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LEAN SCHOOL: A LEARNING FACTORY FOR TRAINING LEAN MANUFACTURING IN A PHYSICAL SIMULATION ENVIRONMENT

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Abstract

This paper introduces the Lean School, a Learning Factory, along with a "game" of physical simulation that is developed in it. All this is focused on teaching-learning, both of students and professionals, of the potential advantages offered by the implementation of the Lean Production in the organizations.

The participants gain a practical experience, based on experimental learning, which gives them a better understanding of the principles and tools of Lean philosophy.

This physical environment is not limited to theoretical teaching, but goes beyond and implements a production system near a real one. It starts from a configuration of a production plant with an unbalanced system and throughout the different iterations, called productions, introduces and implement the Lean principles, which makes its participants acquire not only knowledge but also the skills needed to implement an efficient production in their organizations.

All the constituent elements of the system will be described briefly: the product, the variations thereof, the initial design with its layout, as well as the subsequent productions, and the results of learning of each one.

Keywords

education, Industrial Engineering, Lean Management Production, Learning Factory.

Introduction

Currently, companies develop their activity in an increasingly competitive and global environment, but this reality must be seen not as a threat, but as an opportunity that makes it essential for companies and organizations to adapt to the changing environment through creative and competitive solutions, to guarantee their survival.

In this way, the need for companies to seek and implement actions aimed at improving their functioning is increasingly imperative. Traditional mass production systems give way to industrial concepts focused on the contribution of value. That is, eliminate the activities of their productive processes that do not add value for their clients. This turns out to be the foundation of the Lean Management philosophy and its application in the productive process.

So Lean Manufacturing (LM) is a way to understand the productive activity, and the success of the companies that have made a correct implementation, in their process management, of a lean methodology, is endorsed by the most advanced and efficient form of management.

It is thus obtained, a company able to permanently improve their expectations, through the elimination of waste, which entails the reduction of costs, the increase in quality and safety, improves the work environment, ..., allowing it to improve your competitive positioning.

Given this new perspective, universities have adapted the curricula of their engineering degrees so that their students acquire the skills inherent to the Lean philosophy and the capabilities to use the tools that accompany it [1]. In other words, they have adapted the training to the needs of the organizations, so that the students can face their future work challenges.

The training in Lean so that its implementation is successful, cannot be exclusively through traditional learning methods (Passive Learning[1]), as it would be very difficult to see the authentic repercussions and their full scope. Actions that allow students or workers to experience (Active Learning[2]) Lean tools and encourage discussion, participation and decision-making are required [2].

Books on LM and the traditional teaching methods are not capable of transmitting the fundamental skills necessary for the real implementation. The formative task through new teaching-learning methodologies has resorted to diverse approaches: face-to-face and invited classes, analysis of case studies, visits to plants, interviews with experts, industry projects, and many of them from the perspective virtual and game simulations, some digital and others physical (Learning Factories, Experience Learning) [3–6].

The present work aims to present the Lean School implanted in the School of Industrial Engineering (EII) of the Valladolid University (UVa). This school is a Learning Factory oriented to form and settle the knowledge of users about industrial management according to the Lean methodology.

Lean Manufacturing

The first reference about the term "Lean Manufacturing" or "Lean Production" is in the book "*The Machine that changed the world*" [7], although its principles were developed in the fifties in the heart of Toyota Motor Company by Taiichi Ohno.

The literature on LM with the principles and tools of production management that form it, is very abundant, as well as its definitions ([8–10] among others). However, there is a common feature to all of them, the idea that it is a philosophy focused on continuous improvement (*kaizen*) and the elimination of activities considered waste in the manufacturing system to improve the value of the product for the customer [11]. In [12, 13] there is an exhaustive compilation, of the main publications and the relevant facts about lean production.

The literature generally speaks of 7 types of waste, such as the most common: transport, waiting time, movement, inventory, over-processing, over-production and defects [7]. And more recently talks about 7 + 1 and 7 + 2 wastes, to include the untapped skills and the resistance to organizational change [14]. A waste will belong to one of the following groups:

- Muda: activity that does not add value in the process.
- Mura: activity that arises from unbalanced situations.
- Muri: activity that requires stress or irrational effort of the personnel, material or equipment.

