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INTEGRATING SIMULATION-BASED OPTIMIZATION, LEAN, AND THE CONCEPTS OF INDUSTRY 4.0

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ABSTRACT

Nowadays, due to the need of innovation and adaptation for the mass production of customized goods, many industries are struggling to compete with the manufacturing sector emerging in different countries around the world. The understanding and implementation of different improvement techniques is necessary in order to take part in the so-called fourth industrial revolution, Industry 4.0. This paper investigates how two well-known improvement approaches, namely lean and simulation-based optimization, can be combined with the concepts of Industry 4.0 to improve efficiency and avoid moving production to other countries. Going through an industrial case study, the paper discusses how such a combination could be carried out and how the different strengths of the three approaches can be utilized together. The case study focuses on how the efficiency of a production site can be increased and how Industry 4.0 can support the improvement of the internal logistics on the shop floor.

1 INTRODUCTION

Simulation is a powerful and widely recognized technique for approaching the current challenges in the manufacturing industry. Industrialized countries are often struggling to keep the growing manufacturing sector within their borders. New manufacturing factories are being built from the very beginning to adapt to the tendency going from mass production to mass customization while increasing profitability (Comstock, Johansen, and Winroth 2004). Manufacturing will then be highly flexible at the volume and customization level of production, firmly integrated among costumers, companies and suppliers, and above all sustainable (Shrouf, Ordieres, and Miragliotta 2014). Hence, mainly due to the incorporation of emerging countries with lower-cost labor and major tax-benefits for the international industry, those countries with a well-established industrial sector have seen how major factories have moved abroad. However, in many cases, the costs of transport, logistics and education are significantly increased and the expertise of factories with a great deal of industrial tradition is lost (Fang, Gunterberg, and Larsson 2010). For these reasons, there is a huge effort placed by corporations in different technologies to improve the production in existing factories in order to avoid the alternatives of shutting down or relocating.

Some of the technologies being the base for improvement approaches are simulation-based optimization (SBO), lean production and the innovative concept of Industry 4.0. Lean is an improvement method founded in Japan to improve the manufacturing industry after the Second World War. Industry 4.0 is a promising paradigm based on the emerging technologies of Internet of Things (IoT) and Cyber-Physical Systems, defined to increase the efficiency in manufacturing (Shrouf et al. 2014). These concepts together with SBO have a huge potential to improve production in middle-size and large manufacturers. The implementation of these Industry 4.0 concepts can significantly increase or improve

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production quality, efficiency, flexibility, and security (Shrouf et al. 2014). In this paper, a literature review of Industry 4.0 and SBO combined with lean is presented. A case study with SBO and lean to analyze the feasibility of merging two production lines to increase efficiency is presented. Furthermore, how Industry 4.0 can complement this optimized scenario is discussed.

The structure of this paper is presented as follows: Following the introduction, a literature review of SBO and lean in manufacturing is presented in Section 2 and a review of Industry 4.0 and IoT is presented in Section 3. Section 4 introduces the above-mentioned case study with SBO and lean to merge two production lines and Section 5 presents an analysis to feed these production lines and the potential benefits of Industry 4.0 for this implementation. Finally the conclusions are presented in Section 6.

2 SIMULATION-BASED MULTI-OBJECTIVE OPTIMIZATION AND LEAN IN MANUFACTURING

During the 21st century, simulation has started to be a key technology for supporting and improving many different kinds of systems. Simulation presents a huge potential for product and manufacturing process development and improvement (Tempelmeier 2003). Building detailed simulation models of the different production and logistics systems is the base for a good system understanding and analysis. Nowadays, there are different techniques for process improvement. All of them have different applications for a great variety of more specific purposes such as different process improvement and design or feasibility studies. Some examples of process improvement approaches are linear programming, Markov Chain Analysis, Discrete-Event Simulation (DES), System Dynamics, Monte Carlo Simulation or Value Stream Mapping as well as some other lean approaches.

