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Procedia Manufacturing 39 (2019) 1038–1047

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

25th International Conference on Production Research Manufacturing Innovation: Cyber Physical Manufacturing
August 9-14, 2019 | Chicago, Illinois (USA)

Reusing Equipment in Cells Reconfiguration for a Lean and Sustainable Production

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Abstract

Production cells are considered a flexible production system capable to face new market demands. In most cases, this is provided by their capability of reconfiguration, i.e., by removing/adding new equipment needed and/or reusing the existent equipment for the new demand. Nevertheless, some companies are not conveniently exploring this opportunity. What happened, many times, is the design of a complete new cell replacing all the equipment and sending the existent machinery to the warehouse. This is a decision that, economically and environmentally, is costly. Furthermore, knowing that some equipment could be reused for a new product. In a Lean Thinking, this is waste and a Lean company should promote a more efficient and sustainable production. This paper introduces a study in a Lean company that has developed practices to reuse equipment. The reasons for the non-reuse of the existent equipment were studied and some strategies were proposed to turn this equipment available and visible for reuse. Also, the benefits of reusing equipment related with saved costs and contribution to the environmental sustainability, are discussed.

Keywords: Lean Thinking, Asset management; assembly cells.

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10.1016/j.promfg.2020.01.373

1. Introduction

Companies are faced with an increasingly competitive market, characterized by uncertainty and rapid technological development, with more demanding customers, who expect high-quality products at a low cost [1]. This leads to a need of organizations to adjust and seek out new tools and methodologies, such as Lean Production in order to reduce costs and better respond to customer demand [2], [3]. In this way, Sullivan, McDonald and Aken [4] argue that one of the benefits that Lean Production provides is to achieve greater production flexibility through waste-free production systems. According to Bhat [5], such systems materialize in the implementation of production cells, which allow to reduce costs and lead-times, improve quality and delivery performance, providing the right part at right time. Bhat [5] also argues that production systems must be product-oriented in order to create flow and reduce waste. This makes production cells an appropriate production system for Lean Production context [6]. According to Hyer and Brown [7], production cells are characterized by the creation of flow through the nearness of tasks, equipment and operators, in terms of time, space and information. One of the main advantages of the cells is the ability to adjust the number of machines and operators number according to demand, which allows to reduce costs and increase profits [8]. Thus, when demand falls, it is possible to redistribute work and remove equipment in order to avoid waste, such as overproduction, energy expenditure and an increase in stock, resulting in a more efficient system. To achieve this, a U-shaped cells are preferable to the "I" cells [9].

Nevertheless, many times, to achieve a better production system it is necessary to redesign it [10], even if this implies a hard-decision making process [11]. Sullivan et al. [4] adds that this can also be achieved through the acquisition of more versatile equipment and a multipurpose workforce. However, this source of flexibility has a cost associated with the acquisition of new equipment, technology and labor, although for high capital companies this may not be an obstacle [1]. Thus, the reconfiguration of production systems is a mandatory condition for companies to remain sustainable [10]. However, this reconfiguration does not necessarily imply and should not imply new production means, but should involve its reuse, whenever possible. Ohno [12] argued that if an equipment could guarantee productivity close to 100%, regardless of its depreciation over the years, buying a new equipment would never be cheaper because a new high performance equipment would produce more than what is needed, i.e. overproduction, resulting in increased stock and waste. In this way, it becomes necessary to understand the benefits of reusing the equipment and when it should be replaced.

When comes the time to replace the equipment, normally, due to the increase in operation and maintenance costs of current assets or the technological advances of assets available in the market, organizations face an important decision ([4], [13]) that will affect sustainable development pillars [14]. Nevertheless, organizations could adopt strategies that combine systems reconfiguration synergies and environmental sustainability. Such strategies that seek a cleaner and sustainable production are under the called Lean-Green concept ([15]–[18]). Attending to this concern, this paper objective is to present the standard procedures created to improve the level of equipment reuse and the strategies developed to turn the reuse process easier and clear. In order to carry out the present project, the Action-Research methodology was used, which is based on the active participation of the researcher and everyone involved in solving problems in an organization and implementing one or more actions [19].

