of such changes, taking operational activity to a higher level than currently practiced.

By carrying out a rigorous supervision of the entire production flow, from its beginning to its end, with a view to implementing an AIDC technology, it is also possible to analyse other issues, such as improvements to be made in work methodologies. In this way, the presence of the general manager of operations was considered important, so that, using a Lean Thinking perspective, all the waste found was duly examined to eliminate it or, if this was not possible, to promote its maximum reduction.

After analysing the data collected, such as the industrial space, production characteristics, possible limitations and respective needs, the ERP department will adjust the best technology to adopt. In this situation, it was decided in conjunction with the top management of the company to adopt and implement a traceability system supported by barcodes. The main reasons that led to this decision are set out in Table 6. After decision making comes the phase of adapting the hardware and software to the industrial environment, the stage at which the company was at during the study (July 2022). At this point of implementation, the first pilot tests are carried out to regularize the entire operating method, verifying whether all the needs are being met, achieving all the proposed objectives, as well as analysing if all the information is being tracked and comparing the previous scenario with the projected future scenario. This point is crucial for the good performance of the implementation. For that reason, it was decided to implement the entire registration operation in parallel, using both methods, i.e., using the old formula, via Excel, and using the new model. Obviously, this kind of action leads to a small increase in operation time, impacting manufacturing costs of the final product; however, it is necessary to guarantee that there are no flaws in the system to be implemented, thus providing a greater security and easiness in case interruptions are generated for "tuning" the new system.

Table 6. Variables for deciding which technology to adopt.

Decision Variables	Description
Coding nomenclature	The company is in the transition and implementation phase of an ERP. For the use of this software, all items moved in each manufacturing flow, from consumables, raw materials, components, final products, among others, must necessarily have an associated code. Given this fact, several articles are already coded and with associated SKU nomenclature.
Globalization	Barcode has been operating in the industrial sector for a long time, compared to RFID, and there is now a greater knowledge to facilitate its implementation; This implementation will be for internal use in the management of flows. However, in the future, if there is a need to track the entire supply chain, barcodes are standardized at a global level, which makes it easier to integrate them into it.
Cost/Benefit	Among the alternatives presented, barcodes and RFID, the former is the one with the lowest cost, about half, from the acquisition of the respective consumables (labels) to hardware; Facing internal needs, barcode technology offers the respective solutions.
ERP	The software that the company is currently integrating is not yet prepared to interact with RFID technology.

In the future, and with the objective of completion before the end of 2022, the next stage will be the installation of the new traceability system. During this period, the intention is to receive all the necessary hardware for 100% operation in the new procedures, where it is intended that each operator has a barcode reader to transmit information on the status of the MOs in real time and from anywhere in the industrial field. Additionally, label printers will be acquired. The proposal is to place these in each department, located near a computer, which generates the opening of each MO. In this way, when a production order is generated, the identification label of the batch to be produced is printed, which later the operator will stick on the respective card/box for transporting the pieces.

At the conclusion of the implementation phase, after the idealized design is fully operational, and without any flaws, the time will come to make official the new method of operating with the employees who integrate the production flow. This stage, as seen in Section 2.2.5, includes the awareness of the employees to how advantageous the change will be for the company, as well as the importance of the project, so that there is no resistance from them to change. Nevertheless, employees will have to have, whenever necessary, a support team to solve any problems that may arise, to ensure that there are no work interruptions or anomalies in the information records. It is assumed that, in the initial phase, this type of event has a higher rate of error, since errors when handling the new equipment are more anticipated.

Lastly, the pursuit of excellence should never be overlooked in any project. Given that fact, continuous improvement will have to be present in the implementation, proactively gathering feedback from operators and analysing whether diverse opinions can add value to the new system.

When interviewing the employees of the department that was responsible for the implementation, they stated that it is a meticulous process, vastly detailed, but with a generalist implementation model, and they comtemplated the following points, which substantiate what has been previously described:

1. Project feasibility (which is complemented be the following section);
2. Formation of the project team;
3. Analysis of the current situation—identifying divergences and needs;
4. "Design" of the entire new operating process, integrating all the equipment necessary for the success of the implementation;
5. Implementation of the system.

