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Light Smart Factories: Introducing Peruvian SMES To The I4.0

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Abstract: *The fourth industrial revolution has brought about various changes and issues for large industries, indicating that they must contemplate significant investment to adjust to Industry 4.0. Conversely, this is not an issue for small entrepreneurs, who could gain advantages from lean practices and affordable technology. The paper examines how these small business owners can utilise the Industry 4.0 framework by adopting a "light smart factory" model.*
Keywords: *I4.0, leanness, light smart factory, low-cost technology.*

1. INTRODUCTION

In today's world, change and evolution occur at a fast pace. It indicates that organisations must prioritise innovation to remain competitive in the market landscape. Researchers have concentrated on the characteristics of what is known as Industry 4.0 (or simply I.4.0), for instance, exchanging information in real time. This has been enabled by improvements in the speed of data handling in the cloud, along with new technologies based on the internet.[1]. So, Industry 4.0 is for Peruvian entrepreneurs like a buzzword and they want to operationalize their process by using or applying technologies that support decisions on all levels. So, perhaps due to the dissemination of data science and Internet of Things (IoT) technologies, managers are seeing the opportunity to incorporate tools from a technology spectrum called the Smart Factory, which encompasses various technological components that support manufacturing operations by transmitting production data in real-time. This way, the scope is to study how to reduce manual work and cycle times within the context of the number of operations involved [2]. And I4.0 becomes feasible because its scope is to increase processing volumes and eliminate bottlenecks to obtain a competitive advantage by producing with almost any waste.

Henceforth, with the beginning of the IoT, it's crucial to comprehend how data and connectivity will transform manufacturing methods within the framework of Industry 4.0.[3]. The Smart Factory approach aims to improve manufacturing by reducing losses within production processes, and this can be validated through the principle of leanness in manufacturing. Moreover, nevertheless the Smart Factory concept is most oriented to large production processes and, of course, aligned with large companies, this study aims to verify the possibilities of implementing these technological practices within SMES.

Some concepts related to low-cost technology were examined, and the idea of the Light smart factory was presented. Currently, the research project on the light smart factory involves three companies: two small firms and one medium-sized firm. Wherever the initial insights underpin the hypothesis, it is possible to apply some technologies and concepts used by large firms to enhance the lean production in SMES

2. Smart Factory

The concept that factories could exhibit intelligent capabilities was introduced in 2010, with the objective of enabling autonomous generation of real-time production reports. This advancement aims to assist managers in identifying specific areas of production inefficiency. The major industries have invested substantial financial resources in automating their processes, recognizing the advantages that this technological revolution provides.

To successfully implement Industry 4.0, it is essential to focus on three key features: (1) horizontal integration through value networks, (2) vertical integration within networked manufacturing systems, and (3) comprehensive digital integration of engineering throughout the value chain.

The emphasis on vertical integration pertains to enhancing manufacturing efficiency. Specifically, vertical integration refers to the adoption of the smart factory paradigm, which is characterised by its exceptional flexibility and capacity for reconfiguration. As a result, it is thought that the smart factory can manufacture tailored and small-scale products efficiently and cost-effectively. The Industry 4.0 framework is being progressively adopted in the production, distribution, and marketing sectors globally. The adoption of advanced methodologies represents a significant and intricate transformation, moving from traditional scheduling processes to the utilisation of intelligent reactants, which must be systematically applied at various levels. [7].

Take, for example, machines connected via the Internet that can support decisions by explaining their condition (bad or good) on a single screen. Additionally, the system will outline the viable choices that the manager intends to consider. This process inherently incorporates the optimisation of the potential options to be implemented in the event of a dilemma. It prevents the unnecessary consumption of resources that could have been utilised without advanced technological interventions. As a result, it significantly reduces the environmental impact of excessive resource usage by providing optimal options for resource management. The manager's skill set requires improvement, leading to potential job opportunities in the data science sector [8]. Additionally, the application of data enables industries to enhance their lean production processes.

Each department within the company possesses expertise in its respective phases of development, allowing for the collection of essential data throughout the ongoing process. As a result, the system solution will be considered a crucial factor in the decision-making process by evaluating each development stage. This evaluation will empower companies and managers to respond to changes with strategic countermeasures that address performance outcomes and initial slenderness levels at the project's outset, all with the support of stakeholders. However, to embrace the smart factory approach, entrepreneurs must make substantial investments due to the requirements of this advanced technology.