This paper is divided in six sections. After the introduction, a brief literature review is developed in section two. Section three presents the company characterization, diagnosis and identification of the problem. Proposals to solve the problem are presented in the fourth section. Section five shows some results of these proposals. Finally, section six presents some final remarks.

2. Literature review

This section presents briefly some definitions and concepts related to Lean Production, Lean-Green and physical asset management.

2.1. Lean Production, Lean Thinking Principles and Lean-Green concept

The Lean Production concept first emerged in Japan after World War II when Toyota created a new production management system, Toyota Production System (TPS), focused on reducing the waste of operations [20], and rests on two pillars, Just-in-Time (JIT) Production and Autonomation or *Jidoka* [12]. According to Ohno [12], JIT aims at getting the right material, at the right time and in the necessary quantities, to an assembly line, in order to reduce the stock. *Jidoka* means automation with a human touch, i.e., through the application of safety devices, fixed work tools that assist in guiding the product, jigs, and error-proofing devices, also known as poka-yoke [1]. With this, it is possible to increase the process quality once the problems become visible, and defective products are eliminated [2]. Beyond these pillars, Monden [21] considered other two key ideas: flexible work force and creative thinking or inventive ideas. This is aligned with the "respect-for-human system" as called by Sugimori *et al*. [22].

The designation Lean Production gained great relevance after the publication of the book "The Machine That Changed The World" [20] that is based on the idea of producing more with less resources, eliminating all type of waste. In this sense, Ohno [12], author of TPS, defined waste as all activities that consume resources but do not add value to the product in the costumer's point of view. This author has grouped them into seven categories, namely, overproduction, inventory, transport, movement, defects, waiting, and finally over-processing. Later, Liker [23] considered as an eighth waste, the failure to take advantage of human potential, that is, the waste of not using knowledge and creativity of people, related with the key ideas referred by Monden [21]. Womack and Jones [24] published a new book on the principles of Lean Thinking so that companies could orient themselves in ways that reduce or even eliminate waste because they considered Lean ideas to be the most powerful tool for a company to create value and eliminate waste. These authors defined principles of Lean Thinking as follows: value; value chain; continuous flow; production; and pursuit of perfection.

The application of the Lean methodology presents innumerable advantages for the companies, such as stock and lead time reduction and the quality increase, among others. This is achieved by classifying the activities that add value and the wastes, which consequently leads to reduced investment and increased production efficiency [25]. However, the success of Lean Production is dependent on Lean Thinking mind-set, since it implies a paradigm shift [26]. This will demand a trained workforce in Lean Transformation [27], [28] capable to solve problems [29]. Lean Thinking principles and tools have been adopted and combined in a number of areas, among them is Lean-Green, which is applied to achieve sustainable development [30].

This Lean-Green concept adopt strategies that combine synergies of Lean Production and environmental sustainability [18]. This combines value and efficiency in operational and environmental terms, i.e., minimizes waste and improves financial performance, reducing the environmental impacts [31] promoting the eco-efficiency of the systems [32]. The U.S. Environmental Protection Agency (EPA) [31] classifies the concept of environmental waste as the unnecessary or excessive use of resources, or substances released into the air, water or land that could harm human health or the environment. Environmental waste occurs when companies use more resources than necessary to provide products or services to customers and/or when customers use and discard products.

According to World Business Council for Sustainable Development (WBCSD) and United Nations Environment Program (UNEP) [33], the concept of Eco-efficiency advocates reducing material consumption, reducing the quantity and dispersion of toxic substances, reduce energy consumption in products and services, promote recycling and use of renewable energy, prolong the product life cycle, and ultimately increase service intensity. According to Pampanelli, Found and Bernardes [34], Lean-Green addresses environmental concern by requiring increased resource utilization, reduced environmental impact and environmental awareness along the value chain. The authors also argue that the application of this model should be done after the Lean implementation and can reduce energy consumption by 10% and materials and waste by 30% to 50%. In this context, the reuse of equipment also plays a key role in improving the environmental and economic sustainability of production, improving the cost-effectiveness of the system [12]. According to Gao and Wang [35] reuse of machines or tools can be done by upgrading existing machines to increase productivity and capacity, or by repairing or replacing damaged parts.

