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Production Systems Redesign in a Lean Context: A Matter of Sustainability

Production systems are often kept unchanged for long periods of time despite changes on both the marketplace and on the management model. Over relevant timeframes, this stagnation causes an accumulation of inefficiencies and wastes that leads to unproductive production systems. This paper presents a number of case studies on the redesign of production systems within the context of Lean Production. The findings revealed that fresh graduates in industrial engineering conducting their Master's project, acquainted with different production paradigms, are able to identify a number of problems and the respective need for the redesign of the production system. A number of benefits were observed among the companies that enabled the required changes, namely an improved productivity and flexibility as well as a reduction on the shop floor Lean' wastes.

Keywords: *Production systems redesign, Lean production, wastes, productivity, flexibility, sustainability.*

1. INTRODUCTION

A well designed production system must support continuous flows with minimum non value-added activities. However, even if properly designed, production systems tend to become outdated on the long run. In fact, among other aspects, it is not easy to accommodate the market evolution in terms of the quantity demanded and diversity of the products. The higher the prior investment made in infra-structure and equipment, the higher the resistance to reconfigure the production system. This resistance is more clearly noticed when companies are in need to reduce costs. Many companies, reckoning that major investments are required on one such update, postpone the subject, or otherwise opt for downsizing or impose limits over their growth potential. Here, it is important to notice that different strategies might considerably change the perspective over this subject. One such production strategy is Lean Production [1].

Lean has been gaining reputation, over a number of decades, for delivering world class operations on a broad spectrum of manufacturing activities, and is now spreading to other areas of business as well. Lean is known for making a positive contribution towards the production systems' environmental performance, while keeping up with change requirements by understanding what the costumer's value and supporting efficiency gains grounded on small and consistent incremental improvements.

More sustainable operations are therefore enabled with the adoption of Lean concepts and tools, along with their widespread use. Lean Production is rooted on the Toyota Production System (TPS) [2,3] of the Toyota Motor Company. The TPS evolved clearly in quite a distinct way to that of the mass production system. Their mentors realized that high investments in dedicated systems, along with high production figures for single production models, would never work in a post-war scenario with high financial limitations and much smaller figures for each single model. Accordingly, they have designed a model of production system capable of reconfiguring faster and cheaper, that favours [4]: (i) manufacturing cells instead of job shops (ii) U-shaped subassembly cells in opposition to linear subassembly lines (iii) mixed model final assembly systems to level the demand on their suppliers instead of final assembly of large batches. Assembly lines and cells are favourite production systems within a Lean environment.

This paper exploits the above line of reasoning, by examining nine case studies (involving five companies), each of which an industrial project. Each project was an academia-industry cooperation, conducted by final-year graduates of the Integrated Masters on Industrial Engineering and Management (IEM), a five-year engineering degree at University of Minho. The projects involved a redesign of the production system, mainly from job-shop or assembly lines to assembly cells.

The benefits of the redesigns are presented and the methodology used to form the cells highlighted to show that, sometimes, it does not imply any mathematical or hard approach, normally associated with cells formation. This methodology emerges naturally in a Lean context due to efforts on waste reduction.

The paper is organized in six sections. The first one provides an introduction to the study and specifies its objectives. The second presents a brief literature review. Section three describes the research methodology.

The characterization of the case studies, explanation of the production systems redesign and results are provided on section four. Section five provides the discussion, and the conclusions are outlined on section six.

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2. LITERATURE REVIEW

Production system (re)design is a task of Industrial Engineering, encompassing the delivery of production systems capable of efficiently attend an evolving demand, as required by the customers, in a waste-free way. As demand is continuously changing, a dedicated production system, such as production lines (manufacturing and/or assembly) rarely accompanies one such evolution, therefore suffering from obsolescence. A job-shop system configuration is process-oriented, meaning that they are organized into functional sections by grouping similar machines. This configuration is considered a flexible solution and, accordingly, might candidate for complying with evolving requirements by the marketplace. It remains the case that, for all purposes, since one such approach is not product-oriented, it is prompt for inefficiencies, e.g. affected by many production waste types. To accommodate the production of a large variety of products (each product holds its own path) backtracking and cross-flows are common. Low productivity, high work-in-process (WIP) levels and long throughput times, are common in job-shops [5]. Moreover, defects rate is normally high and production planning and control is more complex on one such system [6].