In a theoretical situation where small and medium-sized enterprises (SMEs) effectively embrace smart factory technologies, the implementation should aim to be both economical and more advanced than the existing proposals related to Industry 4.0.

A. Light Smart Factory

Light Smart Factory represents a modern approach to Industry 4.0 within the SME landscape. Initially, it targeted small manufacturers in the textile and footwear sectors, as these industries are the most prominent producers in the region under examination.

In line with this approach, they were examined to implement improvements observed in large industries to enhance production efficiency by minimising waste and reducing downtime [8]. Several studies support this strategy; for example, Gnanaraj [9] indicates that larger organisations often outsource tasks to SMEs, while Lin [10] found that SMEs frequently adopt the successful strategies of larger firms. Additionally, concerning SMEs, recent insights into Industry 4.0 and its implementation highlight benefits such as creating value for users and maintaining market leadership, based on research conducted in Germany [11].

While there are many positive effects to consider, it is essential to evaluate them within the specific context of Peru, where, as a result of the pandemic, both internet connectivity and the prevalence of SMEs have experienced a slight increase in e-commerce and cloud computing utilisation. Most approaches for introducing SMEs to the I4.0 framework stem from studies conducted in Asia. For instance, research from Taiwan suggests that SMEs need to achieve three objectives to begin their journey toward I4.0 integration: a) to create original products, meaning they should be the authors of their innovations; b) to produce intermediate goods; and c) to serve as intermediate distributors. Furthermore, a simplified model of a smart factory could be contemplated for SMEs, such as the following:

Light Smart Factory objectives:

- To enable small and medium-sized enterprises (SMEs) to adopt the best practices established within larger industries for improved efficiency, while simultaneously capitalizing on the flexibility that SMEs inherently seek.
- To successfully integrate expensive technologies into most manufacturing processes, it is important to recognize that these processes are continuously evolving due to the diverse range of products (and small production batches) that SMEs offer, driven by their considerable quantity and variety of clients..

- To achieve real-time data integration, we propose utilizing cost-effective technologies, including Arduinos and budget-friendly PLCs, in conjunction with open-source AI software.

According to various authors, including [13], two primary obstacles complicate the implementation of I4.0 standards: digitalization and the operational and logistical performance of small firms. Many Peruvian SMEs continue to rely on manual processes, as they have not adopted automated machinery for their operations. This emphasizes that a significant portion of their tasks is still performed by hand. [14].

In summary, the implementation of Industry 4.0 in Peruvian SMEs requires a dual approach. First, it is crucial to analyze the manufacturing processes in order to determine the conditions necessary for automating operations and how these can be achieved. Second, it is important to identify which processes are suitable for automation and which are naturally inclined toward it. This entails assessing how close SMEs are to adopting technology and understanding the actual utilization of technology within these organizations.

The foundational concept stems from the EASI model introduced by [15], in which the authors suggest that implementing smart factory practices in SMEs is achievable by leveraging methods that are Essential, easily manageable (Simple), cost-effective (Affordable), and compatible (Interoperable) with the existing manufacturing processes in Korean SMEs, particularly within the sewing industry.

Figure 1 illustrates the streamlined process of a smart factory, demonstrating how manufacturing machines, such as those employed by shoemakers or textile manufacturers, can be configured to transmit data to clothing via a smartphone. Although it may involve a different type of cloud infrastructure, the prevailing understanding is that all small and medium-sized enterprises (SMEs) in manufacturing employ at least one mobile application, leading workers to carry and utilize smartphones. From this point onward, this represents the foundational technological level envisioned as the starting point for an efficient smart factory.