Therefore, the Lean approach seeks all those activities that do not add value to the final product, which is, those do not provide benefit to the client and therefore are not willing to pay for them, and try to eliminate or reduce them as much as possible. To achieve it, follow 5 basic principles [9]:

1. Identify what the client wants or needs and modify the processes to incorporate it.
2. Identify the flow of value in the production process, the activities to follow to produce according to the needs of the client and those that do not.
3. Flow: The value must constantly be in motion to avoid the inventory waste
4. Adjust production to demand. Pull system.
5. Search for product perfection by continuously and proactively reviewing opportunities to eliminate waste and improve the process.

The successful implementation of this management philosophy, unlike others, requires active participation in the processes of continuous improvement of all members of the organization [14], which follows a structured and scientific method based on a system of "*learning by doing*". This learning system transforms workers into truly active thinkers and apprentices [15].

Therefore, is necessary that the organization is correct and flexible, willing to accept changes, which requires an open mind and a culture aimed at doing things well in terms of total quality, facing problems in situ not meetings of management away from the plant [10]. From this point come the next challenge that must be faced, the awareness and training of all members of the organization, essential requirements to achieve success in its implementation.

[1]Passive learning: a teaching method in which the receiver of information (student), transmitted by the issuer (teacher), assimilate it without feedback from the issuer.

[2]Active learning: a teaching method that focuses on students is part of their learning process.

To apply the principles of the Lean philosophy, the so-called Lean tools have been developed, which are collected in different works [11, 16], among others. And to evaluate the performance of the implementation of these tools should be calculated the most important indicators or the key performance index (KPI). And this is what is intended by the developed Lean School, that students and workers, through their active participation, acquire the knowledge and skills necessary to apply the Lean principles in their jobs.

Learning Factories

The new teaching environment, caused by globalization and the educational changes coming from the guidelines of the European Higher Education Area (EHEA), means that university teachers have to adapt both their subjects and methodologies so that students, in addition to acquiring knowledge, are them those who manage their learning process while developing the skills/abilities necessary for the proper performance of their careers [17, 18].

Within the new methodologies used, simulation emerges. In which learning: "*is undertaken by students who are given a chance to acquire and apply knowledge skills and feelings in an immediate and relevant setting*" [19].

As Einstein said: "*Learning is experience, everything else is information*".

So, learning is based on a theory of experiential learning. Experiential Leaning[3] has been widely contrasted [20–23]. Within them we can find computer simulations and simulations in physical environments close to reality.

The application of serious simulation games, called lean games, is endorsed by [24–27]. And [28] conclude that is "*a relevant delivery mechanism to learn lean principles and to improve attitude, knowledge, skills and competencies about lean manufacturing*".

To teach some basic concepts of LM, simple computer simulation games can be used. But when it is intended learning or training (of students or workers) in greater depth, which addresses more aspects, we must resort to serious games in which the environment is physical and close to reality [29], Learning Factories (LF). For more about LF see [30, 31].

The Learning Factories allow users (students or industrial participants) to test, through active learning, in a manufacturing system, that produces small scale models (idealized replica of sections of the value chain industry [32]), different production strategies.

LF versus traditional approaches provides an improvement in the acquisition of knowledge and the development of skills [33], and is one of the best teaching methodologies at the time that students/workers acquire certain skills in the engineering area. This, together with the support of institutions such as the European government, has allowed it to be incorporated into the education of engineers, including in the curriculum of some engineering programs [31].

Taking into account the above, arose the idea of building a flexible enough to realistically LF, represent different work environments. This is what led to the design and construction of the 'Lean School', which is a training environment that realistically emulates a manufacturing environment, allowing testing the different Lean tools, demonstrating their advantages and disadvantages, facilitates the acquisition of a global conception of Lean Manufacturing, or Lean Production.

Lean School

The first thing that must be done is to establish the context of the simulation game that represents the simplified real world, a "real" company.