The implementation model in use at the company is quite identical to the one referenced in Section 2.2.5, and schematically represented in Figure 3. It can be noted that the model presented by Ngai et al. [8], which has already been applied in the textile industry, can also be used as a reference in the industry where the case study is based, the manufacturing of metal products.

Project Feasibility Analysis

The present subsection is based on supporting the decision-making process regarding the implementation of traceability systems, taking as an example the current case study, carrying out an analysis of the gains that this type of project can instil in the corporation. First, all the operational times of the production flow of the "ring" with gold galvanic treatment with varnish coating were collected. The times were recorded only once. In each manufacturing department, an operator with at least six months of experience in the company was elected; no tolerance factor was attributed. Table 7 describes, for a production batch of 600 pieces, all the times in hours (h) given for each task of the production flow studied, before the changes made as part of the implementation.

Table 7. Production flow operating times for the "ring".

Operational Department	Operation	Time (h)
Logistics	Technical control reception (TCR)	2.5000
	Excel—Register of information on quantities checked	0.0300
	Transport 1st phase: logistics >> machining	0.1700
Machining	PCO—Opening of the manufacturing order	0.0400
	Conventional milling machine setup	0.2500
	Conventional milling machine: symmetric cutting	0.9600
	Batch creation of 300 pieces	0.4200
	Transport machining >> tribofinition	0.0500
Tribofinition	Pre-polishing	4.1400
	Transport tribofinition >> machining	0.0500
Machining	CNC milling machine setup	0.2500
	CNC milling machine: double drilling	3.3600
	Quality control	6.6600
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 2nd phase: machining >> tribofinition	0.0500
Tribofinition	PCO—Opening of the manufacturing order	0.0400
	Vibration polishing	15.1200
	Quality control	0.1680
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100

Table 7. *Cont.*

Operational Department	Operation	Time (h)
Logistics	Transport 3rd phase: tribofinition >> galvanoplasty	0.0200
Galvanoplasty	PCO—Opening of the manufacturing order	0.0400
	Assembling exhibitors	1.7400
	Galvanoplasty: gold treatment	2.0400
	Quality control	6.6600
	Excel—Register of information on quantities checked	0.0300
	Change of exhibitor	6.0000
	Galvanoplasty: varnish treatment	5.1600
	Quality control	6.6600
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 4th phase: galvanoplasty >> assembly	0.0700
Assembly	PCO—Opening of the manufacturing order	0.0400
	Inserting plastic filament	0.0800
	Place male components on 1/2 part	0.0800
	Place female components in 1/2 part	0.0800
	Creating batches of 6 units/Packing preparation	0.2400
	Quality control	0.2688
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 5th phase: assembly >> logistics	0.1300
	Packaging and customer shipping	0.4800
	Total flow time	64.2368
	Total flow time without setups *	63.7368
	Time/Piece (h)	**0.1062**

As shown in Table 7, when all the times are added together, the value of 64.2368 production hours is obtained for a manufacturing batch made up of 600 pieces, including the setup times required for the equipment. However, during the observation and data collection of the respective flow, it was found that the equipment is normally prepared to perform this type of operation, since it applies to various articles. For this reason, the present study will not take into consideration the setup time of the equipment. Thus, the total flow time corresponds to 63.7368 h, which represents an approximate time of 0.1062 h per piece, corresponding to 6 min and 22 s. Equation (6) divides the total flow time by the number of pieces produced, obtaining the time per part.

$$\text{Time per piece} = \frac{63.7368}{600} \cong 0.1062\ \text{h} \tag{6}$$

Through the data collected, as represented in Table 7, several points of analysis can be considered. Counting the total hours used by each department during the entire flow, around half, 45% is consumed by the galvanoplasty department. This involves the operations that add most value to the product, placing precise metals on the parts. In this case, gold. It may be important to focus improvement efforts on this part of the flow, as it adds up to almost half of the total batch production time.