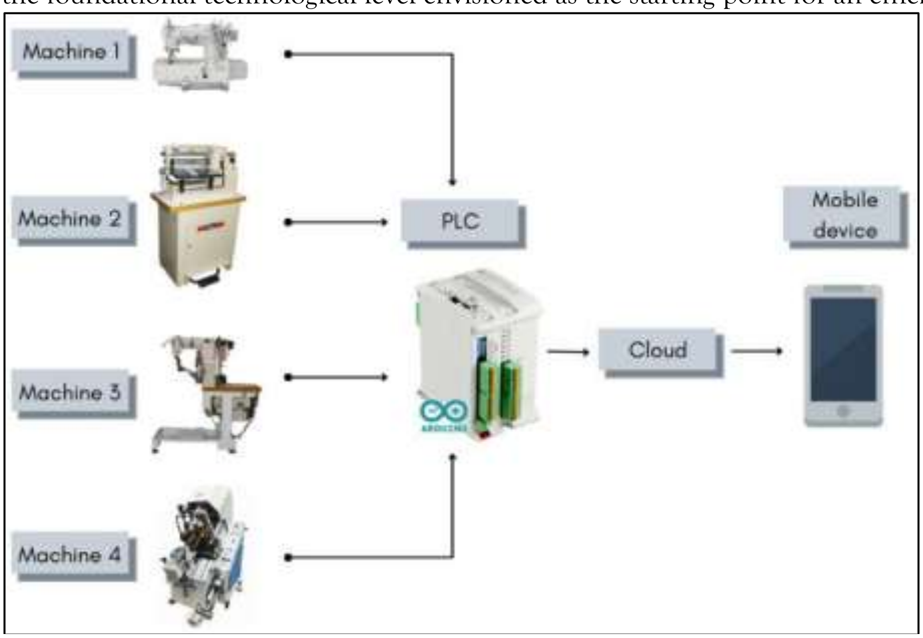

Fig. 1. Diagram of the function of Light Smart Factory

Figure 1 illustrates the interaction model between machinery and technology. In the context of Peru, it is essential to consider the adoption of cost-effective technologies. The next items explain these technologies.

An initial concept to be identified is the Internet of Things (IoT), because it continues developing itself day by day, it is estimated that this kind of related technology would take smart factories to the next level. Technologies such as big data, cloud computing, and robotics represent services that will further enhance development, exhibiting a certain degree of interdependence. The primary objective of the Internet of Things (IoT) is to facilitate connections on a global scale wherever internet access is available. This project is situated within the framework of the innovative Light Smart Factory initiative for SMEs in the Arequipa Region, which aims to develop and integrate a predictive system for the manufacturing sector. The case study specifically examines the machinery used in the production of high-quality leather [7]. Employing a computational simulation tool such as the Discrete Event Simulation Model (DES) will enable the testing,

identification, and reduction of bottlenecks in the workflow [16]. Small and medium-sized enterprises (SMEs) in the Arequipa region primarily function at an artisanal level, relying on minimal machinery or only the necessary equipment. One of the major challenges they encounter is bottlenecks; to address this issue, a proposal has been put forward for enhanced dynamic shift management through automatic control based on control theory.
Protocols for short-range wireless local area networks encompass Bluetooth, ZigBee, Z-Wave, WiFi, and Near Field Communication (NFC). In comparison, long-range and wide-area communication technologies include SigFox, Neul, LoRaWAN, as well as various cellular communication systems.
Figure 2 depicts the ways in which the Internet of Things (IoT) can facilitate the core processes of manufacturing. Furthermore, it delineates the pathway that should be adopted to ensure that small and medium-sized enterprises (SMEs) gain adequate access to Industry 4.0 technologies.

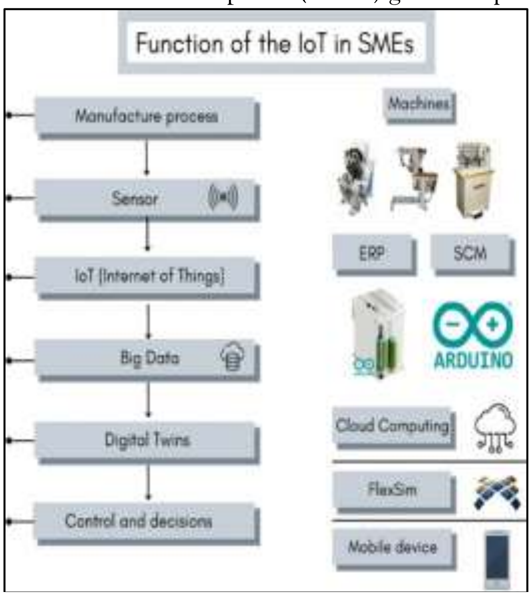

Fig. 2. Concepts of the functions of IoT in SMES

B.

