LEAN PRODUCTION 4.0: A MODEL TO TEACH NEW TECHNOLOGIES FOR PRODUCTION ENGINEERING STUDENTS BASED ON COLOMBIAN MOTORCYCLE SECTOR EXPERIENCES

***Abstract*—Industry 4.0, Lean 4.0, Logistics 4.0 and many other 4.0 production technologies are rising nowadays in industrial processes. However, it is still not clear how all these new technologies can be taught to university students and projected into the industrial scope. In this work, as part of the research project: "Towards a model of implementation of Lean Production 4.0 in the Colombian motorcycle sector" which is currently being developed by Universidad EAFIT in Medelln, Colombia by the "Technologies for production" research group from the Production Engineering Department. This project aims to response to continuous improvement initiatives of training and knowledge transfer of Lean Manufacturing and introducing new technologies in the Colombian motorcycle sector in order to achieve a competitive advantage. According to above and following the industry needs identified, an experiential model of problem solving, project-based learning and experimental "hands on" work will be proposed in which it will allow to bring students the knowledge of Lean Manufacturing methodologies within the concept of Industry 4.0 and what is currently known as Lean Production 4.0 and to understand the main concepts of these new technologies, have real experiences that prepare them to deal with it in the local industry, where these concepts are being introduced progressively in order to fit new production trends worldwide. In order to approach this, a technology surveillance process of the progress so far found in training processes of students in these areas and what has been reported up to now in the formation of Lean 4.0 for engineering students or employees of manufacturing companies will be showed. The proposal of deployment model is followed by the introduction of such technologies using the Production Engineering Program Learning Factory facilities at Universidad EAFIT, which is a learning unit, dedicated especially to assembly processes and manufacturing cells as an example for the introduction of these technologies for the manufacturing and processing areas. The results achieved will expose a methodology to teach lean production 4.0 that compare the different ways to add value in the processes, by simulating three stages of production, traditional basic production, lean manufacturing and lean production 4.0, it will be shown through tracing of a process implementation of Lean Manufacturing tools by using Lean production 4.0 tools used in problem solving at the Learning Factory.**

***Index Terms*—Project-Based Learning, Lean Production 4.0, Industry 4.0, Learning by doing, Experiential Learning, Motorcycle sector, Industry and University Collaboration**

I. Introduction

The Colombian motorcycle industry is in a process of technological development and a productive mentality transformation focused on continuous improvement, customer value (lean manufacturing) and operational excellence as a result of the program PGM developed between 2013- 2017. However, after execution of the program, assemblers have shown the need to increase technical competitiveness and Research, Development and Innovation processes throughout the value chain (assembler and suppliers) to achieve compliance with the National Integration Product (PIN) required by the government.

A. PGM Motorcycle Sector Management program

The PGM Motorcycle Sector Management program was born of the cooperative actions carried out by the Colombian assemblers of Japanese origin, Incolmotos YAMAHA, Suzuki Motors of Colombia, Fanalca Honda and a group of its suppliers, which is part of the development strategy of the national competitiveness conformed by the triad University-Company-State. This phase of the program was operated by Universidad EAFIT as delegated administrator and co-executor, headed by the Research Group on Production Technologies, assigned to the Production Engineering Department and co-financed by the Administrative Department of Science, Technology and Innovation, COLCIENCIAS, the assemblers and the group of participating suppliers of different sectors of the industry. PGM sought to strengthen the competitive growth of the sector through the implementation of a collaborative project of technical assistance specialized in management technologies, productivity and quality, as well as the implementation of technology transfer projects and knowledge in processes and products of several companies. Furthermore, the implementation of the three technology transfer projects, were focused on the substitution of key parts of the motorcycle, that usually are imported from Asian countries, in order to develop national suppliers, and boost the national economy through collaborative projects between suppliers and assemblers. The parts that were selected to be part of this technology transfer projects were headlights, coil springs for shock absorbers, and forks or

swing arms. This process started with the identification of a supplier with capacity and resources to participate and a group of possible pieces to substitute. After that, a technological mission to select an international ally that provides the knowledge, experience and technology transfer is performed. Next, once the ally is identified, the process of set a strategical alliance between the international company and national company for new cooperation, products design and development. Following by prototypes fabrication and validity tests of products made by headquarters and a technological centre. Finally, the process is standardized, and the part is fabricated and delivered to the assembler to include it as part of the motorcycle.