2.2. Physical Asset Management

Recently, many companies start talking about Lean Maintenance, which is an attempt to bring the lean approach to efficiency improvement to the world of physical asset management [36]. Physical asset management is a fundamental process that all organizations face and must be aware, since it is a decision-making process that involves all phases of the life cycle of physical assets, from their acquisition and operation, to their dismantling [37].

Therefore, the decision-making process should be aligned with the strategic, tactical and operational levels of the company, in order to ensure the creation of sustainable value from the assets [38].

According to Van der Velde et al. [39] the management of physical assets is a process of balancing the cost, performance and risk throughout the life cycle of an asset, in order to achieve organizational objectives. In this sense, in 2008, a technical procedure with 28 points was created by the Institute of Asset Management (IAM) and the British Standards Institution (BSI), which aimed to establish and improve the system of physical assets management of companies called PAS55, which in 2013 was passed into the form of ISO 55000 standard [40]. According to this standard, an asset is understood as an article, asset or entity that has potential or actual value for an organization, and can be tangible or intangible, financial or non-financial. However, ISO 55000 is intended for tangible assets, such as equipment, resources, vehicles, among others, although it can be applied to intangible assets [41].

Its application has many benefits, since it takes into account the entire life cycle of the asset, which allows a better asset management, based on risks, costs, opportunities and performance, which leads to an improvement in the return of the asset, investment and cost reduction [41]. However, many companies still do not have any asset management system, so they should be made aware of the need to adopt implementation methodologies so that they can integrate asset management into the production context as a business process in operations [38]. In this way, data management and collection will also be useful in maintaining assets, however, this management needs to be able to confidently predict future costs and how this is affected by the current activities. For this, all data on equipment type, location and age, as well as data on failure rates, asset conditions and other areas are required [36]. According to Shah et al. [42] one of the biggest challenges in the implementation of asset management lies in the collection, feasibility and quality of the data. Thus, this management should involve a multidisciplinary team, from maintenance to financial management, also involving other areas such as systems and software engineering, environmental management, among others.

3. Company characterization, diagnosis and identification of the problem

This project was developed in a German multinational company which produces electronic components. The production system of the company is characterized by being oriented to the product, more concretely, production cells, through a one piece flow. The cells are made up of different universal machines called MAEs, characterized by being used in any type of product and whose depreciation is 11 years. They were subsequently customized for each type of product through jigs and EWAKs, i.e. fixed tools that help guide the product by having the correct size of fit, which allow the production of a variety of articles in a flexible way and whose depreciation is done in three years. Thus, the project focused in four production cells, similar to the one in Fig. 1, of a customer, called here Customer X.

The cells under study operate five days a week in three shifts model, equivalent to 109.58 hours/week, have an average cycle time of 89 seconds and an OEE with a factory target of 90% and a technical capacity of 3989 pieces/week. It should be noted that the number of shifts is agreed upon with the customer as well as the requirement of 15% flexibility for any fluctuations in demand.