C. Light Smart Factory Measurements: Leanness

The leanness concept was established as a manufacturing approach aimed at minimising waste while underscoring the importance of continuous improvement. These lean characteristics have been particularly emphasised during the early years of the philosophy's introduction. In this regard, these attributes have mainly been associated with the initial forms of leanness, specifically lean manufacturing or lean production. [18]. In this context, various methodologies have been proposed for evaluating organizational leanness, structured according to the logical framework of a hierarchical process. These methodologies are designed to facilitate the comparison of organizations from the perspective of their efficiency. In this approach, pairwise comparisons are employed to evaluate the leanness of organizations. The majority of SMEs do not possess a substantial production that can be analyzed. However, much of the research relies on the integrated index to assess organizational leanness, which is calculated as the sum of the scores from the simple or weighted items [20].
Figure 3 illustrates a flowchart that depicts the role of the leanness function within the SME. This functionality focuses on reducing downtime and promoting continuous improvement in the same process, with the primary resource for achieving this being the commitment of our team members.

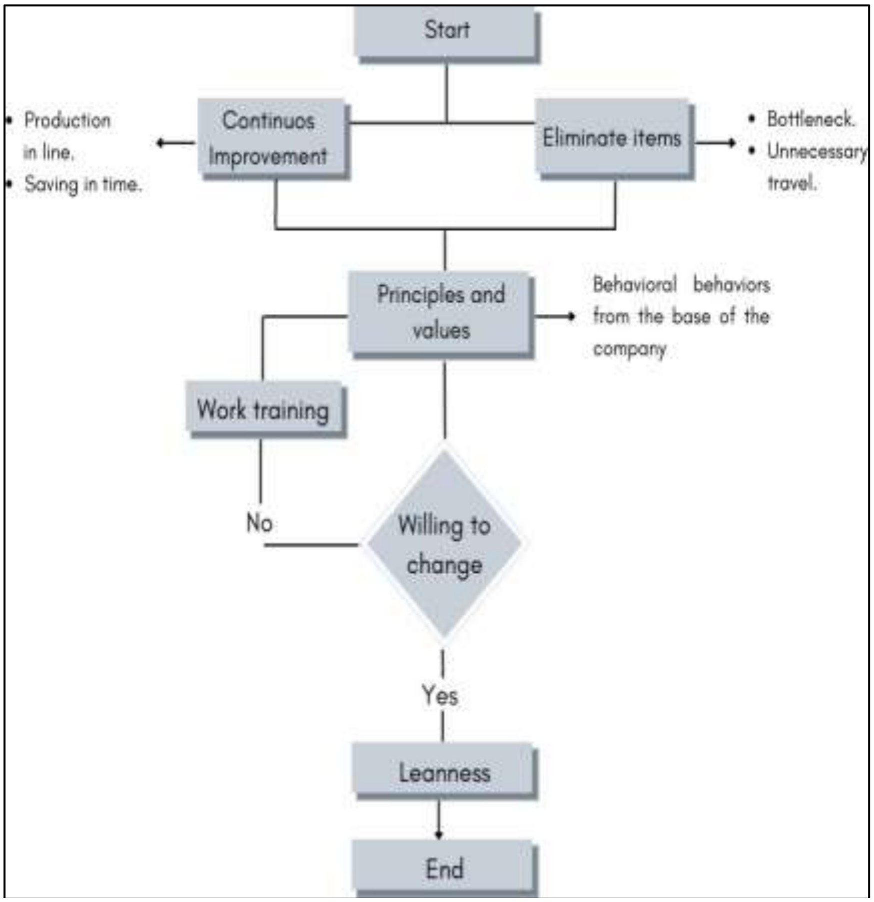

Fig. 3. Flow diagram of leanness working

Leanness is a fundamental concept in the Light Smart Factory framework, as its evaluation provides a more accurate indication of the impact of modifications to manufacturing processes. This is because leanness reflects the degree of waste reduction within an organization. However, further exploration of this metric is essential, and there are various methods available for assessing leanness in a company. Therefore, it is crucial to develop a methodology that enhances the measurement of leanness in SMEs after they implement light smart factory technology.

D. Light Smart Factory Mechanisms: Andon

By definition, this system is responsible for pointing out and warning of any problem that arises through an alarm system that seeks to take solution measures with quick responses, so the Andon system helps to improve quality and avoid future errors. [21]. Andon, a term derived from the Japanese word for paper lantern, refers to a visible control system that incorporates an electric light board (or other signalling devices) positioned near a machine, enabling a worker to request assistance and halt the production line. It has been noted that although productivity may suffer due to these interruptions, the overall quality of the products has improved, specifically regarding the labour production rate, which measures the average number of high-quality parts produced within a given time frame.