DES is often necessary in order to model and represent the complex and stochastic flows in production lines and logistics systems (Tempelmeier 2003). With the use of these DES models, system analysis and comparisons of different parts of the shop floor can be done easily with relatively minor investment. DES provides the results of specific what-if experiment scenarios. However, in order to analyze several scenarios, a large amount of modelling time is usually required, and although an improved scenario can be found, an optimum solution cannot be guaranteed. Since simulation is not an optimization tool by itself, a step that combines simulation and optimization is needed (Pidd 2012). SBO can be especially suitable in those cases where what-if scenarios can become a time consuming and tedious task due to the increasing amount of possible solutions.

Depending on the type of problem to analyze, there are different optimization methods that can be combined with simulation of which several are presented by Figueira and Almada-Lobo (Figueira and Almada-Lobo 2014). SBO facilitates the search for trade-offs between several conflicting objectives (Deb 2001). Moreover, if there are multiple objectives to be analyzed at the same time, SBO is the best approach (Ng, Svensson, and Urenda 2008). These characteristics make this approach suitable for improving complex manufacturing systems with several conflicting objectives.

On the other hand, during the last decades, lean has been commonly adopted by many manufacturing industries around the world (Melton 2005). Although there is consensus on the definition, "it is a philosophy that when implemented reduces the time from customer order to delivery by eliminating sources of waste in the production flow" (Bhasin and Burcher 2006). The lean concept evolved from the Toyota Production System after the Second World War in Japan. Based on some research studies on the huge success of Japanese automobile manufacturers, Womack, Jones, and Roos (1990) originally used the word "lean" to describe the Japanese manufacturing philosophy with Toyota as the leading company (Womack, Jones, and Roos 1990).

During the 1980s and 1990s, automobile producers around the world started to realize the power of this philosophy, benchmarking the production and product development systems of the Japanese car manufacturer based on the vision of its founder, Taiichi Ohno (Liker 2004). Continuous improvement started to be the focus of this genuine learning enterprise (Liker 2004). Since then, lean production has become widely adopted in manufacturing companies. The main principles that led to this revolution of the

Toyota Production System were its long-term philosophy, that the right process will produce the right results, adding value to the organization by developing your people and partners, and continuously solving root-problems that drive organizational learning (Liker 2004).

Several authors have reported the use of SBO with lean for the improvement of manufacturing systems (Uriarte, Moris, Ng, and Oscarsson 2015; Yang, Kuo, Su, and Hou 2015). However, a methodology based on SBO and lean is not commonly presented in manufacturing (Uriarte et al. 2015). Furthermore, many articles about how the concepts of Industry 4.0 can support lean and SBO within manufacturing are absent in the literature.

3 THE INTERNET OF THINGS, FACTORY OF THINGS AND INDUSTRY 4.0

Principally due to manufacturing systems around the world representing a significant growing share of the global trade, and due to the increasing demand of individualized products and natural resources, manufacturing is becoming more challenging than ever (Herrmann et al. 2014). The IoT is a technology based on physical devices embedded with electronics, usually with a wireless internet connection. It is fueling the fourth industrial revolution as well as some other technological revolutions such us Space 2.0 and Health 2.0 (Sacchi et al. 2015; Van De Belt et al. 2010). The IoT is considered to be the key technology to support the implementation of the concepts Smart Factory, Factory of Things (FoT), Factory of the Future, Smart Manufacturing etc., as the extension of the IoT concept to manufacturing systems (Gilchrist 2016; Zuehlke 2010).

Industry 4.0 is considered to be the next step of the evolution of industry following the integration of information technology and automation systems in manufacturing (Dumitrescu 2017). This next step aims at integrating the new technology of IoT to build Cyber-Physical Systems to allow most of the different actuators present on an industrial shop floor (machines, robots, processors, computers, workers…) to be connected to their surrounding environment, databases and to the outside world in order to interoperate and cooperate to achieve individual as well as jointly aggregated goals. This can help to achieve the increased flexibility levels required in production to adapt the capacity to a nowadays more variable and customized demand (Askar et al. 2007).