Table 8 represents the time consumed by each department during the manufacture of 600 pieces of “ring”.

Table 8. Time consumption by operational department.

Operational Department	Time (h)	Representation %
Logistics	3.4500	5%
Machining	11.5300	18%
Tribofinition	19.5580	31%
Galvanoplasty	28.3700	45%
Assembly	0.8288	1%
Total	63.7368	100%

From a Lean perspective, it is also easy to analyse, through the exposed data, which operations add value for the customer and which should be studied for reduction or elimination, since they are not important from the customer’s point of view. Therefore, transport procedures and the recording of internal information are considered wasteful and should be investigated. Table 9 represents all operations from Table 7 that, for the client, do not represent any value.

After adding the times, the value is 0.9200 h, as shown in Table 9. This is the time spent on tasks that do not generate value for the company, i.e., from the perspective that the client will not pay for this type of operation. It should also be noted that this time does not change depending on the number of pieces, i.e., it is independent in relation to the size of the production batch, since registering or transporting one piece has a time very similar to performing this same procedure for thousands of units. Obviously, in production terms, the larger the quantity of the batch to be produced, the more beneficial it will be, insofar as it will be possible to make this type of procedure more profitable on a per piece basis. Nevertheless, there is a set of factors that can be detrimental in the production of series with larger quantities, such as, for example, when there are production defects requiring correction and intervention; the loss is generated according to the size of the batch. The larger the production in question in this situation, the greater the investment in its correction and recovery.

Analysing the total production flow time of 600 pieces, which takes 63.7368 h to manufacture, 0.9200 h represents approximately 1.4434%. In other words, it can be assumed that the analysis carried out is insignificant. However, the idea that should underpin any aspect of business is that of making full use of available time. By removing the 0.9200 h from the flow, the total batch production time would be reduced to 62.8168 h, which, following the same logic as in Equation 6, achieves a time per piece of approximately 0.1047 h and a gain of 0.0015 h per piece, i.e., 5.2 s of profitable time per unit produced. Studying a working day composed of 8 h, with a production time per piece of 0.1062 h, it is possible to produce 75 units. Whereas, with a time of 0.1047 h per piece, it is possible to produce 76 units, i.e., one more unit per day, and an increase of 21 units per month (considering that the month consists of an average of 21 working days), corresponding to an annual gain of 251 pieces (considering that a year has 251 working days).

For this purpose, the implementation underway in July 2022 aimed to seek assistance from an AIDC technology in order to partially automate all information recording procedures. Although these do not create value for the client, they must be maintained to facilitate the management of the company and, therefore, cannot be eliminated. In relation to transport times, not being the focus of the study, these can be reduced, for example, through the study of a possible layout more suitable for the industrial field of the company, which guarantees the capacity to implement a continuous flow, e.g., minimizing waiting and non-productive times.

Table 9. Non-value operation times of the production flow for the part "ring".

Operational Department	Operation	Time (h)
Logistics	Excel—Register of information on quantities checked	0.0300
	Transport 1st phase: logistics >> machining	0.1700
Machining	PCO—Opening of the manufacturing order	0.0400
	Transport machining >> tribofinition	0.0500
	Transport tribofinition >> machining	0.0500
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 2nd phase: machining >> tribofinition	0.0500
Tribofinition	PCO—Opening of the manufacturing order	0.0400
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 3rd phase: tribofinition >> galvanoplasty	0.0200
Galvanoplasty	PCO—Opening of the manufacturing order	0.0400
	Excel—Register of information on quantities checked	0.0300
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 4th phase: galvanoplasty >> assembly	0.0700
Assembly	PCO—Opening of the manufacturing order	0.0400
	Excel—Register of information on quantities checked	0.0300
	PCO—Closing of manufacturing order	0.0100
Logistics	Transport 5th phase: assembly >> logistics	0.1300
	Total time (h)	**0.9200**

As mentioned in Section 4, implementation would make each operator responsible for registering information, each having a barcode reader with integrated software, called a Portable Data Terminal (PDT), so that they can communicate instantly with the company's ERP. In this way, it will allow the employee to register information on the state of production, stages of manufacture, defective quantities, and locations, among others. This is associated with the barcode identifying the batch in production from anywhere in the industrial field of the company, simply by first reading the respective code to carry out the supposed registration.