As outlined by [24], the methodology for the decision-making support system will be employed during the development phase of the project. To begin, the IoT ecosystem comprises smart devices, including sensors and communication hardware, that gather, process, and transmit data. The Andon system will notify production via IoT as needed, serving as a tool that provides insights into machine operations and information regarding production lead times or the number of units produced within a given timeframe. Following this, the collected data will be utilized in a simulation to improve decision-making based on real data outputs. The system is organized into three components: data collection, data storage, and simulation and decision-making.

- **Data Collection**

Sensors are employed in the production area to gather process data through programmable logic controller (PLC) systems. This data will be stored in the machines' database before being transmitted to the server via the intranet. Employing MySQL commands, this information is organized and encoded to meet the simulation input requirements. This process forms the foundational framework for the networking system that enables Industry 4.0. Through this concept, all physical devices can connect to the Internet. It is recommended to utilize the Andon system to encode the data in a meaningful and efficient manner, demonstrating how LMT (Andon) data can be simulated to facilitate decision-making.

- **Data Storage**

By leveraging a database connected to the Internet, data is stored on physical servers that are managed and monitored by a cloud computing provider. Following the collection of the dataset, analyses are performed using simulation software, with cloud computing facilitating the storage of this information in the database as part of a server for computer services. Different colours are assigned to configure readings and status indicators. The use of colour coding is regarded as a vital component of Andon signals, as various colours can convey specific meanings and prompt swift actions by process operators, management, and supervisors.

Each machine in the production line will be equipped with an Andon signal display board, which alerts personnel when a problem arises within the production or quality processes. Typically, the activation of the Andon system is initiated by pressing a button, which automatically halts production and allows the team to gather, implement the Plan-Do-Check-Action (PDCA) cycle, conduct a root cause analysis, and quickly execute a solution. The warning lights are prominently displayed on an overhead sign, which also facilitates the identification of the specific area or workstation associated with the issue.

- **Simulation and Decision Making**

Simulation experiments evaluate the resource requirements and performance of each system, thereby quantifying the benefits derived from the application of the fundamental principles of lean manufacturing. To illustrate the Decision Support System, Discrete Event Simulation (DES) will be employed as a tool to assist organisations in deciding whether to implement Lean Manufacturing by measuring the advantages based on specific circumstances. DES is one of the most prevalent techniques for resolving production issues. Before a decision is reached, the DES model is utilised to predict the system's response for the optimal configuration of decision variables obtained from the optimisation module. The results of the decision-making process will be analyzed in light of business rule management. Additionally, organisations must foster a culture of evidence-based decision-making centred on continuous improvement. A lack of knowledge regarding the organisation's business rules, including problem complexity, insufficient accurate information, and financial constraints, will influence the output results.

E. Light Smart Factory Scope: Digital Twins

Initially, the Arduino technology was going to be used because it is less expensive and accessible for SMES, and the programming code is open. However, from the research and attendance at conferences on technologies implemented in SMES, a new simulator software for production processes became known. This is how it is concluded that managing and implementing research about digital twins that allow to use of data to recreate simulations will serve to predict how a process will work.

Digital manufacturing has delivered significant advantages to the entire industry over the past several decades. Through the creation of virtual representations of factories, resources, workforce, and associated skill sets, digital manufacturing facilitates the development, modelling, and simulation of products and processes. The evolution of information and communication technologies (ICT) has greatly accelerated progress in the manufacturing sector. In recent times, digital twin architectures have gained popularity, fuelled by advancements in essential technologies such as CAD, CAE, PDM, Big Data, cloud computing, and the Internet of Things (IoT). This trend is particularly significant in the context of the fourth industrial revolution, with a strong emphasis on artificial intelligence and information communication.

All these technologies provide opportunities for the integration of the physical world and the digital world, which is an inevitable trend to address the increasing complexities and high demands of the market. However, the full strategic advantage of this integration is not being fully exploited. The process of this integration is a long way to go and the most recent developments focus on Digital Twin (DT) [30].