The concept of FoT can cover from the product design stage to the production planning, final assembly, and shipment of products (Radziwon et al. 2014; Weckesser 2016). The IoT and FoT are intended to help fill the existing gap between the physical world of industrial systems and its representation in information systems (Haller, Karnouskos, and Schroth 2009). However, in large manufacturers' shop floors, this technology is still far from being completely implemented. One major consideration of this Industry 4.0 concept, besides the extensive digitalization and monitoring effort performed, is that still large shop floors are far from being considered as a smart factory, the FoT or the Factory of the Future (Vermesan and Friess 2016). Generally, there are no machines, robots, or production cells communicating with each other to achieve an optimized flow that depends on the demand and individual performance. Instead, in the most successful cases, the machines are usually connected to a central system where the data is collected, analyzed and presented as performance information.

The goal is to have a compound system where different production cells, machines, robots, and devices are interconnected, usually with a wireless connection, to improve and make more efficient production systems (Shrouf et al. 2014). This common wireless connectivity of many devices at the same or different locations or even factories would help establish a highly reliable communication infrastructure where every entity is able to know the state of every machine, device, worker, and product at every time. Most of the information will be shared at the different stages of creating and manufacturing a product. In this way, the device will inform itself about its new position, will adapt to the devices upstream and downstream, and will adapt to its required tasks and production pace. This will allow for sending or receiving data that can help monitor, control, design, program, maintain, and coordinate, among other tasks, those devices in cooperation with all the devices connected or related to that system.

Regarding the information management through databases, the main idea is to have most of the information required by the devices stored in data clouds where remote and distributed processors can access, work with, and modify these common and shared information systems and databases (Gubbi et al. 2013). This technology can be significantly useful when the amount and complexity of the connected devices is not easy to manage in traditional systems. The foundation for achieving Industry 4.0 is starting to be present in many companies with digitalization, monitoring, and integration of production processes. This base should help the future launch of Industry 4.0 and the implementation of real FoT, Smart Factories or the Factories of the Future. Meanwhile, many issues still have to be addressed, such as compatibility of different devices, the concept of "plug and work," more flexibility of machines and devices, reliable wireless communication infrastructures and, finally, security and privacy aspects.

In Section 4, an industrial case study with SBO and lean to improve a production system is presented. In this case study, the important potential to implement the concepts and ideas of IoT and FoT to improve the production is presented in Section 5, Industry 4.0: A more tangible implementation within internal logistics.

4 INDUSTRIAL CASE STUDY

In order to study the possibilities of combining SBO, lean, and Industry 4.0, the use of SBO and lean to analyze the feasibility of merging two production lines in the main shop floor of an industrial partner is discussed. It has been identified that the combination of SBO, lean and Industry 4.0 concepts potentially can be useful for achieving and extending system improvement regarding the production lines, internal logistics, and shop-floor layout. This section is sub-divided into an introduction, the simulation modelling part, the lean production approach and the results.

4.1 Introduction and Problem Description

The objective in this case study is to develop different concept layouts to obtain a more efficient production, considering the merging possibilities of two production lines. The industrial partner has an approximated production of 100,000 units per year with around 300 versions in their main shop floor. There are around 1,200 employees in the factory, 800 of whom are directly related to the manufacturing process. There are eight production lines in the main shop floor and the main objectives are to increase the efficiency of the production lines, to reduce the amount of forklift-truck traffic, and to analyze the possibilities of freeing space in the shop floor in order to expand production.

The production lines share the available space on the shop floor with different machining areas, production of different components, and painting and packing stations. Furthermore, large decentralized storage capacity is dispersed along the shop floor to ensure there is no lack of materials or components at any time. This distribution creates a dense traffic situation with the risks that this generates. Most of the accidents in the factory are related to forklift-truck driving and human factors.

The two production lines in question to be analyzed, lines A and B, have been considered the starting point of a major ambitious and long-term redistribution plan in the factory to meet the production envisioned for the coming years. The actual state of the shop floor, with plenty of manual processes combined with new automated cells and endless improvement possibilities, combined with this vision of the company, made this industrial partner the perfect candidate for the development of this research.

