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A Strategic Model to take the First Step Towards Industry 4.0 in SMEs

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Abstract

Over the last few years, there has been a clear evolution in the suppliers of the automotive industry due to constant demands imposed by OEMs (Original Equipment Manufacturers), systematically requiring an increase in the level of quality and competitiveness of products. The continuous requirement to increase productivity in this sector makes it necessary to modernize technology and the need to monitor all production at a distance, also making the manufacturing process more autonomous. However, more traditional companies in developing countries cannot move abruptly to an integrated production and management system. Thus, it is necessary to establish an industrial implementation strategy for this type of companies. The evolution of the work method on the factory shop-floor must be gradual so that there is a greater effectiveness in the change of working paradigm. This paper aims to establish a model of gradual implementation of industry 4.0 in SMEs currently working in a traditional way, so that workers can have the opportunity to evolve in their cognitive capacities with technological evolution, promoting a symbiosis between technological change and the change of mentality, habits of work and technological knowledge of the workers. In order to test the validity of the model, it was developed a case study, through its implementation in a components' cutting process for the automotive industry. The progress should follow the whole procedure of assembling and shipping of the intermediate product in order to increase their reliability and monitoring. A production control system based on automation and information was created, which allows the product state to be known in real time, triggering the whole process of logistics and subsequent processing in a completely automatic way. After the implementation of this pilot system, it is much simpler to proceed with the training and technological updating of the workers regarding the following processes.

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1. Introduction

The automotive industry continues to be one of the main pillars of the world economy, with very high levels of innovation and organization [1]. In the last decades, the automotive industry has been able to optimize the combination of automation evolution with waste reduction methodologies, significantly improving processes through new production equipment [2-6] and through better management methodologies [7-9], also bearing in mind continuous improvement techniques [10, 11]. However, the technological evolution does not stop, and the possibility of communication between the equipment and the management software, together with the automation and the robotization, have brought new challenges, allowing a greater interaction between the equipment, its peripheral tools and the synchronization of the functioning of these modules managed centrally by management software that receives information feedback and generates new actions accordingly [12]. The window of opportunity that has opened up with the integration of these systems is immense, making the paradigms of production need to be deeply changed. Given the deepness of this change, it was given the name of the 4th Industrial Revolution.