After establishing the purpose of the training ("the game"), that is, the objectives of learning: the participants acquire knowledge and skills on lean production necessary for their work environment.

The development of the game is carried out through a series of rounds (productions) in which the participants solve different real problems in their production system through Lean tools and evaluate them.

The game provides two types of learning outcomes, some tangible as a global knowledge of Lean philosophy and the acquiring of skills such as: problem solving, reasoning, communication and self-evaluation, necessary for their professional development, and other intangibles such as the stimulation to learn new things or cause a change of attitude creating a new slender culture.

The Lean School was inaugurated at the beginning of 2014 in the Faculty of Engineering. Is a pioneering pedagogical project in Spain, in which the University of Valladolid (UVa) and Renault Consulting collaborate, and which serves as a training platform in various Masters (Industrial Engineer, Chemical Engineer, Logistics) and Degrees.

[3]Experiential Learning: teaching method through experience, and is defined more specifically as "*learning through reflection on doing*".

The students of the Lean School acquire a fundamentally practical, experimental learning and fully industry-oriented training of Lean management, based on participation (learning by doing).

The school presented in this work, helps users to get a practical view of the real situation of a company. To do this, the school has been equipped with a series of characteristics so that it meets all expectations when implementing its objectives. Here are the main ones:

- Lean School is the simplified representation of a manufacturing company, in which the user is confronted with the usual real cases in the course of implementation of a Lean management of the productive processes, allowing you to choose between a closed set of answers.
- It is intended that this participatory methodology improves the user's knowledge of Lean in a limited "real" environment and acquires the necessary skills for a real implementation.
- Users evaluate the results of the decisions they have taken against the problems they face, allowing them to have a direct view of the tools.
- Users will be free to make their decisions, but it will be the task of the trainer to guide them towards the ideal solution at all times.
- Users learn that Lean management is not just a set of techniques that can be applied discretely but rather it is a philosophy as a whole.

This article shows a game of physical simulation that reproduces a real factory in which the intervention of users is necessary to apply the Lean tools and thereby improve the efficiency of the production line. With it is achieved to improve the motivation and the acquisition of skills.

Proposal

Description

The product we manufacture is not related to commercial products (to facilitate the learning of students and workers of different industries). It is a product formed by a base and four layers with four color components (green-yellow-blue-orange). The components of the odd layers are simple, while the components of the even layers include an additional piece with different shapes (hexagon, circle, rectangle, oval) (Fig. 1).

Our production process consists of two factories: assembly (Fig. 2) and recycling (Fig. 3). In this way, we guarantee to always have a sufficient flow of pieces at the entrance.

Initially, the components are assembled in layers at the workstations (each in a color), and the product in progress is transferred to an inventory from which the next workstation is fed. The final product is checked at assembly workstation no. 5 before being sent to the customer in batches of 3.

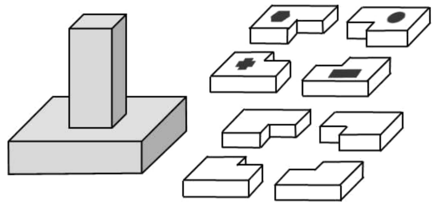

Fig. 1. Product in the "Lean School".

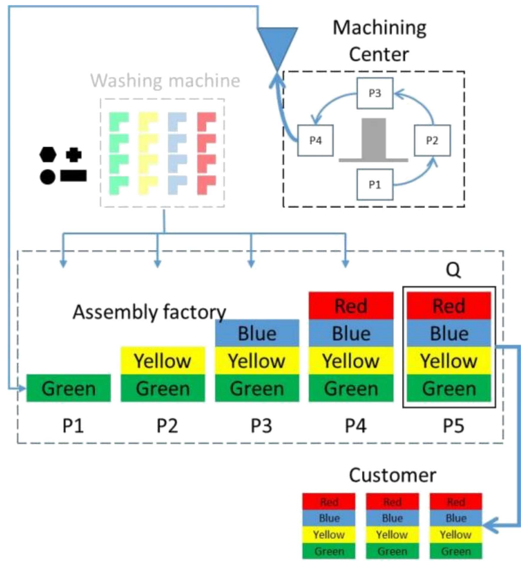

Fig. 2. Assembly factory.