According to Kuhn [31], DTs are digital representations of material or immaterial objects, such as machines, in the real world. They allow a complete data exchange and can contain models, simulations and algorithms that describe their physical counterpart and their characteristics and behavior in the real world.
In simple terms, digital twins consist of creating a virtual replica of an existing physical entity linked to a database. To achieve this, Liu, Shuiliang, Dong & Xu [30] points out that there are 4 phases to implement digital twins in a manufacturing process. Through an in-depth summary and analysis, the types of digital twins applications are identified in different phases of the life cycle, including three applications in the design phase, seven applications in the manufacturing phase, and five applications in the phase of service [30].

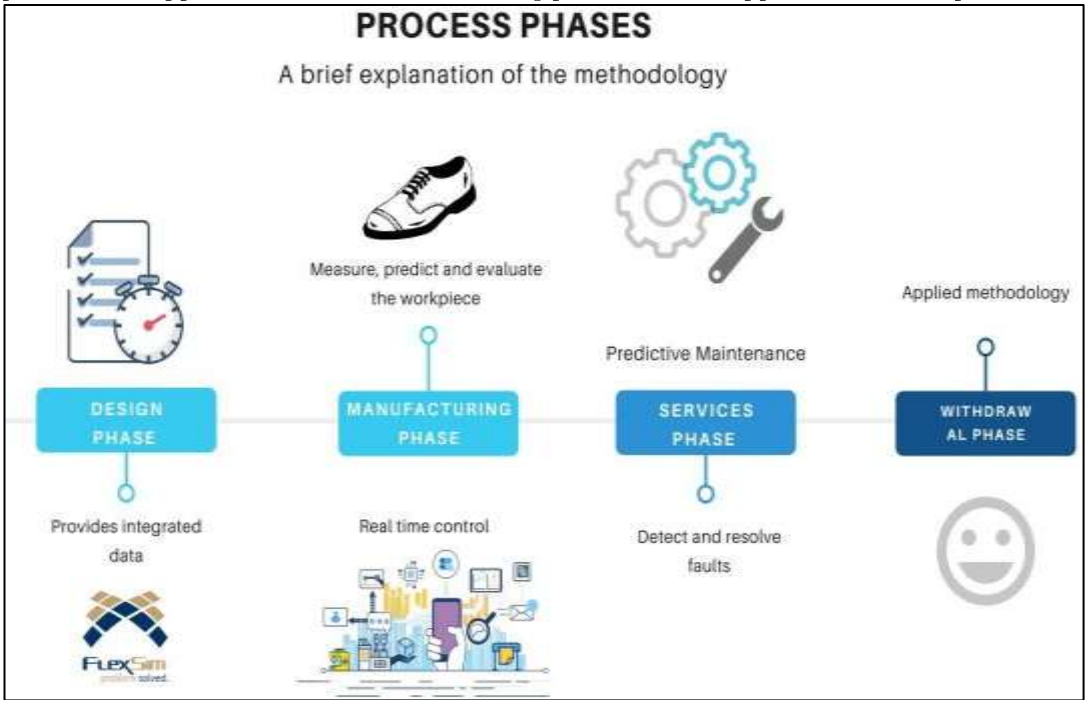

Fig. 4. Industrial applications of digital twins in different lifecycle phases. Adapted from [32]

From the author's point of view, each of the phases is necessary; however, we have to adapt them to the needs and characteristics of the manufacturing process itself. Therefore, at the time of conducting the respective investigation, it will be determined which are sub-phases will be implemented.

F. Light Smart Factory: The Process

Starting with the premise that it is possible to apply the Smart Factory approach in SMES, mutatis mutandis, the first part is always to find a group of entrepreneurs who are able to elicit their manufacturing problems and then purposefully manipulate experiments within their production cycle. For the sake of simplicity and the congruency of the proposal, manufacturing would be as intermittent as possible, because it is better if the production pursues a normal distribution for standardised times and other procedures related to the lean manufacturing approach.
This way, it was possible to get in conversations with two shoemakers and one sewing producer who allows us to perform some experiments in order to apply some cheap technologies. These firms are medium-sized firms in the region, i.e. they have at least ten employees as direct labour and over thirty or more indirect labourers in their staff. For research purposes, it means that they pursue intermediate technology and they have made some additional investments in technology than similar firms or indeed competitors. However, to converge with the objective of attending less sized SMES, for instance, familiar entrepreneurs or individual firms (that are the most likely sized firms around) were intended to review cheap technologies like Arduino, as suggested by the EASI model. Arduino was considered a viable option for the characteristic of offering a detection system that combines quantity, temperature, humidity and UV rays measurements and also pursues wireless connection. All of these features generate many possibilities to articulate technological proposals at low cost. In addition, Arduino could be put anywhere in the factory and is able to be used to take measurements in real-time in concordance with the IoT approach [16], and it is as flexible as possible to

attend to the different protocols used in the industry [6]. Arduino programming allows for automating and controlling processes. The possibility of conceptualising the application of AI and augmented reality (AR) towards the visibility of the manufacturing process of machine stators through robotic vision was studied [18], but seeing the reality of the footwear industry in the city, it seems more convenient to continue with Arduino programming.