2. Literature review

The 4th Industrial Revolution is also commonly referred to as Industry 4.0 or Smart Manufacturing and can be defined as a new level of organization and control over the entire value chain of the product, which is driven by individualized customer requirements [13]. However, at this still embryonic stage of Industry 4.0, there are a large number of definitions that tend to describe the term as an evolution of Industry 3.0, where the equipment was automated and individually controlled by computers, to a system that is able to gather and organize data collected from sensors installed in equipment and its peripherals on the shop-floor, including feeding and supply chain systems, to generate intelligent decisions in a perfectly automatic way, representing a concept that includes the integration of systems and agents with the common objective of improving the efficiency, flexibility and responsiveness of a production system [14]. In order to achieve these objectives, the concept needs to integrate several tools, some newer than others, such as the Internet of Things, Robotics, Machine Learning, Big Data, and Cyber-Physical Systems, among others, with a view to achieving the desired results [15]. One of the biggest challenges of Industry 4.0 is still a true integration and coordination of the different possibilities offered by each of the tools mentioned above [16]. A careful reading of the literature also reveals that one of the greatest challenges for the rapid evolution of the concept of Industry 4.0 is to understand how it can be structured, taking into account the current situation [17]. On the one hand, despite some efforts already made, there still seems to be no consensus on a real roadmap for applying this concept. On the other hand, it seems consensual that it is necessary to prepare the programming of production and the collection of information through mathematical algorithms that can prepare the productive systems, so that the concepts of Industry 4.0 can be applied later, and a correct data acquisition, aggregation and synchronization of this data is necessary for a single information system capable of intelligently managing this information [18]. However, in order for such data to be collected, the equipment needs to be provided with the data acquisition and transmission systems necessary for this to become real. If this happens in state-of-the-art equipment, the same can not be said of equipment that is still in perfect working conditions but needs to be technologically upgraded in order to be able to perform these data collection and transmission tasks automatically and expeditiously [19]. In order for such information to converge and to produce the necessary decisions and actions, it is necessary to create an information system with its own architecture, which can take different configurations. In order to streamline production systems, Meissner [20] compared three different control architectures, such as: centralized production control, decentralized production control, and hybrid production control. This study allowed the conclusion that, given the possibility of interconnecting the machines and the need to streamline the production process, the equipment already has the necessary autonomy to receive data and make decisions, so that a completely centralized hierarchical system does not make sense. On the one hand, when a modern machine park is in place, hybrid control of production is the best solution, allowing faster decision-making at the level of equipment interaction, but the information will have to continue to be centralized. On the other hand, Cardin et al. [21] argue that the evolution registered in the last twenty years in the Holonic Control Architecture is exactly in line with the Industry 4.0 paradigms, allowing flexibility and adaptability in the production systems that the concept requires. Due to the global interest in the advancement of communication systems between equipment, and in order to standardize communication protocols, some authors have proposed the use of an Open Platform Communication - Unified Architecture (OPC – UA), with a view to improving the interconnectivity between productive systems [22]. The requirements mentioned above in terms of the necessary conditions for the implementation of the Industry 4.0 concept are even more acute when it comes to SMEs, where the lack of technical and economic means can be more pronounced, and where production is essentially based on a traditional strand. A paper recently published by Mittal et al [23] clearly states that the requirements for the implementation of production under the concept of Industry 4.0 are designed exclusively for large companies. It is, therefore, necessary to develop a greater number of research works to analyze the real needs of SMEs, so that they can also move to this new paradigm of production. Another paper recently published by Dassisti et al. [24] made it possible to define that the main requirements that are essential for a faster initiation and transition of SMEs to Industry 4.0 are essentially twofold: knowledge-based and scalability.

This work aims to develop a scalable model, which can be applied in any SME and later expanded, clearly defining the requirements that are necessary for the "seed" to be successfully launched, and may exist rapid progress towards a broader, or even generalized, implementation of the concept, underpinning an SME. A case study was developed to validate the model, which is also presented.

3. Methodology: requirements and model development

To carry out this work, the following methodology was used: Problem analysis ˚ Research ˚ Model concept creation ˚ Model application ˚ Model validation. The implementation of the Industry 4.0 concept in companies stuck with traditional equipment and without the capacity of immediate investment in new equipment, needs to be conveniently planned. In order to ensure a corrective actions plan, a set of requirements which must be fulfilled are pointed out in Fig. 1. This diagram was built based on the usual and natural requirements presented by SMEs in the manufacturing companies of components for the automotive industry.

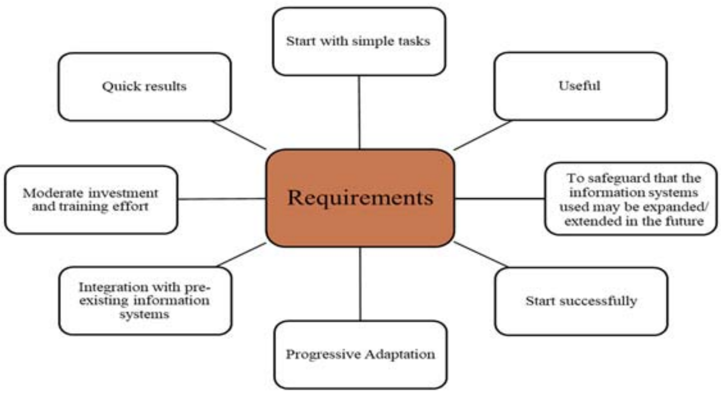

Fig. 1 - Considerations for an initial approach, resulting from the Analysis stage.