Production cells seem to be a suitable alternative to both production lines and Job-Shops, since they bring the productivity advantages of the first and the flexibility of the later [7]. Production cells main principle consists on grouping dissimilar and complementary functional machines and/or people to process a family of parts/products (with similar processing requirements). This provides the required versatility to adapt to a number of different circumstances, as found on a number of surveys [8,9,10,11,12]. Those surveys reported quite distinct cells, varying on a number of aspects, e.g. the starting situation, characteristics of the cells, implementation process, configuration and operating mode, among others. At the same time, cells are evolvable and reconfigurable, to adapt to the marketplace and manufacturing technology [13] as they can accommodate changes that extend their life cycle [14].

A renewed interest in cells is growing once again, due mainly, to the success and span of application of the Lean Production methodology [1]. This methodology demands a flexible and agile production system, which promotes continuous flows to create value for the client [15]. Those aspects are in fact two of the five Lean Thinking principles. Those flows characterize a cellular layout and bring many advantages for the companies [16]. According to Hyer and Wemmerlöv [17], the reorganization of the factory, in a cellular layout, improves its competitiveness, while others consider that cellular production is the preferred production system, when implementing Lean Production [18,19,20,21].

In a Lean context, wastes reduction/elimination drives the redesign of the production systems. This is done by following the Lean Thinking principles of identifying and creating value for the customer and streamlining the value stream of the product (or family). This allows the application of a whole system thinking approach for redesigning a given production system. This can be applied by the system-thinkers of the company [22] that think and holistically perceive the production system as a complete value stream, which transform raw materials into final products.

In this context, forming cells is more than simply applying some Lean tools. It is an important step, but not always a difficult problem. Marsh et al. [23] reinforce this perception with a study, which denotes that companies do not consider cell design (formation) a difficult challenge. The same authors indicate that there is a gap between the type of problems investigated by the researchers and those concerning the management, i.e., that there is a gap between theory and practice. This opinion is also shared by Slomp et al. [9]. Marsh et al. [23] reinforce as well the importance of communication and shared experiences between researchers and managers, as well as the need to use others methods for conducting research, e.g. case studies, action research, field experiments and hands-on practices.

3. RESEARCH METHODOLOGY

Data collection was conducted and a number of documents used for content analysis. The main source of information consisted in nine Masters Dissertations on IEM. The authors of the documents were final-year (fifth year) students which concluded the respective degree between 2008 and 2013 (inclusive). They were supervised by the co-authors of the paper. The content analysis included the following steps: documents organization, data analytical description (codification, classification, and categorization), and interpretation (processing and reflection) [24]. Processing and reflection are two essential phases since they contribute to uncovering and reporting patterns [25].

The nine dissertations were analysed mainly with two goals: 1) to identify the methodology used to form the cells and the Lean tools employed; and, 2) to identify the benefits achieved with the redesign of the production system. Beyond the analysis of the documents, the authors' perceptions and understanding, was gained based on the direct observation, while conducting visits to companies, and discussion with students throughout the supervision process.

The final dissertation project creates an opportunity for the interaction among students, teachers (supervisors) and the industrial companies, with advantages for all involved [26]. In the specific context of the relevant projects of this work, Lean concepts application were the main driver for the development of such projects. The projects were developed using the Action Research methodology. This methodology is characterized by an active involvement of the investigator in the company context [27]. The supervisor follows the student progress on the project and makes at least a visit to the company. This methodology is composed by five stages: (i) diagnosis, (ii) action planning, (iii) action taking, (iv) evaluation, and (v) specification of learning.

The work progress is monitored with regular meetings. At the end of the project, the student gives an oral presentation, following discussion of the dissertation to a jury. The jury may include staff from the company (supervisor, administrator) which are encouraged to provide some feedback on the student.

