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Integration of a collaborative robot in a U-shaped production line: a real case study

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Abstract

In lean production environments, such as the U-shaped cells, flexibility is a priority. Therefore, any element that introduces process stiffness is negatively valued. Former studies establish that robotization of tasks in U-shaped cells presents some drawbacks. For instance: it may complicate continuous improvement, prolong changeover time, use a large space or create safety problems for the operators. However, the collaborative robots (CoBots) may change this situation, since they overcome most of the issues previously mentioned. The present study analyses a real case of de-robotization in a traditional assembly line to transform it into a manual U-shaped line. In a second step a CoBot is integrated in the cell replacing one of the workers. This study empirically compares the manufacturing process in these three scenarios. Results in real production conditions show that a U-shape cell assisted by a CoBot increases productivity and reliability while reducing the surface used. These results suggest that collaborative robotics can be integrated in U-shaped production lines and even increase the efficiency of a traditional robotized assembly line.

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1. Introduction.

One of the main goals of Lean Production Systems is to gain competitiveness by reducing delivery time. This can be achieved by making the system progressively more and more flexible, increasing its capability to produce in one-piece flow and to adapt itself to the customer takt time [1].

In lean production environments, such as U-shaped production lines, flexibility is a priority [2]. Therefore, any element that may introduce process stiffness is negatively valued. Former studies [3] establish that the robotization of tasks in U-shaped cells presents some drawbacks. For instance: it may complicate continuous improvement, prolong changeover time, use large space or create safety problems for operators. However, the collaborative robots (CoBots) may change this situation, since they overcome most of the issues previously mentioned [4]. A collaborative robot is defined as “a robot designed to assist human beings as a guide or assistor in a constrained motion” [5]. However, due to the recent introduction of this technology in industry, there are scarce scientific studies about the integration of collaborative robotics in U-shaped production lines [4].

The goal of this research is to show, through in-depth analysis of a real case, the main advantages and drawbacks of using CoBots in a U-shaped line. Particularly, the studied case shows the evolution of a traditional automated assembly line into a U-shaped that finally incorporated a CoBot to assist the workers on handling tasks. The study of the three designs –one design for each mentioned situation- in real production conditions allows the comparison of different alternatives in the design of production lines. In addition it allows the objective assessment of introducing a CoBot in a U-shaped cell. This study presents the results of the case, its conclusions and possible avenues for future research.

2. Literature review.

U-shaped production lines were conceived as a solution, in lean production environments, for waste elimination and for getting the full utilization of worker’s capabilities [6]. Waste removal is usually achieved by the introduction of pull systems, one-piece flow, leveling and jidoka, while fully utilizing workers’ capabilities requires a system of respect for people based on minimizing wasted movements, ensuring their safety, and giving them greater responsibility in running and improving their jobs [7].

According to Hyer and Brown [8], a manufacturing cell is characterized by the creation of value flow in which tasks, equipment and operators are closely connected in terms of time, space and information. Transfer and waiting times between operations should be minimized and operations should be in physical proximity to each other, making it easier to move materials, to exchange information and to solve problems. In order to keep the value flow and minimize operators’ movements, using large machines results in serious disadvantages. Another aspect that makes U-shaped cell design especially interesting is the capability of adaptation to the customer takt time. This can be achieved by working one-piece flow and varying its cycle time [9]. Therefore, introducing automatic systems is usually discarded because it may interfere the operators’ working cycle, enlarge the changeover time or interrupt the production flow, e.g. operating in batches. Eventually, although the idea of combining human flexibility with robot efficiency is attractive, safety issues due to physical proximity of people and robots may be taken into consideration. Traditional robot restrictions make unfeasible a tight collaboration among people and robots sharing the same working area [3]. For all these reasons, some companies started to cut out automation of some operations when transforming their production lines into U-shaped cells.

In spite of the mentioned difficulties, the recent appearance of collaborative robots (CoBots) opens new opportunities for their utilization in industrial environments. A collaborative robot may be defined as “a robot designed to assist human beings as a guide or assistor in a constrained motion” [5]. Cobots are intended for direct interaction with a human worker [10]. Collaborative robots features allow operators to share the working area with no physical barriers between them [3]. In addition, cobots have generally been identified as being ideal for manufacturers with more variants and smaller lot sizes [11], which is an intrinsic feature of lean production systems. In conclusion, it becomes interesting to carry out an in-depth study on the integration of cobots into U-shaped cells.