The considerations presented in Fig. 1 should be taken into account throughout the process. Process automation should be progressive in order to make them more flexible and adaptable, so it is necessary to study the interfaces existing with the other processes. In order to select the processes that will be initially covered by the implementation of the Industry 4.0 concept, it is necessary to discretise the tasks of each process, analyzing how to automate them, gather information and send that information to other devices or to an integrated system, ensuring their compatibility in terms of communication protocols. Awareness-raising for an initial investment and training effort is essential. It will also be necessary to ensure that the implementation process can be extended easily in the future by correctly defining communication and interfaces. This will ensure that the progression of implementation is now facilitated. Success in the implementation of the first phase of Industry 4.0 concepts will dictate the success of the implementation progression in SMEs. This shift from Industry 3.0 to Industry 4.0 requires an increased learning effort by employees, who will be expecting results. that, can be detailed in the following steps: a) the perception of the existing processes is fundamental to understand its complexity, being the first stage of the process the inventory of all the existing operations; b) define its dependencies, so that in the future it is possible to move from simpler processes to progressively more complex ones; c) the evaluation should be done not only because of the complexity of the operations, but also because of the difficulty of integrating new systems; d) the evaluation should be able to identify simple tasks that allow rapid implementation of the concept and fast feedback on its success, in order to motivate and induce the need to change regarding other processes; e) to decompose the tasks to make them as simple as possible; f) with the integration of additional systems, it is necessary to evaluate the compatibility of systems that already exist, compared to the one that will be added; (g) the way in which the project is structured from its initial stage will facilitate its extension and application to other progressively more complex processes, without communication difficulties; h) a good interface with the ERP (Enterprise Research Planning) systems of the company is fundamental so that all the information is contemplated in the management systems of the daily operations; i) before the implementation, the potential gains with the production control system based on automation and information created, in terms of economic turnover, reliability of results, control of production, among others, should be evaluated; j) after completing the tasks described above, it is necessary to continue the tests to the implemented system, allowing the verification of the reliability of this system; k) with the tests performed, it is possible to evaluate possible improvements and consider the addition of important new functionality for the daily use; l) the conditions for the system to evolve into identical and easily changeable processes are met; m) the transition to more complex operations and the integration of concepts brought by Industry 4.0 are now addressed and comsidered.

Fig. 2 illustrates the developed model, decomposed into different steps that must be considered so that the evolution process can be conveniently carried out.

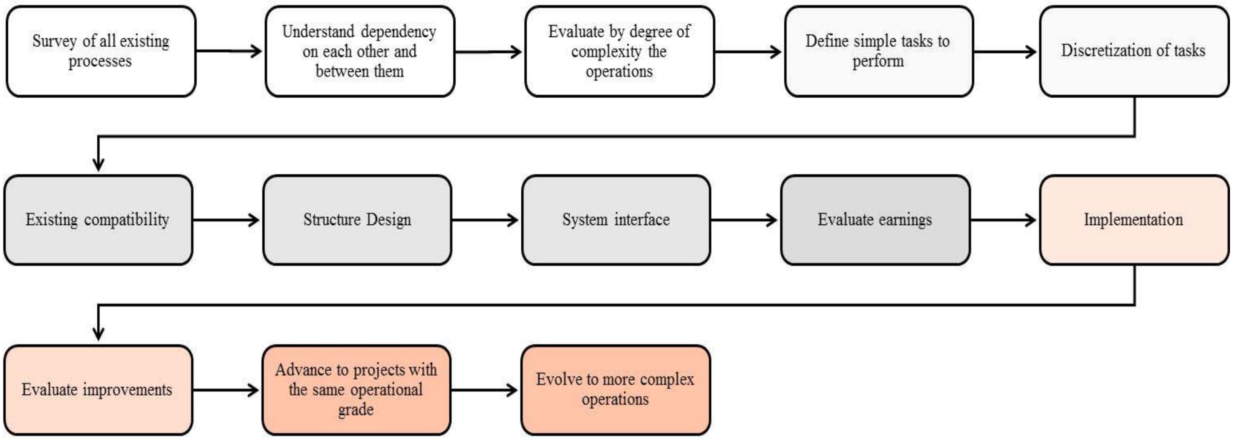

Fig. 2 – Steps to jump from the 3rd to the 4th Industrial Revolution.