4. PRODUCTION SYSTEM REDESIGN PROJETS

The study involved five companies. Table 1 identifies the projects and typifies the companies in terms of: (i) product type; (ii) dimension (number of workers); (iii) type (national (N) or international (I)); and (iv) lean awareness ("Yes" or "No").

Table 1. Companies' characterization

Project	Year	Co.	Product type	#workers	Type	Lean
1	2008	A	Water heaters and boilers	>1000	I	Yes
2 3 4	2010 2012 2012	B	Electronic components and devices	250	I	Yes
5	2009	C	Wood frames	90	N	No
6	2010	D	Metal structures for civil construction	>100	N	No
7 8 9	2011 2013 2013	E	Electronic devices	200	I	Yes

Company A was an 11 year-old large factory producing water heaters and boilers, which pertains to a major global player in several areas of expertise, namely car multimedia systems. Company B was dedicated to the production of electric components (e.g. switches and circuit breakers), pertaining to a major US based international group, with production units all over the world [28].

Company C was a national company from the wooden frames industry that was facing difficulties since the start of the economic crisis in 2008. Company D worked with metal structures for civil construction, and it is a 21 years-old national company. Company E belonged to an Italian international company operating in Portugal for about thirty years.

4.1 DESCRIPTION

The main drivers supporting the need for redesign of the production systems can be attributed to market changes and the need to reduce factory wastes. Three of the companies studied had assembly lines and two had job-shop production systems.

Table 2 represents the transformation required on all 9 projects to improve the production performance, i.e. redesign (R) or improvement (I) of the existing system and the new system configuration.

Table 2. Production system redesign

Project	*Product type*	*Previous system*	*New system*	*R or I*
1	Water heaters	5 Assembly lines	4 Assembly cells	R
2	WA/WD	5 Assembly lines	2 Assembly cells	R
3	ELCB with 4 poles	2 Assembly lines	4 Assembly cells	R
4	ELCB with 2 poles	7 Assembly cells	7 Assembly cells	I
5	Mirrors & pictures	Job-shop	2 Assembly cells	R
6	Frames	Job-shop	3 Cutting cells; 3 Assembly cells	R
7	Circuit breaker S2S20	2 sequential Assembly lines	1 Assembly cell	R
8	Circuit breaker MT-HP	1 Assembly line	1 Assembly cell	R
9	Circuit breaker Restart	2 Assembly lines	1 Assembly cell	R

Project 1, the assembly line of water heaters in company A had 33 workstations [29]. The workstations were called "islands" because the movement between adjacent stations was difficult, and a lot of WIP was found across the line. There was a clear problem of lack of line balancing. Since the assembly area of the front and packing was the critical zone, if the operators of the subassembly preparation were required on another part of the line they would be forced to travel too long distances. The communication among operators and the line coordinator was difficult, given its 40 meters long. This assembly line was converted into two U-shaped assembly cells, like the one depicted in Figure 1. Prior to this study, two others cells already had been designed aiming another assembly line. The student studied the arrangement of the four cells, which were integrated into an intercellular layout. This company continues to adopt assembly cells until nowadays.