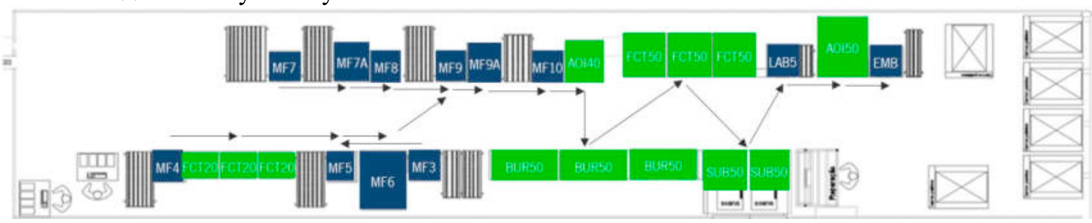

Fig. 1. One of the production cells for customer X

One of the best practices to ensure the sustainability of all investments and of the organization itself is the intelligent use of its resources. In this way, it makes sense to analyze and create procedures that can lead to the best use of the investment made. This can and should involve the reuse of equipment. However, the existing practice in the company under study was to invest in new equipment at the time of designing new cells. Thus, among those responsible for the acquisition and management of equipment, a study was conducted to understand the reason why they were not reused. After a detailed analysis of the situation, four reasons were discovered for the non-reuse of the equipment: i) the lack of a standardized procedure to dismantle the equipment and assure a good storage for a future reuse; ii) the location and functional status of the stored equipment were unknown; iii) customer fluctuation demand change the planned availability of each equipment; iv) new products may require equipment technologically more advanced. These reasons are detailed next.

3.1. Lack of a standardized procedure for equipment reuse

First of all, the researcher tried to understand the reason why the equipment that were stocked in warehouse were not reused. After approaching the areas responsible for warehousing and purchasing equipment, the researcher analyzed the documents in the company database. It was verified that there was no methodology that would guarantee the efficient reuse of the equipment. This happened because there was no standard procedure for uninstalling a cell. It was also found that the equipment did not have a defined destination, nor were they registered on any database, so when stocked, company lost their track.

3.2. Lack of knowledge of the equipment current state and location

The non-reuse of the equipment was also justified by the lack of knowledge of the current state of the equipment, since these were in warehouse without identification of the state and location, and not in any visible database. Therefore, the equipment could not be easily located. Being in an unknown location, the equipment ran the risk of becoming obsolete, degrading or even incomplete, without certain parts could be removed to mount in other similar equipment. In addition, the equipment was sent to scrap only when the warehouse was full, being uncertain their exit dates and unknown the time that they were there. Considering these occurrences, those in charge would prefer to purchase new equipment with guarantees that they would come in good conditions and capable of producing the intended demand instead of using a piece of equipment stored in the warehouse without guarantees of operation. In this way, the researcher started by identifying and registering all existing equipment in the warehouse in an Excel sheet, in order to be able to locate them. More than 400 equipment were identified, of which 150 were obsolete. It should be noted that obsolete equipment is considered scrap metal, which has a value of, approximately, 10 m.u./tons (due to the company confidential it will be used monetary unit – m.u.).

3.3. Uncertainty of equipment availability date

Another reason for the non-reuse of equipment was the fact that customers often give a planned end-of-production date and later it is postponed, so that the date when the equipment is actually available becomes uncertain. So, there was a risk of planning to reuse the equipment from a certain date onwards and not having them available, or on the data planned to install the new cell, production is still planned for the cell to which the equipment belongs. This last case is recurrent and happened with the cells under study, in which the expected date of production of the existing products matched with the beginning of production of the new products. The installation of the cells would have to be done one year before, so it was not possible to reuse existing equipment, since there would be a year of production overlap. In addition, an increase in demand of the current products was verified, as shown in Fig. 2.

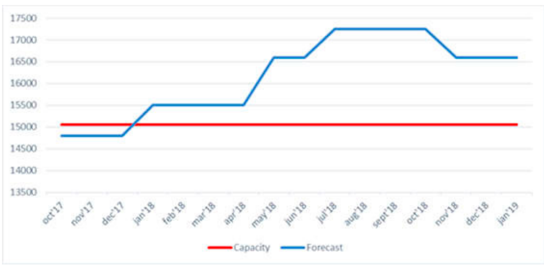

Fig. 2. Existent product demand vs system capacity.

As demand increased, the number of cells needed increased. After a detailed analysis, two additional cells (beyond the current four) were estimated to be necessary for the current products. However, it was intended to avoid the increase in cells since it implies a greater investment in equipment, an increase in the shop-floor area to put the new cells, and the increase of inventory in the warehouse due to the end of production of the current products (that will consequently lead to more scrap and lower environmental sustainability). Therefore, to avoid investing in two new cells and, if possible, reduce a cell of the current products, allowing to release existing equipment, and reuse them in new products, the ideal cycle time (CT) in different shifts model was calculated to use only three production cells (for the current products).