With the integration of new systems, it is necessary to understand how they should work and interconnect. Factory shop-floor level systems should be designed to allow them to be autonomous, assessing the various processes that occur in real time and thus making decisions, without having to wait for information processed by centralized systems. It should be noted that as the evolution in an SME is characterized by the gradual evolution, it is necessary to consider that the development of systems is scalable, thus permitting a standardization of the work developed and, afterwards, preparation for its growth.

In order to test the concepts developed in this section, a case study was chosen concerning a process that needed to be automated in a wire-rope manufacturing company for the automotive industry. Although it is a simple process, the application of the Industry 4.0 concept can significantly help eliminate unnecessary tasks and integrate information into the company's production management system. Indeed, within labour-intensive enterprises with high production cadences, having real-time workflow information eliminates numerous inventory management issues and minimizes the delivery time of products to customers. The whole process of logistics is also favourably supported by automating the process and sending the information in real time.

4. Case study

The different stages of implementation of the Industry 4.0 concept (Fig. 2) to the case study considered in this work are described in detail below. Regarding the case study, some steps of the model were agglutinated, in order to save space.

Step 1. Survey of all existing processes, their interdependence and degree of complexity

The first step allows to understand the operating mode of the company and the operations that are inherent to its business. The model begins with this phase, so that it is possible to plan the next steps. In Fig. 3, the various existing processes, as well as their interdependence, are briefly presented.

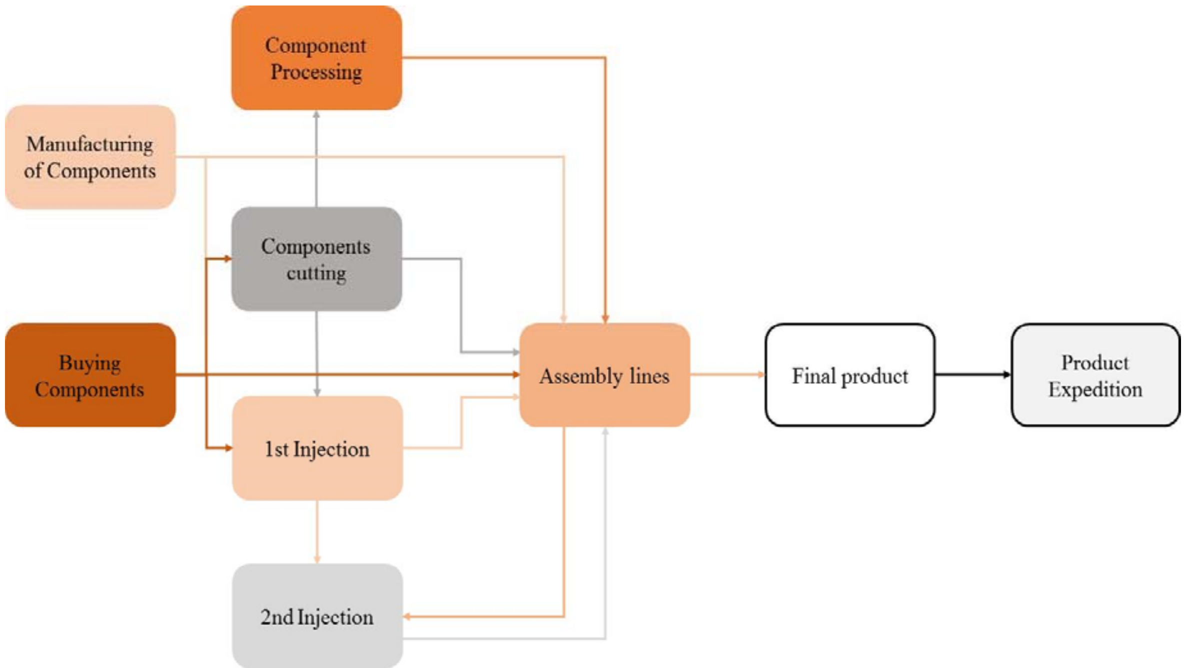

Fig. 3 – Overview of the existing processes and their interdependence into the considered company.