3. Case study description.

This Case Study presents a real execution developed in a Tier 1 supplier for the main car builders in Europe. The manufacturing plant is currently involved in a transformation project from a “Push Production System” to a “Pull Production System” with an additional Industry 4.0 strategy.

The studied production line is dedicated to the manufacturing of a component family for the automotive industry. Products are composed of a plastic body - formed by three welded parts – assembled with a filtering element. Finally a number of additional components, purchased to external suppliers, are also assembled to the body.

3.1. Initial situation: semi-automated line based on a traditional robot.

The product family was originally manufactured in a semi-automatic standard line managed by a monthly planning system. The facility consisted of a robotic cage fed by conveyors plus two isolated manual stations. The line was directly connected to two injection machines by conveyors. The general standard layout of this line is shown in Fig. 1.

At the starting point of the case study a new product family replaced the previous one and it was produced at the studied manufacturing line.

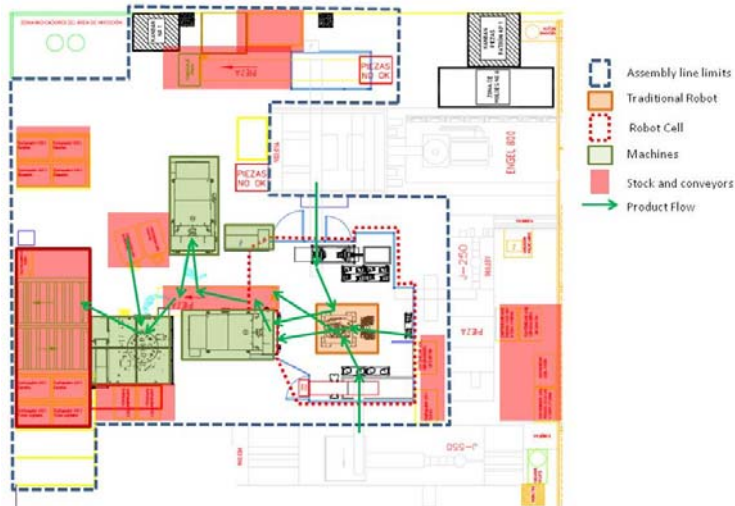


Fig. 1. Standard layout for initial semi-automated production line.

3.2. Intermediate situation: U-shaped assembly line without robot.

The lean transformation project introduced new flexibility and adaptability requirements for the customer takt time, so that the manual assembly operations were disassociated from the injection machines through a kanban. Due to the product features [12], the line was redesigned to a one-piece flow process in a U-shaped production line working in “fixed stations” mode [9], synchronizing man-machine times.

Due to this new cell configuration, introducing a traditional robot into the working space was not possible and the production line was de-robotized, as can be seen in Fig. 2 layout.

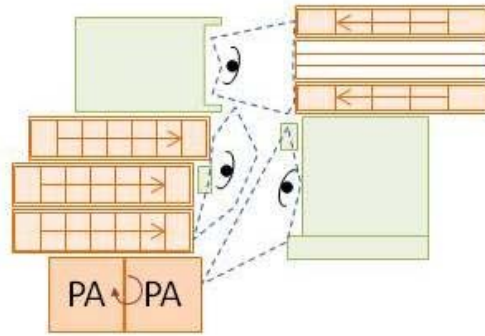


Fig. 2. Standard layout for de-robotized U-shaped assembly line.

3.3. Final situation: U-shaped assembly line with cobot.

Due to needed improvements in labor productivity, new flexible automation options were analyzed according to the Industry 4.0 strategy [13] that the company was addressing. The new possibilities that collaborative robots offer were explored and finally it was agreed to integrate a cobot sharing the working space in the U-shaped cell.

No prior research on the integration of a cobot inside the working area of a U-shaped cell have been found so far, so this might be the first published case of such integration, shown in Fig. 3.

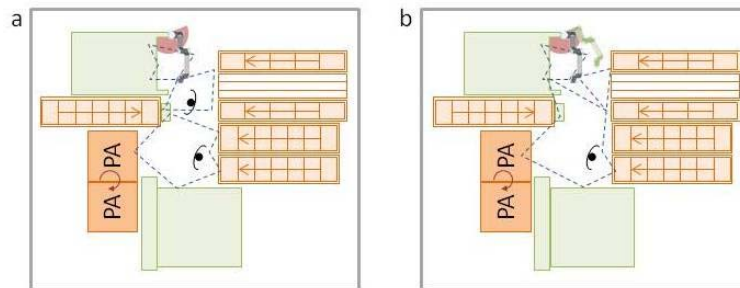


Fig. 3. U-shaped assembly line working in fixed stations with a cobot (a) 2 operators; (b) 1 operator.