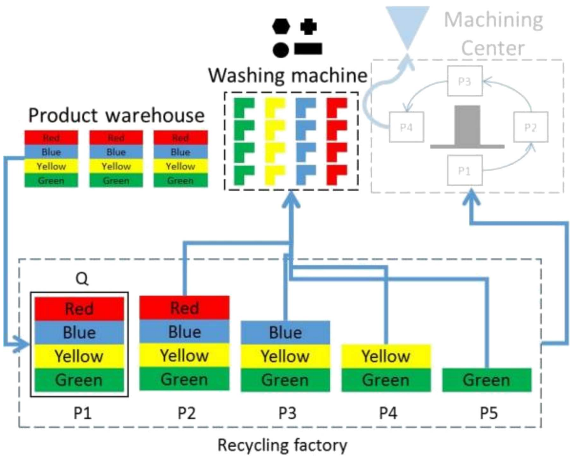

Fig. 3. Recycling factory.

In the recycling factory, the products also arrive in batches of 3, once they have passed through the customer. And the process is similar to the assembly line: at each station, a layer of components is dismounted, passing the product in progress to an intermediate stock from which the next workstation is fed, until the last station that evacuates the bases to be processed in the machining center.

The two logistics workers must take care of:

- to feed of bases to the beginning of the post no. 1 of the assembly line as well as the stores of components in the assembly line from those already processed in the washing machine,
- removing components from the recycling line by inserting them into the washing machine and sending the bases to the machining center for processing,
- take the products that have passed the quality control to the customer, and from the customer to the post not. 1 of the recycling line

Production 1st

When any training begins, the reference state is provided by the instructors (Fig. 4) so that from this initial situation (not optimal) different lean tools can be applied to solve the problems identified by the students and to improve the distribution in the plant, the process and the workstation.

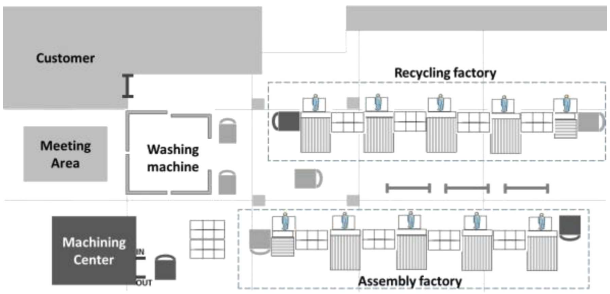

Fig. 4. Initial configuration.

This initial configuration is characterized by:

- Unbalanced workstations since there are 4 workstations where each layer is assembled/disassembled (and the operations to assemble/disassemble each layer are different) and the assembly station 5 (and the recycling station 1) is only in charge of the quality of the manufactured products (or of the received products).
- High intermediate stocks, which are necessary to ensure that the most heavily loaded workstations never stop.
- High stock at the entrance and exit of the machining center (through which all the bases must pass) as the students do not stop to consider the manufacturing parameters of the same and maintain a very high safety stock in the face of possible changes in the quality of the bases.
- High variability in the stock in the washing machine of the components of the different layers, because although we must know the rate of consumption, it does not correspond to the rate of supply of materials.
- Lack of quality of some of the products, as we have not defined a standard work, nor have we adapted the workstation to the operator who occupies it.
- High travels of logistic operators as the stations are very separated (due to the intermediate stocks that are guaranteed between each workstation), and the lack of planning in the tasks carried out by the logisticians.

With this configuration and after the initial distribution of posts among the students: assembly workers (5), assembly manager (1), recycling workers (4), recycling manager (1), logistics operators (3) and timekeepers (2) the production is carried out for 20 minutes. In order to make the flow more or less stable although there are intermediate products in all the stations in the starting situation, the students initially manufacture 5-6 products before the time and data recording begins.