In a business in which the processes are complex and in large number, it is fundamental the schematization and evaluation of each of them, in order to define the implementation guidelines. At the level of complexity, the manufacturing process of components is the most complex, due to the equipment intrinsically linked to the operations, and their variety. The assembly lines are also considered complex because, although they operate in the same way, they have different configurations, their control is carried out by different types of PLCs (Programmable Logic Controller), which would prevent a scaled enlargement of the developed system, needing to be adapted to each of them. The most accessible processes are the components processing, injection and cutting of sub-products from coils, presenting a degree of complexity very similar among them, which allows greater adaptability of the system. The last described processes are those requiring greater control and reliability of values. The process of cutting components should be the one chosen to start the implementation of advanced industrial systems, since it is a process with little control, little reliability in the various analyses made, the equipment is easily adaptable to a new system, is one of the simpler processes, and with the implementation of a production control system, it is perfectly possible to replicate them to the remaining processes, which are equivalent in complexity.

Step 2. Define and decompose processes into simple tasks to perform

For the sub-products cutting process from coils of raw material, the complete procedure was decomposed into simple tasks in order to make the study more objective. It is intended to identify and eliminate operations that do not add value to the product, more specifically in the case of spiral and outer tube cut for command cables used in the automotive industry. In order to implement a production control system in the cutting equipment, the cutting process was decomposed into different simple tasks, in order to better act on the automation aspect and the creation of the necessary information mechanisms. The general procedure was divided into simpler tasks, which can be seen in Table 1. The process consists of cutting lots of spiral tube and inner polyethylene tube with different dimensions, from different master coils. Batches should be placed in pre-packed plastic pre-weighted boxes, which are then sent to the next process, i.e., metal cable insertion and high-pressure die casting of a Zamak terminal.

All tasks should be aimed at successful implementation. To do this, it is necessary to be aware of all the external information that may be given, able to contribute to the improvement process, prepared to the fast resolution of any problem not initially identified.

Table 1 – Tasks defined to start the implementation of the control system

Tasks	Tasks decomposition
Collection of time spent on processes without added value	Sequencing the production process
	Sort tasks and measuring the time spent by each one
	Evaluate tasks that can be eliminated
Identifying the main difficulties in the process	Collect difficulties presented by persons involved in the process
	Identify difficulties at the shop-floor
	Evaluate system parameters to eliminate difficulties
Identify potential advantages and improvements with the implementation of the new system	Automation of the information process on the completion of a batch of the finished product, issue of the label to the container and information sent to the logistics to collect the batch.
Sequencing process	References of cut materials
	Understand the production scheduling process
	Understand logistics planning

Step 3. Compatibility with the existing system, design structure and system interface

When starting the project of implementation of an Industry type concept 4.0, it is necessary to analyze the compatibility between the existing process and the one that is intended to be installed in terms of automation, collection and transmission of information. Thus, the PLC responsible for the drive and control of the cutting process needs to be compatible with the entire control system installed, and have the necessary communication port for network communication. In fact, real-time communication through IoT is one of the pillars of the implementation of any evolution system for Industry 4.0. The scheme of communication between the different devices that will be connected in the case study considered in this work can be observed in Fig. 4.

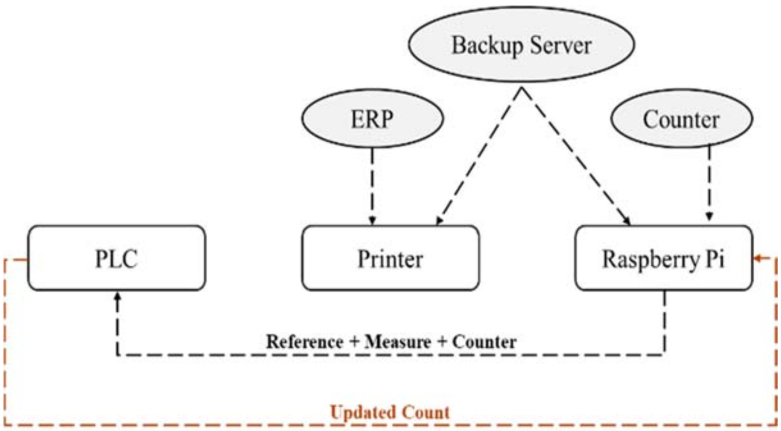

Fig. 4 – Linkage between the different systems involved in the process

The system will be connected by Ethernet, allowing the access at any time and place of the factory to the quantity already cut of each reference, as shown in Fig. 4. This communication is only possible by the existence of a that Ethernet port connection, allowing the connection of all other devices, without having to be physically connected.