After carrying out the pilot test of the idealized implementation of a traceability system managed on ERP and supported with barcode technology, in the production flow of the "ring", operations were replaced and added to satisfy the existing needs where, consequently, the times were altered. Table 10 represents all the times of the operations that were involved in the pilot test of the implementation, equally considering a batch of 600 pieces. All new tasks of the flow were counted, where the time of these was added to those that remained unchanged, since the entire production capacity was maintained. As with collecting the times before the first pilot test, the times were clocked only once. In each manufacturing department, an operator with at least six months of experience in the company was elected; no tolerance factor was attributed to any operation.

Table 10. Operating times from pilot test for production flow of the "ring".

Operational Department	Operation	Time (h)
Logistics	Technical control reception (TCR)	2.5000
	PDT—Register of information on quantities checked	0.0014
	Transport 1st phase: logistics >> machining	0.1700
Machining	PDT—Opening of the manufacturing orde	0.0022
	Conventional milling machine setup	0.2500
	Conventional milling machine: symmetric cutting	0.9600
	Batch creation of 300 pieces	0.4200
	PDT—Batch production status register	0.0008
	Transport machining >> tribofinition	0.0500
Tribofinition	Pre-polishing	4.1400
	PDT—Batch production status register	0.0008
	Transport tribofinition >> machining	0.0500
Machining	CNC milling machine setup	0.2500
	CNC milling machine: double drilling	3.3600
	PDT—Batch production status register	0.0008
	Quality control	6.6600
Machining	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 2nd phase: machining >> tribofinition	0.0500
Tribofinition	PDT—Opening of the manufacturing order	0.0022
	Vibration polishing	15.1200
	Quality control	0.1680
	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 4th phase: galvanoplasty >> assembly	0.0700
Assembly	PDT—Opening of the manufacturing order	0.0022
	Inserting plastic filament	0.0800
	Place male components on 1/2 part	0.0800
	Place female components in 1/2 part	0.0800
	PDT—Batch production status register	0.0008
	Creating batches of 6 units/Packing preparation	0.2400
	Quality control	0.2688
	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 5th phase: assembly >> logistics	0.1300
	Packaging and customer shipping	0.4800
	Total flow time	63.8820
	Total flow time without setups *	63.3820
	Time/Piece (h)	**0.1056**

An analysis of Table 10 shows that there was a reduction of 0.3548 h in the total production time of the batch, a gain of 21 min and 17 s which generates a time per piece of 0.1056 h, Equation (7), corresponding to 6 min and 20 s.

$$\text{Time per piece} = \frac{63.3820}{600} \cong 0.1056\ \text{h} \tag{7}$$

Regarding tasks that add no value to the customer, from the viewpoint of the Lean philosophy, these accounted for a total of 0.5652 h after the pilot test, as described in Table 11.

Table 11. Non-value operation times from pilot test for production flow of the "ring".

Operational Department	Operation	Time (h)
Logistics	PDT—Register of information on quantities checked	0.0014
	Transport 1st phase: logistics >> machining	0.1700
Machining	PDT—Opening of the manufacturing order	0.0022
	PDT—Batch production status register	0.0008
	Transport machining >> tribofinition	0.0500
	PDT—Batch production status register	0.0008
	Transport tribofinition >> machining	0.0500
	PDT—Batch production status register	0.0008
	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 2nd phase: machining >> tribofinition	0.0500
Tribofinition	PDT—Opening of the manufacturing order	0.0022
	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 3rd phase: tribofinition >> galvanoplasty	0.0200
Galvanoplasty	PDT—Opening of the manufacturing order	0.0022
	PDT—Batch production status register	0.0008
	PDT—Register of information on quantities checked	0.0014
	PDT—Batch production status register	0.0008
	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 4th phase: galvanoplasty >> assembly	0.0700
Assembly	PDT—Opening of the manufacturing order	0.0022
	PDT—Batch production status register	0.0008
	PDT—Register of information on quantities checked	0.0014
	PDT—Closing of manufacturing order	0.0008
Logistics	Transport 5th phase: assembly >> logistics	0.1300
	Total time (h)	**0.5652**