B. Lean Manufacturing Project at PGM

On the other hand, the value of all process must be defined by the final customer [1] for this reason, one of the tools designed to improve aspects, such as quality, productivity and job site conditions, which have been used by leading companies in the automotive industry has been known as lean manufacturing, which refers to a set of tools that reduce waste in production processes, improve the work environment, increase productivity and achieve greater agility in the development of new products, among other factors. Lean manufacturing project started with an initial diagnostic to set a base line in the first stage. Then, a knowledge transfer in lean manufacturing tools was accomplished in each participant companies and assemblers in the second stage. Following this in the third stage, an international assessment was done by a foreign Master Black Belt consultant, in order to identify the current state and level of lean implementation and set a road map to follow. Once the results were known the fourth stage, the extended kaizen, started with the improvement opportunities that were identified, and a work plan was set in each participant companies with a leader in each one. This work plan was composed by a pilot area definition, data gathering and key performance indicators (KPI) setting. Then, a Value stream Map (VSM) analysis to identify improvement plan and set the activities work. After, the implementation of lean tools to reach and comply the KPIs defined in a previous phase. Finally, closing and consolidation of results is done, and new improvement opportunities are identified. On the next phase, trying to build up the knowledge of Lean manufacturing tools and lean thinking and consolidate all the experience gathered in implementation and execution, an international certifiable Lean Six Sigma Yellow Belt, Green Belt and Black Belt course for one leader of each participant company. In order to get the certification, a practical and theoretical test must be submitted. Beside the test, a project using the methodology learned must be accomplished, for this reason, the fifth stage, is the strengthening stage, consisted of strengthening the knowledge in each of the companies and applying the concepts acquired in the specialized assistance in management technologies and continuous improvement; In addition, provide support and make an accompaniment in the tools learned during the Black Belt course, in order to implement them in the plant. During the planning of this phase, it was determined that the most important thing was leaders empowering of the process and the application of all knowledge acquired during the Black Belt course, in this way they could contribute to the company's growing. [2]. To conclude this Lean manufacturing project, for the last stage, a final diagnostic is carried out, to compare the results of all the project. This diagnostics showed a opportunity of upgrade the manufacturing processes with technologies and digitization, that enable to improve the flexibility and increase the competitiveness.

C. Lean Manufacturing and Industry 4.0 initiatives

This initiatives, requires a process of technology transfer and knowledge, to develop their suppliers and ensure compliance with the quality standards required by their headquarters to achieve a competitiveness advantage. To do this, through lean manufacturing concepts and tools with the advanced application Cyber Physical Systems (CPS), Internet of Things (IoT) and digitalization, that allow to increase flexibility, reduce costs and boost competitiveness of Colombian industry and thus explore a possible road to industry 4.0, automation and the creation of smart factories, as possible solutions to these needs.

II. Framework setup

This project aims to propose a design of Lean production 4.0 technology implementation model that allows the use of industry 4.0 tools, such as data analysis tools, the internet of things, and the interaction between the machine operator, the approach towards an intelligent factory that achieves through of the collection and use of information in processes, the synchronization of data to bring a traceability of products and processes and thus increase flexibility, reduce errors, optimize production and maintenance processes, and increase the speed of decisions before any client's request, following the Lean Manufacturing principles. In this way, increase competitiveness in the Colombian motorcycle industry and the strengthening of technical skills and their R + D + I process. But, in this changing world, and continuous evolution of all this new advances in technology and resources, how all those technologies are taught, understood and applied in the academical and industrial environment? Is necessary, in addition to a possible implementation of the model at an academic environment, to evaluate it in different production systems and create knowledge on new trends in manufacturing and information systems of the correct application following a basic principle of Lean: Add value.