Step 4. Evaluating earnings

With this implementation, the manufactured product is valued by the elimination of processes that do not add value, allowing the reduction of time spent and corresponding costs. The resulting scrap is immediately segregated and communicated to the company's ERP system, eliminating the possibility of misinformation about the actual quantity of cut tubes that meet the specification. There is much more effective control of what is produced with quality and the scrap generated, in an unambiguous way, allowing a more rigorous control. The control and reliability of the process are increased, allowing a real-time response: operators will only be able to produce the next manufacturing order after completing the series of products they were cutting with quality. The report of the manufactured products is carried out automatically, and it is not necessary for the operator to wait in turn to register the production at the terminal. The circulation of paper becomes almost non-existent, which induces savings in economic terms and time in the treatment of some information. At the economic level, the investment made is easily recoverable by eliminating the expenses inherent in the old process.

Step 5. Implementation

After the end of the analysis, all conditions are met to start testing and implementing the system. The implementation allows the change of traditional processes in the manufacturing unit and the integration of several areas of automation. Also, the mechanics, presented by all the physical part that integrates the equipment, and the electronics, that is visible in the processing of signals sent and received sensors that equip the machine are vital to this process. The control and imposition of actions can now be ensured by the company's production management system, where the production scheduling control algorithms are designed.

Step 6. Evaluating improvements

Now, the implementation needs to be evaluated by the people involved in the process. Training and adaptability are necessary, and suggestions for improvement are collected. In the case of the study here presented, the operators' receptivity was quite good, due to the reduction of operations performed during the production, allowing to reduce the number of people associated to a group of machines, and increasing the speed in communication and solving of production problems and malfunctions.

Step 7. Evolving to other processes adjacent to the first implementation

The success obtained in the implementation of the system in the components cutting equipment, such as spiral and outer tube, allowed the reproduction in processes of equal operational complexity. The system was extended for the injection and thermal treatment of components, being possible the standardization of the processes by the ease of scheduling. The scheme of Fig. 5 shows the enlargement process and the controlled variables under the WIP (Work-In-Progress) developed application.

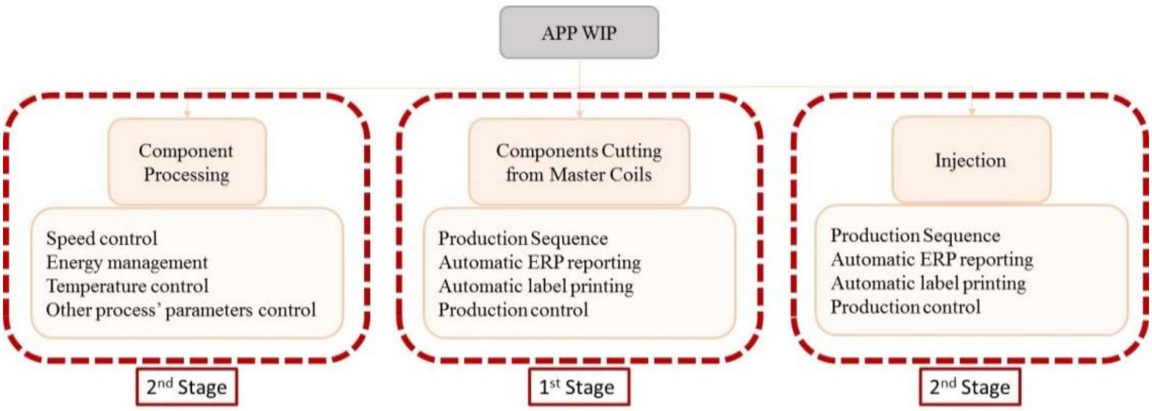

Fig. 5 – Illustrative diagram of the implementation evolution to other adjacent processes