When the manufacturing process is finished and as we have been recording the instants in which each of the products were assembled/disassembled, we will be able to calculate the cycle time of both the assembly factory and the recycling factory.

Logically in this first production, we do not comply with the takt time requirements defined by the client and the students must identify the aspects that have been satisfactory and the problems they have had because they have possibilities for improvement.

Different tools are analyzed in different groups:

1. Analysis of areas dedicated to different activities: operations (20 m^2), stock (50 m^2), quality control (3 m^2) and flow (177 m^2).
2. Spaghetti charts to see the movements of the workers in the different logistics flows carried out (Fig. 5):
   - supply to assembly of components (from the washing machine) and bases (from the machining center),
   - pick-up of components from the recycling factory and introduction into the washing machine and from the bases to the machining center,
   - flow of finished product between the exit from the assembly factory and the customer, and between the customer and the entrance to the recycling factory (50000 estimated steps for the planned daily production based on those made during production 1st).
3. Flow chart (Fig. 6). We can see graphically the operations that provide value (◯), quality controls (□), stocks (both in transport trolleys and on

racks) (▽) and movements of handling and movement (⇒).

Students can see the amount of movements and transports we are making between the different workstations that add value, and especially the large amount of space dedicated to inventories in progress where there may be (and in many cases there are) material in process (WIP).

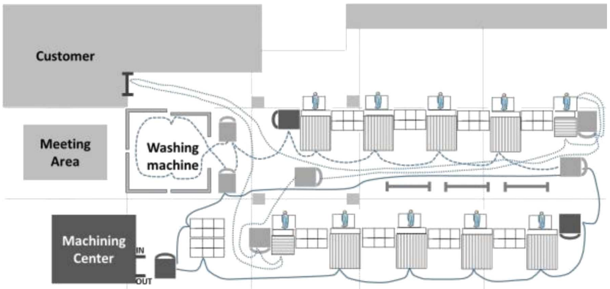

Fig. 5. Spaghetti chart of Production 1st.

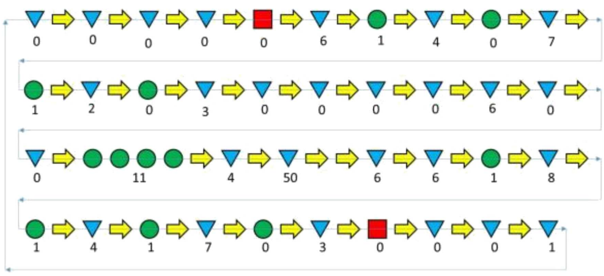

Fig. 6. Flow chart of Production 1st.

4. Value Stream Map (VSM) (Fig. 7) to see where large quantities of inventory accumulate, to detect imbalances in jobs, and above all to keep in mind the great goal: to satisfy customer needs at the rate set by the customer.

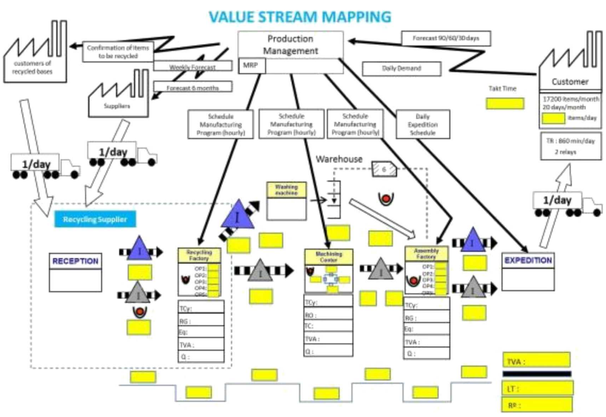

Fig. 7. Empty VSM.

Production 2nd

In the second production, and based on the analysis of the results obtained in the first production, a new scenario is proposed so that the students, in addition to eliminating some of the problems detected (unbalanced workplaces, no quality assurance, many working in process inventories, ...) have a new objective to achieve. And what is proposed is to reduce the space occupied in the factory to 50% of the original space and reduce the lead time to a third of that obtained in the first production.