A. Problem Based Learning (PBL) conceptual basis

The importance of the implementation model in an academic environment specifically in engineering education, has a strong connection with global economic and social development. [3] [4]. For this reason, learning and teaching methods should focused on situations as related to real life. PBL or

Problem based learning pretend to analyze problems from the learning base process, knowledge integration and practice, as well as collaboration and group working [5]. This "Learning by doing", challenge the student to understand the information they know, identify the one that need to be known to come up with strategies to approach the solution [6].

B. Lean Manufacturing conceptual basis

Lean manufacturing as a production strategy, is focused on create value added actions, by reducing wastes, to do more and more with less resources, increasing the productivity, flexibility, improving quality and delivery at the right time that the customer need [1].When applied in organizations, results in a continuous improving processes and waste elimination to guarantee value added activities in the value stream. [7] [8].

C. Industry 4.0 conceptual basis

On the other hand, Industry 4.0, concept was introduced during the Hannover Fair, in Germany 2011. Structured as a government strategy to revolutionize the manufacturing sector through technology. Also is related as the fourth industrial revolution, with the introduce of high technologies supported and enabled by Cyber Physical Systems (CPS), and Internet of Things (IoT) in the world of digitization [9]. This digital transformation has not only changed the organizational dynamic, but the market is been transformed. [7]. To delimit the research, and clarify the construct, [10] propose that industry 4.0 is operationalised as the usage of intelligent products and processes, which enables autonomous data collection and analysis as well as interaction between products, processes, suppliers, and customers through the internet. Based on [11], all research of literature must include the following concepts CPS, IoT, Smart factories or digitization.

D. Lean Manufacturing and Industry 4.0 conceptual basis

Industry 4.0 can be integrated in Lean production by increasing the integration of Information and Communication Technologies [12].Lean processes can be stabilized and refined by applying industry 4.0 tools [13] [14]. Lean production and Industry 4.0, favour decentralized structures over large, complex machine an both aim for small modules with low level of complexity. [12] [15] [16]. The recent integration between Lean production and industry 4.0 has been denoted as Lean automation [15].

Applying industry 4.0 to established Lean production could lower risks of integration due to existing advice for the organizational integration. [12]. The standardization, transparent and reproducible processes are fundamental for introducing new technologies. In addition, by reducing product and process complexity, Lean Manufacturing enables the efficient and economic use of Industry 4.0 tools [13].

Judith Enke et al. expose that lean Production is a Value-based approach, where the workforce is always looking for a continuous improvement by reducing waste and solving problems, to pursue quality, costs, time, and workers motivation. While, Industry 4.0 adds elements of optimization by individualization, and connected systems. [17]

III. Methodology

To approach this issue, a technology surveillance process through a literature review of the main concept of the progress so far found in training processes of students in these areas, and what has been reported up to now in the formation of Lean Production 4.0 for engineering students or employees of manufacturing companies will be showed.

A. Literature review

1) Lean Manufacturing learning process: Tortorella 2017a et al. [6] exposed a complete detailed literature review of the teaching methods of lean manufacturing. Some of the teaching methods of referenced on 2005,predominates lectures, simulations, and analysis of cases. Also, long term (semester-Project) projects of lean implementation in real companies, and plan tours to understand lean implementation. Back on 2008, Hands-on projects, and experiential based assignments, where introduced to improve professional skills. In order to introduce Problem based learning, through simulation and real projects. From 2014, PBL approach to lean six sigma, explore the ability of students how to understand real problems, analyze situations and possible solution, followed by application of concepts to solve it. [18]

Andrew 2017 et al. presents in his work, the development and adoption of a Lean Six Sigma in a curriculum and program in higher education. The application and implementation of Lean programs within higher education has been the focus of much academic debate and development over the years. Following it original application the manufacturing industry Lean has spread rapidly into the service sector and now in higher education. Much of the Six sigma implementation is based around its own methodological application: Define, Measure, Analize, Improvement, Control (DMAIC). On the literature review, the key highlights identified by Andrew 2017 et al. were the Lean oriented tools and techniques, (VSM, Cause and Effect Analysis, 5s etc.). Then, the importance of DMAIC methodology, not just with the statistical took but the tools applied to improve, always focused on the customer needs and requirements. [19]

2) Industry 4.0 learning process: Industry 4.0 is focused on creating smart products, procedures and processes. Smart factories to manage complexity in process, less prone to delay and more flexible, where humans, machines and resources, communicate naturally. [20]. To help this, the concept of Learning Factory has been developed to improve learning and training in manufacturing, aiming to bring the learning process closer to industrial practices [21] and develop experiences through an active learning approach [3]. The continuous efforts for developing and implementing flexible production systems

with new technological trends are increasing, in order to fulfill more customer needs [22] [23]. Digitalization, CPS, and IoT has become an important objective in teaching and training [24].