Then, taking into account the ideal cycle time, the processes that were preventing to achieve the target and, consequently, limiting the capacity, were analysed (Fig. 3). In this, the stations marked with green color are inspection and tests workstations, while the blue posts are manual assembly stations. Thus, there were seven workstations whose operation times exceeded the target, being the ones analysed in order to reduce this time.

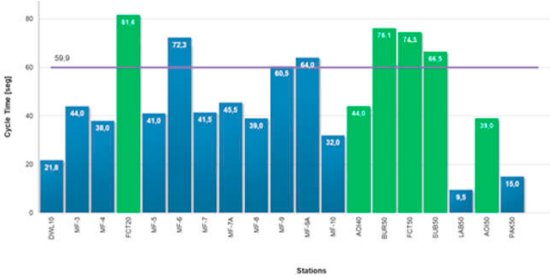

Fig. 3. Workstations operation times for the production cells.

3.4. Waste on existing cells

When the production cells are reconfigured, they should be analyzed in order to reduce and/or eliminate wastes, so that the process and flow of the new cells is better and more efficient than the previous one. In this way, a study of layouts was done in order to minimize waste. Some layouts iterations were studied and compared against some criteria such as the total distance traveled by the operator and the percentage of movements without add value. Three layouts proposals, using paper and Styrofoam material, are presented in Fig. 4.

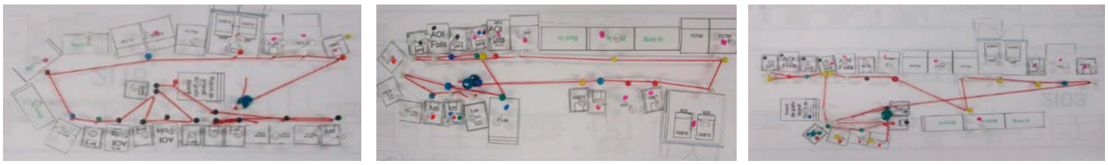
Fig. 4. Three layouts proposals studied and compared against criteria pre-defined.

One of the problems found through the study was that the material feeding shelves of the cells presented several wastes, the most visible being the occupied area, which meant that the operators had high motions and, consequently, a higher time. The cell under study implied a total motion of almost 47 meters and a percentage of movements without add value of 44%. It became necessary to analyze material feeding shelves better, therefore the study was focused on the most critical workstation in terms of material feeding shelves. Thus, after a deep observation to the workstation, a more detailed analysis was carried out, where it was found that use of standard containers represented several wastes, such as: 1) Occupied area by the workstation: 4,5 m²; 2) Operator motions: 6,6meters/cycle; 3) Extra movements caused by the material coming in blisters, inside boxes, and because it is not positioned in the point of use, nor in the correct assembling position; 4) High work in progress (WIP).

4. Improvement proposals planning and implementation

This section presents the solutions adopted regarding the potential improvement points identified previously.

4.1. Implementation of a standardized procedure

In order to be able to reuse the equipment, it is essential a standard procedure for disassembling and managing the equipment in storage. Thus, a systematic procedure was created on how to disassemble the equipment from the production cells to the warehouse. This procedure includes six steps: 1) Remove the equipment from the production cell; 2) Analyze the status of equipment; 3) Take a photo of the equipment; 4) Pack the equipment; 5) Identify the equipment on a database; 6) Store the equipment.

4.2. Creation of an online database

Several issues were found on the process of reuse. Most times users do not have sure which equipment was available, the status of them or the location. Based on this, an online database was created to add transparency and facilitate the management of physical assets, as well as to better understand the maintenance intervention needs.

4.3. Processes improvements in cells

Since the current production cells did not have the capacity to produce a greater quantity, the renegotiation of the shift system with the customer was started. Thus, it was negotiated with the customer in December 2017 to change the shift system from three to four shifts model from the beginning of January 2018. The negotiation was a success, leading to a change from three to four shift model increasing the production capacity and the utilization of equipment (see Table 1).