4.2 Simulation Models

The simulation methodology used is based on the simulation steps presented by Banks (Banks et al. 2005). Due to the complexity of the systems to analyze, DES was chosen. After defining the objectives and the description of the problem, data collection and model tasks followed. The problem formulation was based on the shop-floor layout space limiting the expansion and development of new long-term plans as envisioned by the company. The objectives of the project are to develop several proofs for concept models of the possible alternative solutions to improve two production lines, aiming at the production of an increased amount of versions and at the merging alternative.

Once the problem and objectives were clearly defined, it was possible to start model conceptualization and data collection. These steps are the "key steps" to a good model in order to obtain accurate results. The required data can be collected by using historical records, work measurement procedures or estimates from subject-matter experts (Freivalds and Niebel 2009). When not available, however, historical data can be enough if based on the records of similar, previously performed studies that can serve as an estimate of the required data (Freivalds and Niebel 2009).

In this project, a great amount of available data for the new technologically adapted production cells existed; however, there was an important lack of data on the more primitive machines and manual processes. Time studies were required and time standards were applied in different processes of the production lines to obtain accurate data from the real system. With the help of operators and extra resources, some sub-projects of data collection were organized to obtain the requested processing times of all the processes in the production lines. A clear definition of the boundaries (start and finish moments) of every process had to be made to perform accurate measurements.

Common problems in this data collection phase are the large amount of different product versions and the amount of non-reliable data. On the one hand, there were different versions with different process times, sometimes with significant differences. Due to this reason, an analysis of the versions with similar characteristics was performed in order to group them into bigger families to simplify the data collection process. Nine version families were defined and the processing times for each of them were collected. On the other hand, non-reliable data is generated automatically by the system when the data of a product or process is not introduced correctly by the staff or device, or when some activities are interrupted Therefore, some boundaries, previously specified by experts and managers, were established in the different processes and classifications of products.

In parallel, the construction of the conceptual model was performed. The conceptual model of a system is an accurate representation of itself. It can also be considered as a detail process mapping of the production lines in this case. It is useful for understanding the system, when establishing the processes to model for the purpose of the project, and to define the data necessary for the model construction. In this case, all the processes represented in the conceptual model were revised by going through the system as a product. In order to explain why and which processes that were rejected from the conceptual model, a list of assumptions was created. These assumptions contain the information of all the specific cases that were rejected since they were not considered important for the aim of this project. Once the model conceptualization and the data collection are finished, it is possible to start with the model translation.

In order to translate the conceptual model into the simulation model, the software tool FACTS Analyzer was selected mainly due to its DES and optimization capabilities combined with a user-friendly interface and without additional major programming efforts (Ng, Svensson, and Urenda 2008). Nine different kinds of product versions in the merged solution of lines A and B were represented in three optimized scenarios: One scenario with a fishbone concept, mounting some of the components outside the main flow of materials, one scenario with separated mounting cells, and a third scenario with a common flow of materials. The three scenarios are optimized to minimize the buffer capacity and amount of operators while maximizing the throughput. While the first scenario has a main production flow with some parallel stations outside the main flow to meet the demand of different versions, the second scenario has an independent production flow and processes for some specific product versions (20% of the total amount of products). The mentioned 20% of special versions are produced in a separated area and then added to the main flow of products. The third scenario has a common flow for all the versions, thus, the working stations have to be more flexible to be able to work with the different product versions.

The original simulation models had to be verified and validated in order to consider that the simulation represents the system as it is. Verification is a determination of whether the computer implementation of the conceptual model is correct (Banks 1998). In this case, to perform the verification, every different family of products and staff of the model was monitored during a few simulations to ensure they performed their processes and tasks as they should. The number of resources, product versions, and schedules was also revised. The next step was to validate the model.

A replication analysis and the definition of the warm-up period were implemented to avoid the variability of the output of the model and to know how accurate the obtained results were. Minor deviation of the results was noticed running twenty replications on nine days with a warm-up period of four days of simulation. At this point, the model was verified and validated when the comparison of results of the real system and simulation model was accurate enough. The validation was mainly based on the parameters of lead time and throughput of the different main version families of the production lines.