As shown in Table 11, there was a decrease of 0.3548 h in the operations that do not generate wealth to the product, equivalent to a negative variation of 38.5652% of these types of actions in the respective flow in comparison with the scenario before implementation, as shown in Table 9, which would be achieved by partially automating several of these tasks, such as opening and closing manufacturing orders in each department.

Although minimal, production performance increased with implementation as the time worked throughout the flow decreased. Based on Equation (3), prior to implementation, production performance was around 98.5566%, Equation (8), and based on the times collected in the pilot test, this indicator rose by 0.5517%, obtaining a production performance of 99.1083%, Equation (9), in the batch of 600 pieces that was analysed.

$$\text{Productive performance}_{\text{standard}} = \frac{62.8168}{63.7368} \times 100 \cong 98.5566\% \quad (8)$$

$$\text{Productive performance}_{\text{w/implementation}} = \frac{62.8168}{63.3820} \times 100 \cong 99.1083\% \quad (9)$$

In quantitative terms, the efficiency of the implementation measured through the ratio between the output generated after conducting the pilot test to that previously generated before the changes is minimal. To calculate this indicator, a working month consisting of 21 days of 8 h of work was considered, i.e., 168 h in total for the month. Before implementation, with the results obtained, 1581 pieces of the "ring" would be generated, as shown by Equation (10). After the pilot test, 1590 pieces could be produced each month, as given by Equation (11). Based on Equation (2), an efficiency of 1.0057 was obtained; although it is low, it is higher than 1, which proves that it is beneficial for the company. Equation (12) calculates the efficiency indicator of the pilot test of the project.

$$\text{Monthly production}_{\text{standard}} = \frac{\text{Time worked (h)}}{\text{Piece manufacturing time (h)}} = \frac{168}{0.1062} = 1581.9209 \cong 1581 \text{ units} \quad (10)$$

$$\text{Monthly production}_{\text{w/implementation}} = \frac{168}{0.1056} = 1590.9091 \cong 1590 \text{ units} \quad (11)$$

$$\text{Efficiency}_{\text{implementation}} = \frac{1590.9091}{1581.9209} = 1.0057 \quad (12)$$

Finally, it will be interesting to check the profitability of the investment associated with the implementation taking place in the company. As mentioned in Section 2.3.1, this indicator expresses the return generated by the increase in productivity, associated with a financial investment, an effort made by the company. After interviewing the financial department, the characteristics are detailed in Table 12.

Table 12. Financial characteristics of the "ring".

Financial Characteristics	Unit Value per Piece
Sales Price/Revenue	€19.1235/unit
Variable cost [1]	€10.5299/unit
Fixed cost	€4.3233/unit
Invoicing quota	4.0193%

[1] The variation in variable cost has as its main factor the cost of acquiring each batch of precious metals, in this specific case, gold.

Using the information collected, it is possible to calculate the net profit generated by each piece produced. Equation (13) performs the same calculation based on Equation (5).

$$\text{Net profit}_{\text{"ring"}} = 19.1235 - 10.5299 - 4.3233 = €4.2703 \quad (13)$$

The investment associated with the implementation, not considering any type of interest in obtaining capital, is €380,000. However, it should be noted that the monetary effort was made for the entire company, that is, for all flows and production units. In this way, to calculate the return on investment through the analysed flow, it is necessary to find out the share of invoicing associated to the article in question, expressed in Table 12. Multiplying the total amount invested by the percentage invoiced comes to the value of €15,273.3400; the part of the financial investment that concerns the flow under analysis.