3. SITUATION AND RESULTS

A. Current Situation of SMEs to Work

For the development of the research, agreements were signed with three SMEs, two in the footwear area and another in sewing, all of them based in Arequipa.
SME 1: Dedicated to the textile industry, dedicated to the production of t-shirts, jackets, and uniforms. This company is moving to a new space to be able to maximise its operations, mainly producing for the southern region of Peru. After making a detailed study of its operations, it was concluded that applying the Light Smart Factory concept to the cutting area, where it produces a lot of downtime, bottlenecks.
SME 2: Dedicated to the footwear industry, its production focuses on products for export to Bolivia, where it sells more than 60% of its production, manufactures school shoes, women's shoes and sports shoes. After conducting a detailed study, it was seen as convenient to apply the Light Smart Factory concept to the assembly area, where the greatest amount of downtime and bottlenecks occur.
To digitise the cutting area, it was proposed to place tablets in the assembly machines and apply the Andon concept; in this way, the operator can make decisions at the time of failure. Later, the data collected by the sensors will serve as a database to apply the Digital Twins and to be able to simulate the area and find optimisations.
SME 3: Dedicated, like SME 2, to the footwear industry, the latter being much larger in size and production compared to those previously studied, the company produces for the entire southern region of Peru, exports to Bolivia, and has as goal to enter the Lima market, said company has three production lines being luxury footwear, safety footwear (TNT), school footwear and for women, it also has an external line dedicated to the production of soles for export and use for its products. The most stable line over time is that of safety footwear (TNT), and it is for this attribute where it was recommended to start the investigation, unlike the previous SMEs, in this particular a Lean Six Sigma will be carried out due to the complexity of analyzing each area in detail, in meetings with the area managers and principal manager, one question was highlighted from the owners: If I have the same machinery and accessories as my competitors, why can't I match production with my main competitors? At the end of the Lean Six Sigma study the area where the Light Smart Factory concept will be tested can be identified.
For digitization, it is required to first finish with Lean Six Sigma, find the area where the Andon concept would be applied, in this area, tablets will be required for each machinery and a screen located in the upper part where operators can see their real time progress towards the proposed goal. With the data collected in each tablet they will serve as a database for the Digital Twins, and be able to simulate the entire area and be able to find solutions even when the problem does not yet exist

B. Former Results

Three entrepreneurs agreed to take part in the study and opened their doors to research after some local companies were contacted to explain and investigate how the light smart factory could be established in the real world.
Following an initial diagnosis, it was discovered that two of the SMEs, surprisingly, use an ERP system that tracks output but shows that they are unable to produce at the time the ERP prescribes.
Therefore, the first method proposed was to create a digital twin, which entails creating software that uses a computer to mimic the behaviour of industrial processes. Consequently, it must be feasible to figure out how to automate the primary procedures. In the meantime, it was possible to identify four production areas as a whole: cutting, modelling, manufacturing and finishing. The most problematic of them is the cutting area, so it is possible to affirm that it is the hardest one to automate. However, this last serve to indicate that applying the Light smart factory concept, it is so difficult to think about the short term. It may take around one year of research.

4. CONCLUSIONS

In order to make effective decisions, it was viable to work with three case studies that were part of the Light Smart Factory application. These case studies included data gathering by Arduino sensors and the Digital Twin modelling of their processes. Since it is a method that SMEs can afford, we think it will be improved further, increasing the potential and problems of the transition from SMEs to Industry 4.0.

Through the combination of sensors, the suggested approach will assist us in creating unique technologies. Light Smart Factory is situated in Industry 4.0, which is the final phase of the Fourth Revolution. In this way, Peruvian SME will be able to diminish their lead time and ramp up their production in order to be more competitive.

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