4.3 Lean Production

After analyzing the results of the original system and the three main scenarios, refined simulation models were built considering some of the lean production concepts that appeared promising for the improvement of the production lines. These concepts must have a clear flow and effectivity in production, emphasize the value creation processes, include waste identification and reduction, and have the just-in-time and pull system approaches. Implementing these concepts based on lean principles to improve the system was the focus of this application. Figure 1 presents a diagram representing these main principles for continuous improvement in manufacturing systems.

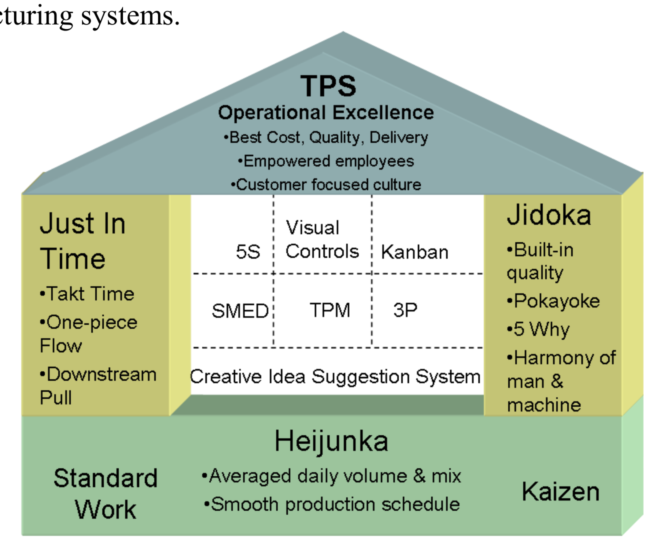

Figure 1: Toyota Production System (TPS) principles (Liker 2004).

This figure represents the basic pillars the Toyota Production System: standardization, balancing (Heijunka), Kaizen workshops for continuous improvement, just-in-time production and the Jidoka concept to find the root causes of problems. All together combined with the expertise of the different production team members point at the operational excellence of the Toyota Production system.

The three scenarios of the merging alternatives of the production lines were improved by considering the mentioned lean concepts and principles. Several meetings with the operators, supervisors and managers were arranged. Kaizen Workshops, and Genchi Genbutsu (get the shop-floor perspective of the problems and improvements) were continuously performed during the development of the project with the different production team members.

With an iterative improvement process combining lean and simulation, the results of the different alternatives considered for merging both production lines were found. The best alternatives were optimized for different amounts of operators and different processing time variation for the versions of products in the new production line. Some of the results are presented in the following sub-section.

4.4 Results

The results of this SBO and lean project are a range of optimal alternatives to merge both production lines. The optimization study measures the throughput against the amount of workforce required and the variation in processing time of the different merging alternatives. Figure 2 shows the throughput (TP) for each of the three mentioned alternative scenarios, presented in the first column, combined with the standardization work in processing time of the different variables (low, medium and high variation in processing time), presented in the second column. Additionally, the extra workforce variation, is shown in the third column. These three parameters are presented against the throughput expressed in the Y axis. As mentioned earlier, the three scenarios considered to maximize the output of the system are: Scenario 1 with a fishbone concept by mounting some of the components outside the main production line, Scenario 2 with separated mounting cells for the different flows of products, and Scenario 3 with a common flow of products with shared mounting cells.