Based on the data obtained after the pilot test, it was possible to verify that, in terms of production, there was a monthly increase of nine units (difference between Equations (11) and (12)). Thus, the expected annual return on investment associated with the production flow of the "ring" is €422.7597, considering 11 months of work during the year. This value was generated by multiplying the net profit of each "ring" with the monthly production increment that was obtained with the implementation and the number of months worked during the year, as given by Equation (14).

$$\text{Annual net profit}_{\text{"ring"}} = 4.2703 \times 9 \times 11 = €422.7597 \quad (14)$$

Through the result obtained, it is now possible to quantify the annual return on investment, which is 2.7680%, as expressed by Equation (15) and based on Equation (5).

$$\text{Annual profitability}_{\text{implementation}} = \frac{422.7597}{15273.3400} \times 100 = 2.7680\% \quad (15)$$

In quantitative terms, from the results obtained in the equations described above, it can be concluded that although the implementation brings benefits, these are minimal. However, this type of implementation should not only be evaluated under quantitative measurement metrics. New operating practices were discovered to provide greater flexibility to the operating circuit, facilitating the consultation of data in real time and ensuring greater management support.

5. Conclusions

There are several benefits underlying a project of this type, that can be measured besides the monetary return, such as the impact of the technological solutions on the company operation.

One of the requirements that led the company in the case study to make this implementation was the outdated technology. The fact that the company is not digitalized causes it to lose market power in the face of competition; thus, this project was mandatory. Digitizing a company provides security, speed of communication and transparency to customers, since the change will allow for the management of various information about the products made, features of enormous relevance to them. With this change, it is easy to identify each production batch, as the new operating method standardizes the printing and labelling of each batch in the production flow and, through this operation, it is easy to access, in the ERP, various data such as locations, states and associated production dates. In this way, the company guarantees reliable and swift information for correct communication of its customers' respective orders in progress, a differentiating factor in the business world.

In the same context, it is also important to analyse whether all the gaps identified in the production flow prior to implementation were solved. By using the new practices for recording information, Excel was extinguished, since the operator records through their PDT. This allows the operating method to be standardized, i.e., maintaining process uniformity, without running the risk of making changes to established procedures, something that could happen with the use of Excel in this type of function, as well as allowing better adaptation to new employees joining the respective production cycle. Thus, the data gains greater credibility, because once it is recorded through the barcode reader, it can never be altered, unless it is modified by the administrator of the respective system. Therefore, issues such as lack of credibility and the resolution of procedural problems were solved.

In this sense, it was also possible to better control production, something that was seen as a great internal need, because once a departmental manufacturing order was opened, the traceability of the batch produced was lost until the moment it was closed, i.e., it was not possible to check the production status during the various manufacturing phases of each section. The implementation of this new system allowed this inconformity to be resolved through the addition of small operations of batch picking and registration of manufacturing phase information after the completion of each internal stage of the department. Operations called "PDT—batch production status register" allow communication to the company, through the ERP and in real time, of the situation of each production in progress, controlling the entire production process more effectively. The production manager, supported by the new traceability system, will be able to monitor the manufacturing status of the products, identify production bottlenecks and reduce waste.

Internal traceability systems, i.e., for the company's own use, supported by AIDC technologies are considered a very powerful tool that largely assists in management, information gathering, monitoring and production planning. It also assists in the fulfilment of requirements that the market segment of this luxury goods industry demands, such as digitalisation and easy tracking of information; never compromising on high levels of quality. In general terms, it can be stated that this study was part of the company's continuous improvement policy since it allowed for the company's digitalization. The objective was to carry out a concise and compact literature review about traceability, AIDC technologies and implementation models, to correctly formulate a valid implementation proposal, supported by a feasibility analysis of the respective project. In other words, the purpose of this study is based on the integration of a traceability system supported by AIDC technologies, in an industrial environment, in a simple and robust way, allowing automated data collection and processing.