To achieve this, students must come up with ideas and, divided into groups, implement them in a real way in the factory:

- elimination of ongoing product inventory for which it is necessary to balance the workload of the workstations,
- remake the distribution to reduce the distances walked by the logisticians,
- define working standards to guarantee the quality of assembled or recycled products,
- define the reference situation of your workplace by applying the concepts explained in the 5S lesson.

One of the usual configurations for the new plant layout is with the workstations together (no stock between them) and in V-shape with assembly station no. 1 near the washing machine and the machining center (as all the bases must pass through it) and with station 4 of the recycling factory near the washing machine (where all the components have to pass through) and with roller tracks send the base to the machining center (and thus reduce logistical trips) (Fig. 8).

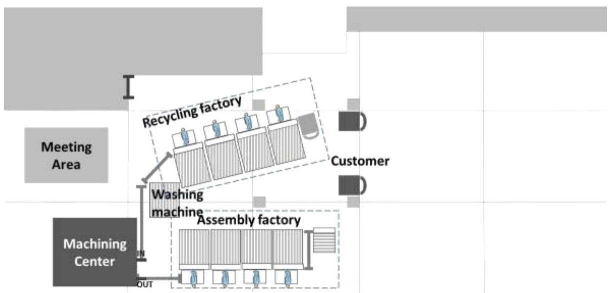

Fig. 8. Usual configuration of Production 2nd.

With this configuration, the distribution of job is: assembly workers (4), assembly manager (1), recycling workers (4), recycling manager (1), logistics operators (2) and timekeepers (4).

In order to balance the jobs there are different options that students should explore based on their knowledge and the tools explained in class. The most common variants are:

1. at workstation no. 1, assemble a complete layer (4 components) and 1 component and piece of the second layer, leaving workstation no. 2 in charge of assembling the other 3 components with their respective piece of the second layer,

2. at workstation no. 1, assemble a complete layer (4 components) and 2 components (without part) of the second layer, leaving workstation no. 2 in charge of assembling the other 2 components and the 4 parts of the second layer,
3. at workstation no. 1, assemble half a layer (2 components) of the first and second layers, leaving workstation no. 2 in charge of assembling the other two halves.

All the variants assemble the same number of elements (6), differing only in their complexity (as they have different shapes and sizes), so the assembly/disassembly times of these three alternatives are not the same and the students have to decide which option to choose (if the different variants are considered). The option they choose is not as important as the process they carry out to determine which balancing is the best, since the results obtained will lead to new conclusions, and it is even interesting that the assembly and recycling lines come to different conclusions.

Logically, when changing the components that are assembled/disassembled in each of the work stations, the students must reconfigure all the stocks they have in the shelves of their work station, in addition to applying ergonomic concepts to adapt their work space to the conditions of the worker (height of the table, seat, ...).

Once the students have had time to get used to the new configuration and have trained with the manufacturing standards defined by them, 15-20 products are manufactured, calculating different times and parameters with which to continue evolving in training based on the improvements they propose.

Figure 9 shows the spaghetti chart of this second production, in which the routes made by logistics operators are clearly reduced by approximately 50% as the area dedicated to assembly (and recycling) has been reduced by that percentage (132 m^2). It should be noted that in no case has the area dedicated to assembly and recycling lines been reduced to add value (20 m^2), but only the areas dedicated to stocks (30 m^2) and quality control (and therefore all related flow areas) have been reduced.

And in Fig. 10 we can see the flowchart in which the square symbols (□) have disappeared (since we have eliminated quality controls by ensuring the same with self-control at workplaces as defined in the work standards). Moreover, the triangular symbols (▽) have been reduced (since we have eliminated several stocks of work in progress) and therefore the arrow symbols (⇒) by reducing handling and movements.

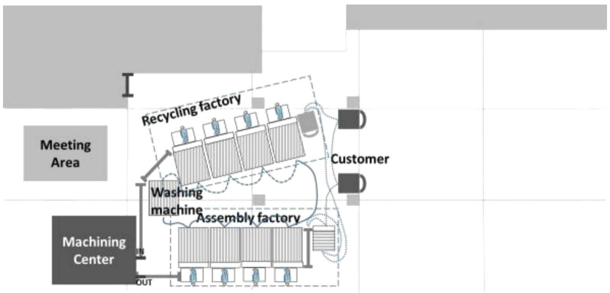

Fig. 9. Spaghetti chart of Production 2nd.