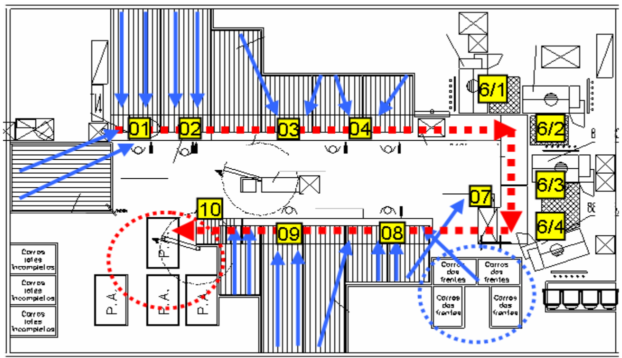
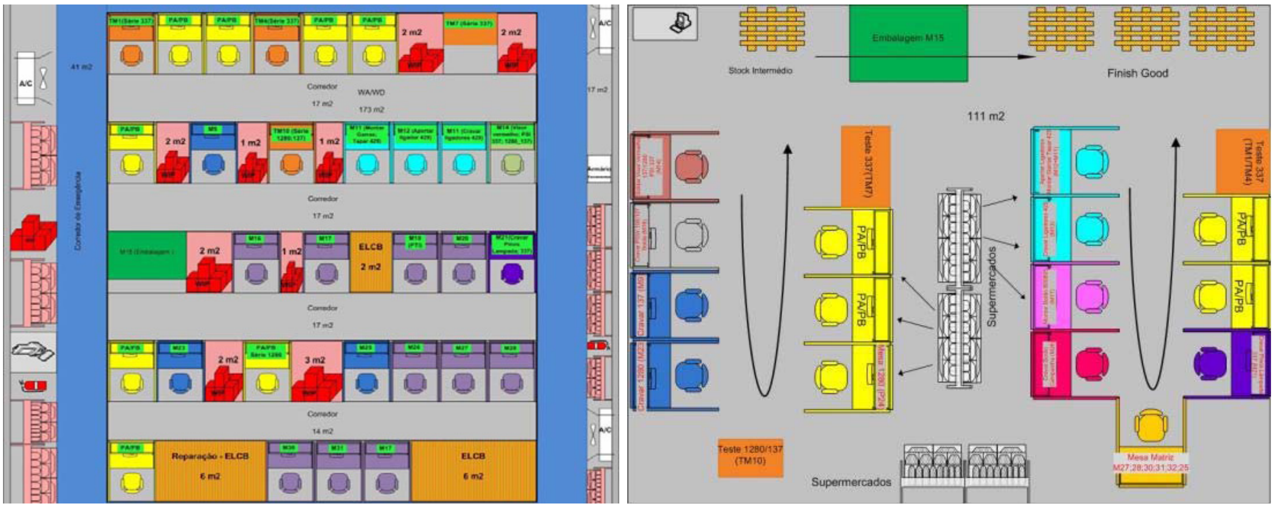


Figure 1. U-shaped assembly cell of water heaters in company A [30]

Company B was already in a process of implementing Lean before the student moved to the company, and some projects were carried out in different years and in different company sectors. The sector where project 2 (2009) was developed was in need of a strong restructure. This sector assembled sockets, switches (mechanisms), electrical accessories, bells, dimmers, among others, for industrial and home applications and it was known as Wiring Accessories (WA) and Wiring Devices (WD) sector (WA/WD).

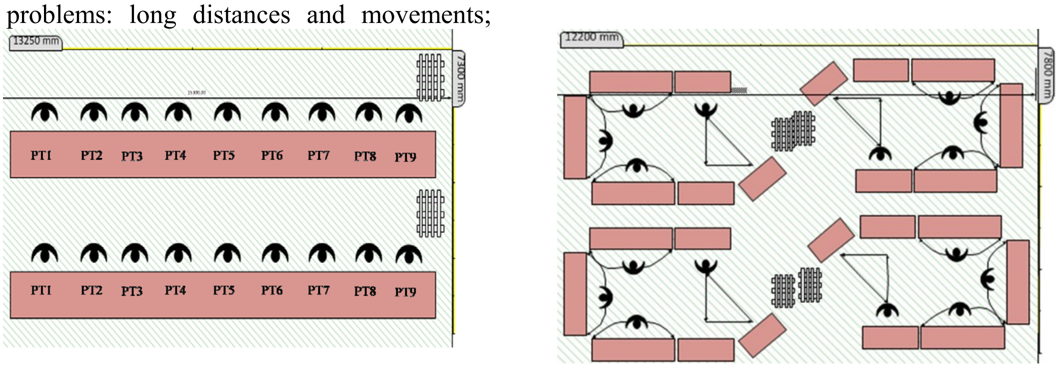
This was a product which had been losing market share. Before the study it occupied an area of 219m^2. The production system had 31 workstations distributed by five assembly lines and ten operators (Figure 2a). The operations were mainly manual, with the need of some minor equipment, such as crimping machines, screwdrivers and electrical testing. Problems with this layout include: long distances travelled by the materials and operators; long transport time; high area occupation; high WIP level; late delivery times (of at least one month), errors and too much time in the materials supply; supermarket disorganization. Beyond these, the student made some interviews with the operators of the assembly line, which were demotivated and unhappy, since they could not understand what was wrong nor achieve any satisfactory work within this production system. The disinterest in this sector was visibly accrued, since the deliveries of components from the others sectors, were commonly late or wrong. The five assembly lines were reconfigured into two U-shaped assembly cells (Figure 2b).