This implementation was based on the model formulated by Ngai et al. [8], previously applied in the textile industry, which proved to be equally adaptable to the metallic products manufacturing industry of small luxury pieces. With this project, it was proven through the results obtained from the pilot test that the associated investment brought quantitative gains, measured at the outset. Although small, the performance indicators and productive efficiency, as well as the return on investment, were positive. In qualitative terms, the profits had greater strength, as they outlined the weaknesses in terms of traceability that the case study company had. The change to a standard business model, without proprietary files, such as Excel, and supported by AIDC technologies, allowed the company to gain efficiency in the treatment of production data, greater logistical control of the production process, increase the credibility of the data collected during the respective production flow and facilitate the location of production batches, as well as knowing their manufacturing status in real time. Through this implementation, the company is now able to grow in the market, be closer to the client and quickly monitor all orders in the manufacturing process.

In summary, evaluating a traceability system implementation supported by AIDC technologies restricting analysis to quantitative data and ratios may make it unattractive for companies to proceed. While the above calculations convey a very small return, in financial and productive terms, this implementation guarantees impact in functional and monitoring terms, which provides enormous benefit to the management of production flows. These are features that are not measurable and which will have a positive impact on the company in the medium to long term.

Suggestions for Future Work

The purpose of this subsection is to provide suggestions for new research directions, both at the level of the company, which served as the object of study for this investigation, as well as in terms of scientific knowledge.

First, in terms of the case study company, the next step suggested is to expand and integrate the traceability system implemented throughout the industrial field, not only in all the existing productive flows, but also in all the operations that are conducted in the industrial field; e.g., in the management of products in warehouses regarding entries, exits and location of material goods, recording in real time the same in the system using AIDC technologies.

In the future, based on continuous improvement thinking, it will be important to follow the development of RFID technology. As explained in Section 4, the latter was excluded mainly for cost reasons. As time goes by, the RFID support tool tends to become more easily accessible not only due to the reduction in the cost of acquiring hardware and respective consumables, but also due to the global evolution of standardization related to its use. A traceability system supported by RFID technology presents characteristics that provide any company with high gains at the operational level. Of all the motivational factors for the incorporation of this technology into a traceability system, the most noteworthy is the total elimination of time spent on information recording tasks associated with object identification, as this entire process can be carried out fully automatically. i.e., without any human intervention and in real time, greatly reducing waste in tasks that do not add value to the product, especially from the customer's perspective.

Another point that could be interesting to study would be to analyse the possibility of implementing production units with continuous assembly lines. As seen in Table 11, the time invested in transport consumes almost all the operations of the production flow that add no value to the customer, and with this implementation it would be possible to place fixed barcode readers able to perform the reading and collection of productive information in a fully automatic way. In this way, all the operator's attention would be invested in operations that add value to the article to be produced.

Additionally, systems based on computational vision and artificial intelligence in the scope of Industry 4.0 could be implemented to carry out quality control in a fully automatic way, after being duly parameterized with the acceptance criteria of each brass component. In the case of the proposed implementation, it would be the equipment communicating the information and not the human through the PDT. The inclusion of this technology would improve the post-production quality data.

As far as scientific knowledge is concerned, no research theme is concluded with the elaboration of a scientific article; neither is the technological aspect, which is in constant development. Given this fact, it is important to suggest a proposal for future developments.

The purpose of this work was to contribute to the evolution of scientific knowledge of traceability applications in the context of Industry 4.0. In this field, it would be interesting to carry out future research works which aim to implement traceability systems supported by AIDC technologies in other types of industries, resorting to the model that served as a basis for the present study. This way, it would be possible to verify its adaptability, as well as how it could be possibly globalized at the industrial level.

Author Contributions: Conceptualization, P.D.G. and G.F.; methodology, P.D.G. and G.F.; validation, P.D.G.; formal analysis, G.F.; investigation, G.F.; resources, G.F.; data curation, G.F.; writing—original draft preparation, G.F.; writing—review and editing, P.D.G.; supervision, P.D.G.; project administration, P.D.G.; funding acquisition, P.D.G. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported in part by the Fundação para a Ciência e Tecnologia (FCT) and C-MAST (Centre for Mechanical and Aerospace Science and Technologies), under project UIDB/00151/2020.

Conflicts of Interest: The authors declare no conflict of interest.

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