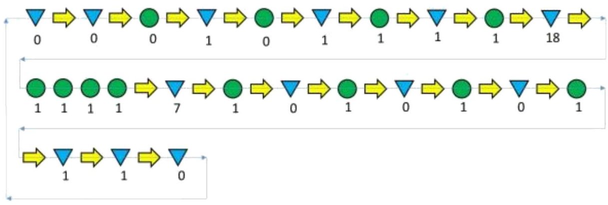

Fig. 10. Flow chart of Production 2nd.

Production 3rd

In the second production must have achieved the objectives of reducing delivery times, the area dedicated to the factory and the movements of logistics operators, all ensuring the quality of the products (both in assembly and recycling).

Depending on the capacity of the students who are in the assembly stations, even the main objective of fully satisfying the customer's demand at the rate that the customer asks us for the products (takt time) can be achieved. Although it is usual not to achieve it by a small margin of time that the students usually justify in the lack of skill.

At this point, and in order for students to see that the improvement process must continue following the PDCA cycles in order to try to satisfy the customer, a new scenario is proposed in which the customer (who has almost been served as he wanted) poses new requirements. The clients have been bored of using the product with that color combination and want us to be able to manufacture them in any color combination (maintaining the requirement of layer without piece and layer with piece alternately).

In other words, we are not only going to have to produce the green-yellow-blue-red combination (GYBR) but also the combinations GRBY, BYGR, BRGY and if we allow the repetition of colors: GYGY, BRBR, GRGR, BYBY, GYGR, GRGY, GYBY, GRBR, BYBR, BYGY, BRGR, BRBY (16 possible combinations).

In a first approximation, students tend to think about repeating as many references as possible on workstation shelves. The problem is twofold: first because there is not enough space available in the workstation to put the necessary number of shelves as we only have enough space to put 6 and need an average of 8 shelves in each workstation, and second the quantity of parts and components would double and cause an increase in the lead time of our plant.

In addition, when the students are still discussing how to increase the space for the shelves in the workstations, we introduce an additional complication as the marketing department has proposed to introduce 4 new colors (2 with and 2 without a piece) in order to reach new market niches: peach (P), sky blue (S), magenta (M) and forest green (F). This means that we have a total of 256 color combinations to create our "cubiton" and that we need an average of 16 shelves in each workstation.

And in addition, because of the introduction of more diversity, the client's demand increases, so the takt time decreases. Students are asked to design the new production system with the same number of workers.

And since the factory management was very happy with the space gains that we had achieved between 1st and 2nd production, it asks us to achieve a reduction of at least 30% because they have obtained a new production line and thus guarantee the survival of the factory.

In this way, we force students to think of a different solution and allow us to introduce advanced concepts in lean manufacturing such as the use of kits with parts that need to be assembled into part or all of a product.

In order not to take too long to make decisions we divided the group in two: one in charge of redesigning the layout of the factory to meet the requirements of the management, and another in charge of designing the kit of parts to assemble (and recycle) the "cubiton".

The students in charge of redesigning the layout when using the parts kits and eliminating the shelves for the stock of components usually arrive at the configuration shown in Fig. 11 or some very similar variant.

The students in charge of designing the kit containing all the components and parts necessary to assemble the product have to take into account some conditions: all the parts must be visible and placed in assembly order, plus some recommendations regarding ergonomics and fastening elements. The result is very variable because it depends on the imagination of the students, but it is the task of the facilitator to guide the result by making them see the problems of some of the proposed alternatives. An example of a kit is shown in Fig. 12.