a) b)

Figure 2. Production system: a) previous: five assembly lines; new system: two U-shaped assembly cells [31]

Two more projects took place in 2012 in company B (project 3 and project 4) as a result of the success of the conversion to assembly cells. This triggered some reflection on the best approach for production of the earth leakage circuit breaker (ELCB) product. The production was organized in the two assembly lines (project 3), with nine operators (PT) in each line, as shown in the Figure 3a). The lines exhibited the following problems: long distances and movements; high percentage of non-value-added activities; push production; high WIP level; outdated operation times and sequences; unbalancing; no rotation between workstations; non-ergonomic workstations; repetition of operations; work without standard, high level of defects and low productivity. The possibility of formation of cells was studied and the new system proposed had four U-shaped assembly cells as represented in Figure 3b).



a) b)

Figure 3. Production system of ELCB: a) Previous: two assembly lines; b) new system: four U-shaped assembly cells [32]

In project 4, seven cells dedicated to the production of another model of ELCB (the model with 2 poles) were improved in order to attain an increase on the demand. The analysis of these cells revealed: operations' balancing problems, damage/loss of components and inexistence of a standard concerning the components location on the workstation. Furthermore, one of the operations – the thermal calibration – was responsible for a large number of non-conformities. To overcome these problems, it was decided to implement a kaizen policy.

The production unit in company C (Project 5) was organized in a job shop fashion, holding high levels of inventory, transportation, movements, waiting, overproduction, and defects. An important family of products (frames for mirrors and pictures) manufactured and assembled in that production unit was manufactured and assembled in batches. The objective was to create one or two cells to improve the production performance and therefore reduce the costs to eventually recapture previous sales levels [32].

Company D (project 6) had a job-shop production system to produce products such as: footbridges, spatial trusses, stairs, gutters, gates, grids and frames [33]. The company had been facing problems of inefficiency of the manufacturing processes, lack of quality in some products and failing to comply with customer deliveries deadlines. The layout was reconfigured through the formation of three cutting cells (functional cells: C1, C2 and C3) and three assembly cells. The functional cells cut the raw-material and the assembly cells execute the other operations: drilling, welding and deburring (CM1, CM2 and CM3) [33].

The objective in company E was to transform gradually their assembly lines into assembly cells. The first project took place in 2011 (Project 7) and was focused in transforming two separate assembly lines into a single assembly cell. The first set of operations were issued in a line called "coil line", dedicated mainly to welding and other assembly operations, while the second set of operations took place in another line, dedicated to other assembly operations, testing and packing. The aim of project 7 was to bring all operations together in a single assembly cell in order to reduce WIP, lead times and increase productivity.

Project 8 was developed two years later in the same company E. An assembly line for another model of circuit breaker, classified as Magneto Thermic High Performance (MT-HP), was redesigned since it was misadjusted with current demand [34].

Only one operator worked on this line. It had a length of 8.6 meters and a width of 5.4 meters, thus occupying an area of, approximately, 46 m^2. So, beyond the many wastes on transportation and motion, the materials flow was confuse given that it produced three variants of the model. A number of Key Performance Indicators were poor (e.g. low efficiency, high level of defects, high throughput time). The new assembly cell occupies an area of, approximately, 32 m^2.

The purpose of project 9 in company E was to transform two separate assembly lines, dedicated to the assemblage of two different electric circuit breakers, into a single assembly cell, able to assemble both product types. The objective was to reduce the occupied area, improve the quality and productivity, as well as reducing lead times.