However, in order to increase capacity without increasing the number of cells and still be able to reduce another cell, in addition to changing the number of shifts, it was necessary to reduce cycle times as shown in the analysis performed in section 3.3. In this analysis it was found that to reduce the number of cells, the CT of the stations should be less than or equal to 60 seconds. Thus, to achieve 60 seconds it was necessary to remove duplicated tests and improve, the system reprogramming and redistributing the tests by the inspection equipment. Regarding the manual assembly stations, a change was proposed in the process, consisting transferring tasks to other stations. With these changes, it was possible to reduce the CT and thus reduce the number of cells needed for the current production (see Table 1).

4.4. Reconfiguration of production cells

As seen in section 3.4., the existing layout was not the best due to its configuration and material feeding shelves. Therefore, it was proposed to change the layout to a U-shaped that in addition to providing a better flow, allows a total motion of 33 meters and a percentage of 17% of movements without add value (Fig. 5). To this end, however, a material feeding shelves, represented by the arrow in red, should be constructed to interconnect the stations to avoid more movements without add value, as well as to eliminate the material feeding shelves.

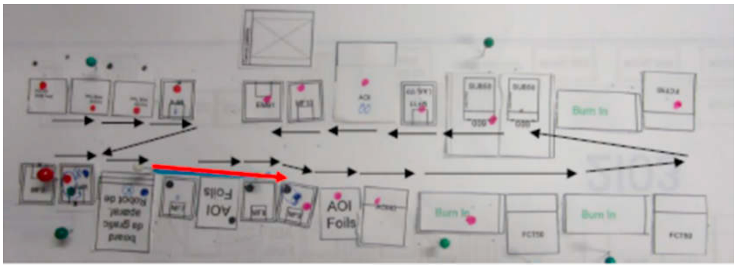

Fig. 5. New layout proposal for cells of client X.

However, the U-shaped layout caused the packaging zone to be in the middle and not at the end of the production cell, as it was initially. This constrained the picking of the finished product pallets and contamination of the product in process due to the carton used in the container, so this solution was excluded.

For the most critical station, a new concept of material feeding shelves was created so that the quantity of material on them was only the necessary, supplied in a one-piece-flow (Fig. 6).

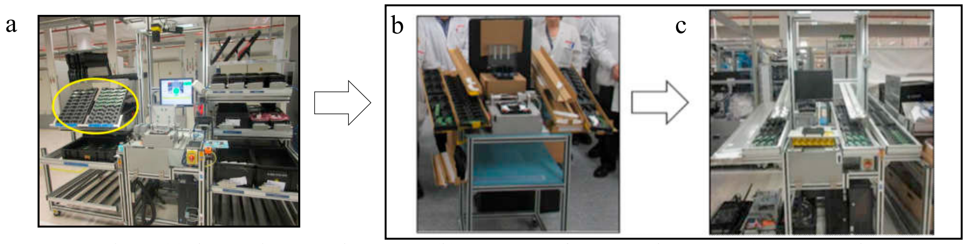
Fig. 6. (a) the previous supply system; (b) prototype of new supply system; (c) new supply system.

Also, the materials were within operator reach and in the position to be assembled. Thus, this workstation becomes more efficient what improves cell performance.

5. Discussion and analysis of results

This section presents and discusses the main results of the proposals presented in previous section, quantifying whenever possible the gains obtained.

5.1. Reduction of investment in new equipment

The creation of a standard procedure for disassembly the production cells facilitated the whole process of disassembling and storing the equipment, allowing uniformity for all involved. The registration of all entrances and exits from warehouse equipment to the shop floor not only allowed the equipment responsible to begin to identify which equipment was available for reuse and where it was found, but also increased the confidence of those for their reuse. This record allowed to track better the equipment and control their movements and to identify the value saved in reuses, which was higher than 248.692 m.u..