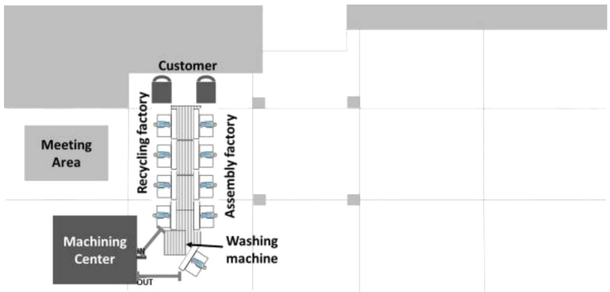

Fig. 11. Usual configuration of Production 3rd.

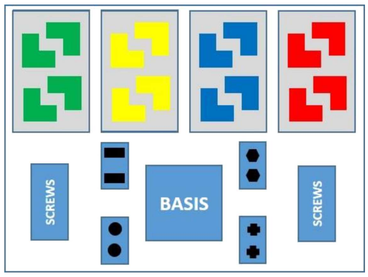

Fig. 12. Example of kit.

The flow of the process can be seen in Fig. 13, which clearly shows the reduction in stocks (▽) and movements of pieces (⇒) where no value is added to the product maintaining the same operations that add value as those defined in production 1st, as these are an indispensable requirement for the manufacture of the product and that it has the functionality required by the customer.

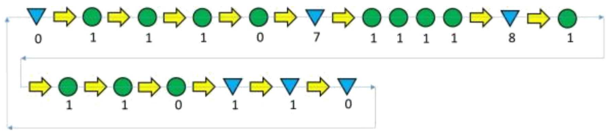

Fig. 13. Flow chart of Production 3rd.

The end result is that the students have managed to reduce the space initially occupied in the factory to one third, satisfying the customer's demand requirements, and reducing both lead time and stocks (and therefore capital assets) of the factory. This solution proposed by the students also guarantees the quality of the products supplied and increases the variety of color combinations and therefore the possible customization of the final product.

This solution is not the end. We can continue to improve the process, because there are still no handlings and movements of parts by workers who do not bring any value, and stocks of work in progress that could be eliminated in the future. How? We leave that to the imagination of students: from solutions already present in many factories such as AGVs (automatic guided vehicles) to 3D printing or drones.

Conclusions

Lean Manufacturing is a term that originally emerged from the MIT study conducted by Womack, Roos and Jones in 1990 that led to the book "The Machine That Changed the World" based on the Toyota Production System and whose goal is the elimination of waste (muda) but meeting the pace of customer demand (takt time).

In Lean School, applying the methodology described in this paper, students are involved in systematic elimination of waste process, analyzing physical flows and information flows base on:

- Identify and eliminate waste through flows improve process.
- Reduction of stocks to improve the lead time, surface used and obtain gains in terms of productivity.

In order to reach this objective, different tools must be used: tools on which to base the improvements: standardization of the workstations operations, visual management, leveled production (heijunka), so that using the cycle of continuous improvement (PDCA) and supporting us in the pillars of quality, 5S, pull flow, ... we can satisfy the client in the required time and quality with the lowest possible cost.

However, no tools can be taught alone, they must be learned and the best way to learn is when the students themselves are responsible for applying them in a real case, and so arises the Lean School where we have a learning factory with an environment similar to that found in any factory. In this way, the students learn (each one at their individual tempo) how to solve different situations by applying the tools explained in class.

The different groups of students (and workers) who have used the Lean School have started from an initial configuration to which they have been making improvements based on the problems detected. The same problems are not always found as some groups with more experience have applied tools to eliminate problems even analyzing only the initial approach. This is not an inconvenience as it allows us to advance in the objectives more quickly and to pose new challenges.

Even when the training ends (as the hours are limited), we always raise possible situations that the client (virtual) could demand based on news that we find in newspapers or magazines.

The most important is that the students who have studied at the Lean School have assimilated the concepts explained in class better than those who did not go through the laboratory, having experienced the improvements proposed by themselves in an environment similar to a factory.

And a very interesting aspect is that the Lean School can evolve at the same time as the factories evolve, allowing to experiment the improvements in a scale more assimilable by the workers, as much in tools as in the concept of production systems, lean kata, or in the introduction of new technologies: AGV, drones, ...

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