4.2 METHODOLOGY AND TOOLS

Four production families of water heaters (similar assembly processes and times) already existed in company A. This has facilitated the conversion process. Additionally, the company knew and implemented many Lean concepts, such as: levelling box, Kanban, milk-run, among others. After selecting the families to be produced in the new cells (based in the most similar ones), making the decision to have three cells for one family and the fourth produced three families), the balancing of cells followed. Then, a plan was established to convert the assembly line into the assembly cells, in two phases. The layout of the cells was studied to enabled the possibility of exchanging operators between the two cells (three alternatives were studied). Finally, the intercellular layout of the four cells was studied. Six alternatives were analysed (including the previous assembly lines), and the best one selected using the Factor Analysis Method [35], attending to some criteria, such as occupied area, production rate, ergonomic, materials supply, versatility, WIP level and throughput time. All alternatives were better than the existing assembly line.

In the case of project 2, redesign of the WA/WD assembly lines to assembly cells, the student used a formal methodology developed during the PhD studies of his supervisor [36]. This started with an evaluation on the better configuration for the product, attending to a set of criteria related with quantity/variety of product (Q/P analysis); the generic configuration selection (a product/function oriented production system), among others [37].

The result was a selection of a product oriented production system: the assembly cell. After presenting the proposal in a meeting and discussing some aspects/restrictions on implementing the cell, the project started. Attending that this sector produced more than 1000 references, the first study developed was an ABC quantity analysis to know what products were more produced in this sector. A VSM was designed for the product selected.

The rest of the methodology followed the phases, normally, considered in the literature: identification/ selection and/or formation of the part/products families; grouping machines (equipment) and people for the families created, organization of the intracellular layout and the intercellular layout with the materials supply and the production activity control system. Families were formed attending to the operations sequence and a clustering algorithm was applied. Nevertheless, due to a high frequency of common operations between the products (a product/operation 102x19matrix was built without significant results) it was difficult to extract the families from this. After defining the families and a first workstation grouping, two cells were designed.

A competences matrix was developed before affecting the operators to the cells. The number of operators was based on the Takt Time (TT) calculated for each cell. For the intracellular layout, various alternatives were studied, attending to the families routing, being selected the U-shaped cell. Seven alternatives were analysed for the intercellular layout using the occupation area (assembly, finish goods and supermarkets), transport time and cost and total parts made. The integration of this layout with the rest of the production system was also analyzed. Additional lean tools used were the 5S, visual management, poka-yoke mechanisms and standard work.

Project 3 used the same methodology of the first one, but in this case it was easier to form the families since they were previously identified, i.e. eight products produced in the assembly line. The intracellular layout was studied attended to the operators' mobility, information exchange and mutual aid.

The working balance was the selected operating mode. The CRAFT method was used to evaluate alternatives for integration of the assembly cells with the rest of the production system in order to reduce the distances travelled.

Project 4 in company B consisted on the improvement of the existing cells and included a detailed analysis of the performed operations, supply of components and internal organization of the cells. Several operations were improved (in terms of adequacy and time spent), the organization of the components' supply and location was redesigned (new racks and containers were applied) and the cell layout was slightly improved.

A new lubrication mechanism was proposed and implemented. Moreover, the intercellular layout was also modified in order to facilitate the flow of materials (components and final products).

In company C (project 5) the managers clearly identified the family of products to be assigned for the project. The cell design and implementation included: the operation times collection for the range of families of products; collection of demand patterns; cell design based on CORELAP method; training and motivate workers to perform all operations; training workers in different cell configurations for different demand levels; training workers in different operating modes (Rabbit

Chase and Working Balance). In order to allow rapid reconfiguration of the cell to fit specific combinations of product type and demand level, some workstation had to be adapted to include wheels as well as other changes. Regarding material supply, new devices and equipment had to be designed and built to reduce workers movements in reaching for components [38].

Student in company D started by performing an ABC analysis of value to distinguish the most important products of the company, attending to the economic value.

The frame selected was a metal profile used as pillars or beams in constructions such as metallic support structures of signs, footbridges of shopping malls or factories. Because the company had no operation times for any product, a study of this nature for this product was made. The flow of this product was also studied using process analysis and sequence diagrams. The current state VSM was designed, pointing out the problems: high transports and motion, high WIP level and high lead times.