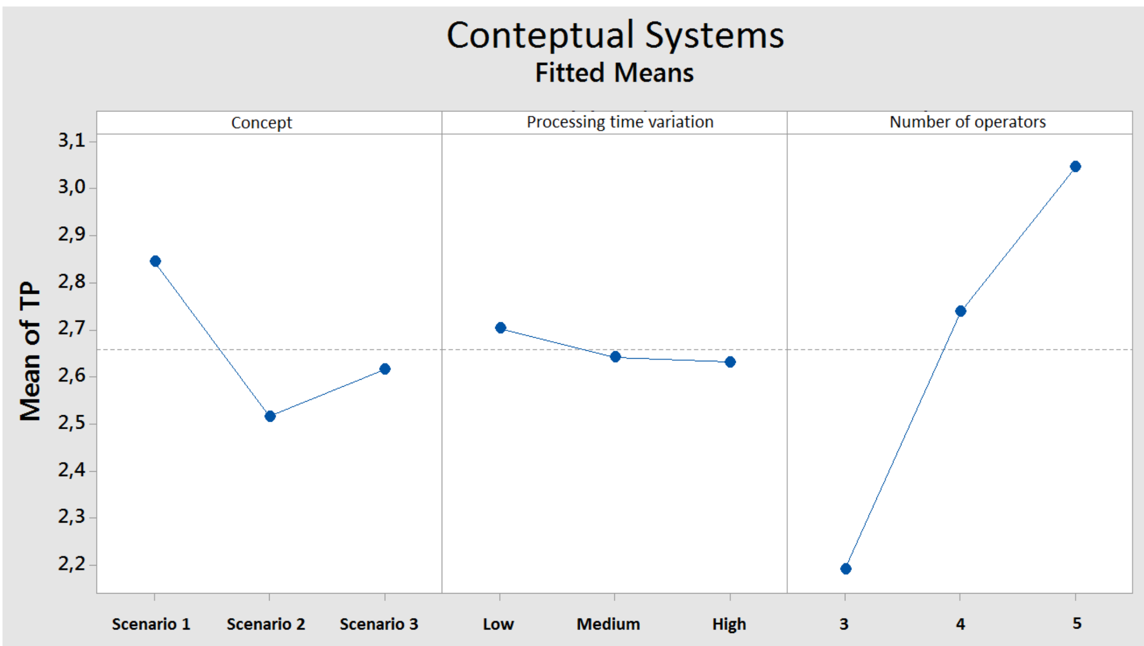

Figure 2: Throughput results for the three scenarios, processing time variation, and number of operators.

The different processing time variation, Low, Medium, and High represent the variability of the time needed to perform most of the tasks for the different product versions. Low represents the lowest variation in processing time, achieved with extensive work with standardization of the processes for the different product versions; Medium represents an improved reduced-product variation by standardizing some of the tasks in the production line; and High represents the originally considered processing times for the different product versions. The throughput of the two original production lines was reached by the throughput of the new merged designed scenarios with half of the original workforce. A relocation of these operators to perform other tasks on the shop floor was considered.

Going through the results, different optimized scenarios to perform the merging implementation are compared and valuable knowledge for managers and stakeholders is presented. It is clear how by expanding the workforce in this new production line the throughput increases, but also how by adding a second extra operator it results in a more significant impact than if adding a third one. A significant impact on throughput by changing the layout of the production lines can also be estimated. In the same way, it is possible to estimate how the throughput results of working with the processing times of the different versions affect the system; however, it showed to be less significant than expected by production managers. The following section presents how the concepts of Industry 4.0 can contribute to the general improvement of the production and the implementation of the new production line.

5 INDUSTRY 4.0: A MORE TANGIBLE IMPLEMENTATION WITHIN INTERNAL LOGISTICS

Industry 4.0 and the concepts of IoT and FoT can be implemented in a wide range of manufacturing industries (it has to be considered that a certain level of automation is required). In this project, in order to support the new production lines improved with SBO and lean, an analysis of the future state of the shop floor implementing this technology is presented.

The main shop-floor layout taken into consideration can be divided into machining and assembly, supported by a complex internal logistics system with several storage areas acting sometimes as buffers disseminated along the shop-floor layout. There is storage for incoming goods from internal and external suppliers as well as buffers before and after the different machining centers and production lines. Most of the required internal logistics are performed by forklift trucks using pallets as containers. Generally there is a lack of communication between the production lines and the machining areas. Additionally, information regarding the amount of available places in the different buffers and storage areas is usually not available. This situation generates a huge amount of traffic in specific parts of the shop floor where important flows of people and other transports converge. As already mentioned, accidents involving human errors amplified by the use of forklift trucks are not isolated issues. The following sub-sections are dedicated to the main areas for improvement analyzed in this research considering Industry 4.0: buffers and storage, material flows and internal logistics.