5.2. Increase in available storage area

Through the survey of the equipment in warehouse, it was identified that 37.5% of the equipment were obsolete. These were sent to scrap in two trucks with several tons each, which represents more than 100 m.u. in scrap retained in the warehouse. In addition, more than 150 m^2 of warehouse area was released, corresponding about 20% of the total warehouse area. Given that the company quantifies the value of the free space, this release means a saving of 1170 m.u./month.

5.3. Increase in capacity and use of equipment

By changing the shift system from three to four shifts model and improving the cycle time from 89 to 60 seconds, it was possible to increase the capacity of the production cells and the use of the equipment. Table 1 briefly summarizes the gains achieved through the implementation of the proposal.

Table 1. Gains obtained with the capacity increase.

Measures of performance	Before	After	Gain
Cycle time (seconds)	89	60	33%
Capacity per cell (parts/week)	3202	6296	96%
Total number of cells	7	4	43%
Occupied area (m^2)	336	192	39%

This change avoided the investment in two new cells for the existing products, and therefore saved about 2.800.000 m.u.. The CT reduction also allowed to reduce an existing cell, thus releasing all their equipment for the new products, instead of having to invest in a new complete cell, it was possible to reuse some equipment, thus saving more than 500.000 m.u.. On the other hand, the planning and preparation time of the cell for the new products was reduced, since the equipment was already available in the shop-floor. Due to that, since the reconfiguration of the cell for the new products could be done immediately, rather than waiting around three months. Another advantage was the fact that the equipment was already on the shop-floor, which allowed to reduce inventory in the warehouse and, consequently, the occupied area.

5.4. Increase of environmental sustainability

One of the greatest benefits obtained from the results was the contribution to the concept of eco-efficiency, which consequently led to an increase in environmental sustainability. This was achieved through the reuse of equipment, by extending its life cycle. The reuse of equipment also lead to the production of new investment which would occupy more space, either in warehouse or on the factory floor, and would imply a higher consumption of energy and an increase in environmental pollution, since these would come to be scrap (about 15 tons, estimated value). The fact of not investing in new equipment also implies a lower consumption of materials, energy and water and less emissions of pollutants in the production of new equipment.

5.5. Reduction of waste in the reconfiguration of production cells

The anticipated gains by changing the layout are visible in Table 2.

Table 2. Gains obtained with the layout change.

Waste	Before	After	Gain
Total motion (m)	46,7	33	29%
Movements without add value (%)	44%	17%	61%
Cells area (m²)	80	60	25%

However, this proposal was not implemented, since the packaging would be in the middle of the production cell, which is considered a product contamination zone.

With respect to the new concept of supply to the production cell, a 13% gain in the operator's cycle time was achieved, as well as reducing and eliminating some waste. The gains with the elimination of the material feeding shelves can be observed in the Table 3.

Table 3. Gains obtained with the material feeding shelves.

Waste	Before	After	Gain
Operator CT (sec./cycle)	49,1	42,5	13%
Area occupied by the workstation (m^2)	4,5	2,23	50%
Movements without add value (m/cycle)	5,5	0	100%
Stock (parts)	2040	188	91%

6. Final remarks

This paper presents the results of a project that questioned the non-reuse of equipment in a production cell. A detailed analysis allowed the identification of four main reasons for not doing it. Solutions and practices were advised and implemented. To sustain such practices, they need to be part of the routines of top and middle management. More important was the lesson taken from this that launching a new product does not necessarily imply new equipment acquisition, even if this investment is supported by product client. From an environmental sustainability point of view who directly pays do not matter because in the end is the planet that pays the new equipment through more materials extraction, more energy, more water consumed, and more pollution. Having this enlarged vision and a Lean attitude, the company allowed this study achieving excellent gains at all levels. As so, it is concluded that the reuse of equipment plays a key role in improving the environmental and economic sustainability of production, improving the cost-effectiveness of the system. The project success leads to the interest in replicating this practice in other company cells. And, though this study was applied to a case study, the “lessons learned” in it could be applied in any company, as reuse is one of the first “R” to apply to obtain sustainable production.

Acknowledgments

The authors acknowledge the company for allowing this study.

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2019.

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