Step 8. Evolving to other more complex processes

In the last phase of the methodology, there is a joint need to make the implementation evolves, extending the implementation to other adjacent processes, making the processes more autonomous and controlled, in order to increase the area under control, increase the value of the product, as well as the quality of the information on the evolution of production. With the success and receptivity shown by the operators in relation to the implemented system, it is mandatory the evolution to the implementation of systems with greater complexity, allowing the networking of the various production systems. A more judicious and reliable decision making can be achieved, as well as a better flow of more credible information across the organization, permitting a much more reliable control of a large part of the productive sector. Thus, the system needs to evolve to greater automation of the jobs, through the incorporation of robots that replace some manual tasks, and then proceed to the integration between jobs, through the implementation of Automated Guided Vehicles (AGVs). Integration at this level will revolutionize the company's internal logistics. Thus, the control becomes effective from the reception of the raw materials until the delivery of the finished product to the final product warehouse.

5. Results and discussion

This work allowed to demystify the process of passing from the theoretical concept of Industry 4.0 to the practical plan, clearly surpassing the problems pointed out by [17]. With the system here developed, it is possible to continue to utilize the same materials used so far, but now in an optimized way and provided with remote control of the process, using sensors to control the production and allow greater reliability in the values reported to the company's ERP. As pointed out by [20], hybrid control systems are the most effective, allowing faster communication and decision making.

The model outlined for the gradual implementation of the Industry 4.0 concept proved to be easy to apply in practice. During the implementation process, there were no shortcomings in its operation that prevented its application, restricted its scope or involved a reformulation of the model. Particular sensitivity is required for the early stages of the process, as only properly trained technicians who are familiar with the concepts of Industry 4.0 and the manufacturing processes in the company can accurately identify the processes by which the implementation is to be initiated. Unlike the one indicated in [15], in this first approach, only the Internet of Things and the Cyber-Physical Systems were used. However, the extension of the implementation already implies the use of Robotics and Big Data, because the operations will be robotized and the quality control will be achieved through Artificial Vision. However, the integration of some more basic concepts begins to be possible even through rather economical systems, such as Raspberry PI type boards. This shows that the integration difficulties pointed out by [16] can be easily overcome.

Along with the technological advance registered, the evolution of the acceptance by the organization was increasing. With the application of the case study, it was possible in a factory floor environment to identify gains for the organization, being at the moment a requirement on the part of the responsible ones the advance and amplification of the knowledge to other departments.

6. Conclusions

The model developed through this work has shown the necessary characteristics to be successfully applied in SMEs, as demonstrated by the case study presented here. It was also demonstrated that it is possible to apply the concepts of Industry 4.0 to traditional industries, but the approach should be carried out according to the indicated methodology. The main barriers identified by other authors as difficulties in implementing these concepts are now outdated, and the system can be applied in a gradual way, allowing the adaptation of the means to the desired evolution. If there is awareness on the part of everyone involved in the process of implementing these concepts, it will be easier to achieve greater global autonomy. The speed with which this can be achieved will also be much greater. From the execution of simple and easy-to-solve tasks, the advancement to the test and implementation phases of the system is promoted, which allows the success of the project to be achieved. With the case here presented, this evolution was remarkable, since with the insertion of simple systems that improve the process and make the actions more reliable and controlled, it was possible to evolve to processes of higher complexity. With the integration, it is intended that the various systems are connected and possible to be interconnected on the shop-floor, monitoring the raw materials from their entry, during processing and ending in the dispatch of the final product. This frees up resources for other higher added value tasks. In addition to the systems implemented, with the knowledge and direct contact with more technologically advanced systems, SMEs are better able to take the step to other levels of integration of the concepts of Industry 4.0, through the implementation of AGV's and Robots on the factory floor.

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