5.1 Buffers and Storage

In order to improve the overall system and to find solutions that follow the future-vision plans of the factory (such us increased production, space restructuration, new production lines for new products etc.), some studies show how the redistribution of the store capacity on the shop floor can be rearranged and minimized. Some studies point to the advantage of having a Material Preparation Area (MPA) or central kitting area located on the shop floor in order to receive and supply material for the machining area and the production lines. The integration of Industry 4.0 in this implementation has to consider the monitoring and control of the storage levels, input and output flows of materials, transports, production planning and demand. Every item going through these storages and buffers should be uniquely identified and this information shared in real-time with the interconnected devices.

Both possibilities of having the storage areas needed to feed the lines located in a dispersed manner or having a central storage area have been analyzed. Several meetings with the managing team of the factory, production managers, and operators were performed when analyzing the potential Industry 4.0 benefits. Lean approaches combined with the knowledge obtained from different simulation models were analyzed and discussed. Finally, it was demonstrated that a mixed-model solution could fit the necessities and requirements of internal and external suppliers on the shop floor; a central MPA could free more space, especially in the production-line area. Additionally, it would reduce drastically the traffic around the production lines where usually the transit of people is concentrated. However, to fully benefit from the implementation of Industry 4.0 technology, the internal logistics have to be entirely redesigned to cover the pick-up and delivery of material to these storage and buffer areas. This is presented in the sub-section 5.3 Internal logistics. Following the analysis of the different flows on the shop floor is summarized in 5.2 Material flows.

5.2 Material Flows

Having as a point of departure a solution with a MPA complemented with disseminated small buffers, as mentioned before, a priority was to monitor the stock levels and the input and output flows of materials. The input flows of this MPA coming from internal as well as external suppliers and the foundry of the factory have to be analyzed, classified, and stored. In some cases, the material should be classified and reunified to be prepared in kits into standard plastic boxes or pallets. Every product in these flows should be uniquely identified by RFID or barcode readers and additionally, in order to reduce failures, augmented reality could be used for complex or tedious tasks of pick-up and classification (Syberfeldt et al. 2016). The output of this MPA also had to be identified and a just–in–time automated transport system seemed to be the most suitable solution to cover the transport of boxes and pallets to the different machining cells and eventually directly to the production lines.

These boxes or pallets are delivered directly to the production lines or to different buffers within close proximity. The demand for the production lines and available space at the buffers located at the beginning of every line should be considered in real-time. In order to analyze the different devices that are part of this process, IoT could be embedded into most of the electronic systems involved in this flow of materials such as machines, robots, conveyors, RFID or barcode scanners, automated warehouses, and transports (Gubbi et al. 2013). How these material flows are transported to the different locations to support the new production lines and the production planning is presented in the following sub-section.

5.3 Internal Logistics

In order to deliver material to the machining areas, MPA, and from there to the production lines, different transport alternatives have been considered. A mathematical optimization study to compare the requirements for transporting all the material was performed. In this study, the use of forklift trucks, tow trains, and AGCs (Automated Guided Carts) were considered. Optimization with mathematical models showed the amount of AGCs or tow trains needed to substitute the existing forklift trucks. As optimization parameters, the capacity and amount of tow trains or AGCs, and the minimum safety storage levels of the production lines were considered as variables. As a result, considering the output of the optimization, the long-term cost and the reduction of accident risk, the research team led to the AGC solution, a decision supported by managers and stakeholders. Having this as a starting point, an analysis was made on how Industry 4.0 with AGCs can support the new designed production lines. A detailed explanation of the characteristics of the processes and the equipment needed to supply material to the machining area as well as to the merged production line is presented here.