The VSM of future state was also designed, considering the TT based on the demand. This TT was compared with the cycle time of operations and another problem was discovered: unbalancing of the processes. Attending to the different processes, it was decided to design two cells. Then, the number of operators was estimated for the cells. The cutting cells were designed because of long length of the frames. Other tools implemented were 5S, poka-yoke mechanisms and standard work. For the control of the production activity it was used the CONWIP mechanism implemented with the FIFO concept and one-piece-flow (OPF).

The projects in company E followed basically the same methodology. The process started with collection of the sequence of operations and operation times for the products. Then a main route was found to incorporate all possible routes, and then established a cell configuration by using several PDCA cycles, until a good result was achieved. Integration of cells with the remaining system was also an important step. Standard work, 5S, visual management and matrix competences were tools also used to help in designing of the cells.

4.3 BENEFITS

Table 3 summarizes the benefits achieved by the companies. In the case of company A (project 1), the main reason was to vary the number of operators in the cell to respond to changes on demand. While the line had 33 operators, the cells could accommodate from 3 to 13 operators each.

A distinguish benefit of project 2 was that of a renewed trust by the operators. The number of operators in the WA/WD sector was reduced from ten to eight while achieving the same output. Eleven workstations were eliminated from the previous system. The increased productivity enables the production of an additional 5390 products per year.

Project 3 most important benefit was the gain in confidence by the operators that, after some time, preferred to work in the cells instead of the lines, in spite of standing-up on the cells (previously regarded with wariness).

Table 3. Main benefits attained by the companies

Proj.	New system	Benefits	
		Reduction on	Improvements on
1	Assembly cells: #4	N. of operators: 26 (33) WIP & Throughput time Occupied space (length): 12m (40m) Disturb. & deficiencies	Flexibility to accommodate changes Process Transparency Materials supply efficiency
2	Assembly cells: #2	N. of operators: 8 (10) WIP level (days): 1 (8) Occupied area (50%) & shorter dist. Transp. time & cost (80%)	Productivity Flexibility Workstations usage
3	Assembly cells: #4	N. of operators: 16 (18) WIP level (units): 5 (32) Occup. area: $95m^2$ ($97m^2$) Processing time: 21 sec. Defects rate: by 6,5%	Productivity: 6 (5) parts/h-man Production rate in 12%
4	Assembly cells: #7	WIP level (units): 3 (8) Throughput Time (s): 245 (295)	Productivity: 12 (11) parts/h-man Levelling efficiency Standardized supply and location
5	Assembly cells: #2	WIP (units): 38 (1385) Lead time:49min.(5 days) Need for rework	Productivity: 120 (35) parts/h-man Increased quality
6	Cutting cells: #3 Assembly cells: #3	WIP; Defects and errors Occupied area and Delivery delays Lead time: from 11 to 2 days (80%) Transport & travelled distance by 25%	Simplified flows Standardized procedures Levelling efficiency
7	Assembly cells: #1	Occupied space: < 50% Transport & movement Lead time: from 20 days to < 10 hours	Productivity: 22%
8	Assembly cells: #1	Occupied area: 31% Movements: 80% Defects & scrap (rates): 39% & 6% Throughput time: 3.5h (13h) (73%)	Production Efficiency rate: 37,5% e.g. from 15 to 22,5 poles/hour
9	Assembly cells: #1	Lead time: 3h (10h) Utilized space: 37%	Productivity: 9% Line efficiency (average): 13% Production rate: 40%

The outcome of project 4 were savings of about 590K€ per annum, essentially related with a strong decrease on the WIP, an improvement on productivity and less rework, requiring an investment of about 10K€. Project 5 most impressive results relate to WIP and lead time reduction, as well as on productivity improvement. The Lean implementation (general aspects) in project 6, and the cells implementation in particular, promoted a "wind of change" in the company that retained the intention of replicating these results to other sections (e.g. carpentry).