Learning factories has been the most common, and effective way to teach and learn industry 4.0 technologies and improve technical skills. Chistoffer Rybski et al. expose that horizontal, and vertical integration, digital end-to-end engineering, CPS, and new social infrastructures, force the creation of a technical training scheme to prepare the human resource to work and improve technical, transformation and social skills for the future work. [21]

Mo Elebestawi et al. came up with four main characteristics of industry 4.0 that should be considered in designing and developing Learning factories: vertical networking of production systems; horizontal integration of global value chain networks; end-to-end engineering of overall value chain; and using high-impact disruptive technologies such as Artificial Intelligence (AI), augmented reality, 3D printing, Smart systems with, collaborative robots, advanced sensors, actuators and micro processors. All this technologies have helped to reach advancements in areas such as IoT, CPS, Data analytics and communications infrastructures [25].

3) Lean production 4.0 learning process: Another function of learning factories in academic environment is the usage as a test area for new technologies and processes, such as lean manufacturing, logistics and energy and resource efficiency [21] [24].

Harald Bauer et al 2018 [26] proposed an approach of lean principles (Value, Value stream, Flow, Pull, Perfection) in context of digitalization, to enhance the training concept in lean learning factories to meet the evolving new requirements of industry 4.0 by setting challenges of real situations. According to Harald Bauer et al 2018, the procedure must follow three steps: First, definition of customer demand, lean methods and limits; then, selection of Industry 4.0 tools and applicable technology; finally, Challenge objective and instructions.

Dennis Kolberg et al 2015. [12] exposed that production processes in lean production are more standardized, transparent and focused to essential work, for this reason, some industry 4.0 tools can be applied and combined in smart world (Operator, product, machine and planner), each one can be combined with lean production principles and methods. For instance:

- Smart operator equipped with a wearable smart watch by using Andon method, can receive a timely notification to reduce time from failure occurrence until failure notification. Augmented reality can support a continuous flow, track cycle time and Just in time support
- Smart Product could collect data for analysis, and kanban information to control production processes, also can be used to follow the VSM behaviour.
- Smart Machine, with sensors and computing capacity, can be integrated with a CPS that support maintenance, failure, and performance. Single Minute Exchange of Die (SMED) should be reduce with plug and produce transfer station. to increase the flexibility by reducing reference change.
- Smart Planner, turn the production programs into a dynamical production following the one piece flow principle and a highest flexibility by using kanban fixed cycle times; working stations with CPS, could set the highest capacity depending on the production demand. Optimization of production processes can support the business objectives: time, throughput, and efficacy.

A. Mayr et al. 2018 [13] developed a matrix, with a conceptual conjunction of Industry 4.0 tools and Lean methods. This matrix combine Just in Time, Heijunka, kanban, VSM, Total productive maintenance (TPM), Visual Management, and Poka yoke with Industry 4.0 tools such as Additive Manufacturing, Plug and play, Automated Guided Vehicles, Virtual representation, intelligent bins, Digital Object memory, Cloud computing, Big data and data analytic, Machine Learning and others. The main objective was a possible use of each tool with each method, it can be powered, and set in a Lean production 4.0 learning process to apply and introduce in a methodological practice.

Judith Enke et al. 2018 [17] described the lean Production and industry 4.0 approaches for similar targets, in philosophy, foundations control principles improvement and problem solving and information acquisition. She identified four action areas of Lean benefits from industry 4.0: Digitalization improves production with the customer demand, Real time data creates new opportunities for existing methods of Lean production, Digitalization helps to establish lean production in new areas, and The product knows the Lean production environment and can control it. Those benefits are connected with a Lean 4.0 curriculum, that includes Lean 4.0 Basics, Core elements and culture.