In the machining and assembly areas, the different processors should have a computer or device connected to an internal Ethernet or secured internet network. This allows the remote data collection and cloud storage as well as interaction with the station thus analyzing among others: production planning, produced parts, input and output flows, setup times, failures, shortages, stock levels, and product information (Gubbi et al. 2013). The transport should have a computer or equivalent mobile device connected to the network via Wi-Fi, Bluetooth, WIBREE, ZIGBEE or equivalent wireless technology which could be used in real-time (Gubbi et al. 2013). Transports should be able to communicate with automatic doors, machines, robots, operators, and other transports to handle traffic situations in a more efficient manner (for example avoiding collisions, temporary obstacles in the path, peak times of operators starting/finishing a shift, going for lunch etc.). In order to be able to adapt to unplanned dynamic changes and obstacles, the transports should have a simulation aided, knowledge-based routing algorithm or equivalent technology (Klaas et al. 2011).

The main advantages of AGCs are the high flexibility and efficiency as well as the possibility of automatic loading and unloading of the material to conveyors. The sensors and motors of these conveyor systems should be controlled by a PLC (Programmable Logic Controller) with embedded IoT technology for the communication with the different stations and transports (Gilchrist 2016). Information about the transports should also be gathered (failures, state, location, items loaded, identified obstacles, speed, battery load etc.). This information could be accessed in real-time by different computers or mobile devices with permission to adapt the production pace, establish task priorities, traceability, decisions, performance monitoring, and routes and tasks definition (Gubbi et al. 2013).

Having all this data as a base of digitalization, production rate and inventory levels can be significantly improved, adapting to the demand in real-time (Zuehlke 2010). Additionally, with all this historical data stored, organized, and accessible all the time, the steps of system analysis and data collection for lean and simulation projects can save a huge amount of time and resources. In this case, the improved production lines with lean and SBO require the redesign of the internal logistics. As presented, this redesign, supported by Industry 4.0 concepts, can contribute significantly to an overall production improvement of the industrial partner. This could be extrapolated to similar manufacturing companies. In addition, most of the technology specified here is already present in manufacturing processes. However, a huge effort in standardization, data security and privacy still has to be performed by most of the manufacturing companies. In the case of the industrial partner of this research project, after several meetings with the managing team and project leaders, the results of this research project showed the benefits of this Industrial 4.0 paradigm combined with lean and simulation. Furthermore, the extension of this project to other production lines of the factory is being considered and the allocation of an Industry 4.0 team and resources to support system improvement with lean and simulation is now a reality.

6 CONCLUSIONS

This paper demonstrates how SBO combined with lean has a huge potential for the system and process improvement in manufacturing. While SBO can be used to analyze complex dynamic systems with high variability and a large amount of possible solutions, lean tools can make up a base for continuous improvement in individual processes (Uriarte et al. 2015). However, an important factor is that there is often a lack of data in order to start working with lean and simulation approaches, especially in factories with a long history and tradition. Hence, the integration on the shop floor of Industry 4.0 concepts can be a solution to this common problem of lack of digital data (Vogel-Heuser and Hess 2016). The first steps to this Industry 4.0 paradigm, the FoT or the smart factory of the future, include monitoring and digitalization. Going through this project, it can be appreciated these pillars can to a great extent facilitate and integrate the use of lean and simulation for system improvement.

Furthermore, as demonstrated in this project, when a major change is required within manufacturing and the improvement of the system considers production, internal logistics and shop-floor layout, the combination of SBO and lean with the paradigm of Industry 4.0 can be extremely valuable for managers and stakeholders. Especially when considering a long term improvement perspective in the production facilities, the combination of the three approaches can lead to an overall system improvement; beginning with the base of lean and Industry 4.0, for the local as well as more strategic improvement, both of them can be complemented with SBO to analyze, materialize, and evaluate the possible improvement of the system in consideration. Most of the technology required for the Industry 4.0 era is already present in production. In the same way, it is common that manufacturing companies have lean and simulation teams and projects; however is less common that they work in a coordinated manner. A solid methodology for lean and SBO in manufacturing can be very useful and a strong coordination with the emerging paradigm of Industry 4.0 should be considered in order to increase the efficiency and concurrence of the existing manufacturing facilities.

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