Project 7 resulted in a single assembly line able to produce all operations required by the product family, using less than 50% of the space, previous required by the assembly lines, and reducing the wastes of transportation and movement. The gains in project 8 were estimated at about 4K€ per annual savings. Finally, project 9 also produced many interesting improvements, as presented in Table 3.

5. DISCUSSION

The U-shaped assembly cells designed and deployed in the case studies, were much alike the ones considered in the literature as being TPS, as advocated by Black

(1991) [39] and others. The benefits found in literature bare similarities to those found when deploying the concept on a number of industrial case studies.

The methodology used in most of the case studies did not include clustering algorithms or meta-heuristics approaches or other mathematical approaches [40,41]. Therefore the authors consider that these, so called, complex problems, as described on the literature, are not a prefixed requirement nor always characterize the endeavour of forming cells or define a production layout. As Marsh et al. [23] noticed, this is an important but not a difficult problem, most of times. The reason for this could be that in three of the five cases they already had production families. This is the first step to design cells, followed by the grouping of dissimilar equipment to produce the families.

Attending to the above, and in particular to the results achieved by companies B and E, conversion to production cells is incremental, not comprehensive as Marsh et al. [23] showed in their paper. Contrary to what some authors advocate as disadvantage of cells, loss of flexibility was not a problem in the design of the cells. More critical seems to be the existence of a flexible workforce which is aligned with the Lean methodology, to whom is given a higher level of importance to that of equipment, and workload balance is preferable.

By one side, it is possible to say that the Lean context, in some of the companies, promoted the need for production system redesign, since it brings to surface the hidden wastes. By the other side, if the company was not Lean knowledgeable, the promoter of the change was the student/researcher which framed the redesign requirement to eliminate the wastes [42]. In both cases, it is important to notice that the redesign process is supported by others Lean tools, such as: 5S, standard work, SMED, poka-yoke mechanisms, TPM, levelling, pull systems, material supply tools (supermarket, milk-run, …) among others.

These projects were developed by IEM students instructed in Lean principles and methodology. In this context, students must be aware of the difficulties they will face and must be system-thinkers [21, 22]. In a Lean context, production systems redesign should not constitute a hard decision-making task [42], but something that is natural and derives from the companies' embedded culture, and facilitates a quicker redesign of the production system for each product or product family when the market demands it.

6. CONCLUSION

Production cells are well-known production system configurations, which give productivity advantages while maintaining the versatility of job-shops. When the market demands change, it is relatively easier to reconfigure, promoting its continuous improvement to ensure a good performance and reduced waste. In a Lean context, many companies rethink their production system.

This paper presented nine projects on five companies, which promoted the redesign of the production system for one or more products. Three of companies, systematically, evaluate the production system for their products as they are involved in a Lean journey of continuous improvement. Its system-thinking culture enables one such evaluation. The tangible benefits of the redesign are always rewarded, along with intangible benefits, such as the ones related to people being more compromised with continuous involvement of their "own" system.

The applied methodology, contrary to what research advocates, could be streamlined, without the need for methods to solve "hard" problems. Nevertheless, it is important to follow a methodology that guides the way, to help to evaluate in an iterative process, the alternatives solutions and to integrate them in an efficient way with the remaining of the system. Production cells seem to, more than ever, make sense, being the more versatile production system to nowadays challenges.

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РЕДИЗАЈН ПРОИЗВОДНИХ СИСТЕМА У КОНТЕКСТУ LEAN ПРОИЗВОДЊЕ: ПИТАЊЕ ОДРЖИВОСТИ

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Производни системи често остају непромењени у дугом временском периоду упркос променама на тржишту и у моделу управљања. У једном релевантном временском оквиру ова стагнација доводи до акумулације неефикасности и губитака, што ствара непродуктивне производне системе. Рад приказује неколико студија случаја на редизајнирању производних система у контексту lean производње. Истраживања показују да су недавно дипломирани студенти индустријског инжењерства на мастер студијама, са познавањем различитих производних парадигми, оспособљени да идентификују одређени број проблема и потребе за редизајнирањем производног система. Утврђено је да компаније које су извршиле потребне промене имају користи од тога, тј. повећање продуктивности као и смањење губитака у погону.