IV. Results

Lean manufacturing learning process is taught with a PBL approach that helps the student, or worker understand each tool and apply to solve real problems. During PGM program, the general strategy of the plan, was to make a tour through the lean manufacturing tools, where the waste reduction, work stations order, visual management, as well as, reduction of operation time and inventories, productivity increasing and the quality improvement allows greater flexibility, guaranteeing this way a continuous flow and a standardization of the processes. The strategy follows a knowledge transfer of lean manufacturing tools and an applied exercises of each tool focused on a pilot area to develop and solve a problem identified. Then, on the Lean Six Sigma stage, where the leader of each participant company, in order to get certified

as Lean Six Sigma Black Belt, must accomplished a project in a pilot area, using the methodology, and show real cost savings. [2]. The methodology used in PGM program, did not vary much of the one exposed in literature review, by using real situations to strengthen and internalize the lean principles and tools, besides, the Lean Six Sigma Black Belt, approach the learning methodology by DMAIC, combined with all lean tools.

From this experience and the need of advance in terms of technology, digitalization and industry 4.0 streams, Lean Manufacturing project was a important starting point and learning factories advances, came in to play an important role in terms of teaching new technologies and production methods.

A. Proposal

The proposal, as a result of this research, is taken from learning factories methodology by using a experiential learning approach, and setting a challenge, using three phases of production: Basic/Traditional production, Lean production, and lean Production 4.0. To upgrade from each phase, the student must understand and apply some transition core tools to work on the next one, analyze the KPIs and compare the advantages of each production style.

1) Basic/traditional Production:

- Description: Production system, paper based with a high inventory levels, structured by processes without standardization, wastes and low quality levels. On this phase, the participant must assembly the production a quantity set, take cycle times, pieces produced, and different KPIs.
- Transition tools: To get to the other phase, Lean thinking, and concepts of mudas (wastes), Just in Time, Kaizen (continuous improvement, and lean principles, must be understood, as well as customer value.
- Application: Identify improvement opportunities, use of KPIs and lean manufacturing tools (VSM, SMED, Standardization 5s, etc) and apply in the production system.

2) Lean Production:

- Description: with the concept, of value added, Just in time, Flexibility, standardization, wastes reduction, the students must work on this phase, and life this transition, between traditional to lean production, but without technology help.
- Transition tools: Concepts of digitalization, Cyber physical systems, and IoT are introduced. The importance of data acquisition, and data analytic, integration and communication between processes, hierarchy and other actors will help decision making and flexibility to satisfy customer needs.
- Application: The combination of lean manufacturing methods, and industry 4.0 tools, to help the digitalization and integration to a smart production system.

3) Lean Production 4.0:

- Description: Real time data, traceability, high levels of flexibility, CPS, real time KPIs to decision making, or different Industry 4.0 tools depend on the challenge set.
- Transition tools: Depend on the technology, the exercises, and practice should vary, for example, robot collaboration, CPS systems, Augmented reality, Artificial Intelligence or other Solution based on lean manufacturing foundation.

This proposal is set to be executed and analyzed in future works, in universidad EAFIT's Learning factories, and plastics processing labs. The scope of further work, include learning sessions with companies to prepare them to this digitalization and smart technology renewal.

V. Conclusions

The vision of industry 4.0 guided by lean manufacturing can lever the companies to reach an operational excellence, by taking advantage of standard process and continuous improvement culture. Traditional and solid production paradigm, lean Manufacturing is improved by Industry 4.0 tools and technology, helping to increase flexibility, productivity, speed, quality in the framework of digitalization and communication of all integrated processes and actors. To maximize this relationship and gather the best benefit, learning processes of integration, comprehension, and application must adapt to the combination of lean methods and industry 4.0 tools (Lean production 4.0). Lean production 4.0 learning processes are under construction and Learning factories can be used for the identification of lean methods and transition tools to industry 4.0. Understand business challenges, customer requirements, operation improvement, performance management and people management are the next challenge. Teach students and workers to interact with, and accelerate decisions is fundamental to reach and manage new production trends.

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