4. Methodology and results.

A longitudinal single case study empirical methodology has been used in order to empirically measure the effectiveness of each solution along time. Effectiveness Key Process Indicators (KPIs) have been defined aligned with the lean transformation project objectives. These KPIs have been measured for each solution. Additionally the strategy to achieve the KPIs targets has been identified and described.

KPIs defined to measure the effectiveness of the different solutions are described below:

- Labor productivity: number of good units divided by man-hour (units/hour/#operators).
- Surface: Total surface occupied by operators, machines and materials (m²).
- Surface productivity: Actual capacity divided by production surface (units/hour/m²).
- Performance: % over standard labor productivity.

4.1. Initial situation.

As mentioned before the initial situation was based on a fixed cycle time production, manual handling by operators in isolated and dedicated stations, some operations were carried out by a traditional robot and parts were moved through connecting conveyors.

In such a situation the strategy followed to increase labor productivity was based on:

- Maximum reduction of the cycle time for a maximum saturation of workers and machines.
- Adaptation to the demand variation by means of large batch production in discontinuous production periods.
- No strategy to raise space productivity was considered at this stage.

The KPIs for this initial situation are shown in Table 1.

Table 1. KPIs for the initial situation.

KPI	Value
Labor Productivity (u/h/o)	100
Surface (m ²)	170
Surface Productivity (u/h/m ²)	0,61
Performance (%)	75%

4.2. Intermediate situation.

This situation was characterized by the fact that the production line was de-robotized in order to produce with variable cycle time and increased flexibility. As a result, a U-shaped production cell with variable cycle time, depending on the customer takt time, was built. In this case handling was fully manual.

In such a situation the strategy followed to increase labor productivity was based on:

- Man-machine synchronization to avoid operators' idle times.
- Continuous production permanently adapted to the customer takt time.
- Adaptation to the demand variation by changing the number of operators (from 1 to 3).

In this case the strategy to raise space productivity was based on:

- Compact U-shaped configuration.
- Decrease of in-line supplies by means of a frequent mikrun.

The KPIs for this intermediate situation are shown in Table 2.

Table 2. KPIs for the intermediate situation.

KPI	Value
Labor Productivity (u/h/o)	78
Surface (m ²)	45
Surface Productivity (u/h/m ²)	1,98
Performance (%)	92%

4.3. Final situation.

This situation was characterized by the inclusion of a collaborative robot partially replacing one operator. As in the intermediate situation, a U-shaped production cell with variable cycle time, depending on the customer takt time was used. Regarding handling, loading and unloading tasks at one of the machines was carried out by the cobot.

In this final situation the strategy followed to increase labor productivity was based on:

- Man-machine synchronization to avoid operators' idle time.
- Continuous production permanently adapted to the customer takt time.
- Adaptation to the demand variation by changing the number of operators (from 1 to 2).

The strategy to raise space productivity was based on:

- Compact U-shaped configuration.
- Decrease of space needed in the collaborative robot area.
- Decrease of in-line supplies by means of a frequent milkrun.

The KPIs for the final situation are shown in Table 3.

Table 3. KPIs for the final situation.

KPI	Value
Labor Productivity (u/h/o)	118
Surface (m2)	45
Surface Productivity (u/h/m2)	2,59
Performance (%)	92%

4.4. Discussion.

A summary of the KPIs evolution is shown in Table 4:

Table 4. Comparative results.

KPI	Initial	Intemediate	Final
Labor Productivity (u/h/o)	100	78	118
Surface (m2)	170	45	45
Surface Productivity (u/h/m2)	0,61	1,98	2,59
Performance (%)	75%	92%	92%

Fig. 4 shows that labor productivity decreased by 22% when the robotized line was transformed into a manual U-shaped cell. The inclusion of the cobot in the production cell increased productivity by 18% with respect to the initial baseline.

Surface requirements decreased from 170 m2 to 45 m2 due to the cell layout. The inclusion of the cobot did not require any additional space due to its collaborative features, which allowed its integration into the space of the U-shaped cell.

Surface productivity increased by 225% due to the U-shaped layout. The inclusion of the cobot did not modify the surface requirements but increased the surface productivity due to higher capacity.

The facility performance improved from 75% to 92% due to the simplification of the robotic system, saving maintenance and set-up resources.

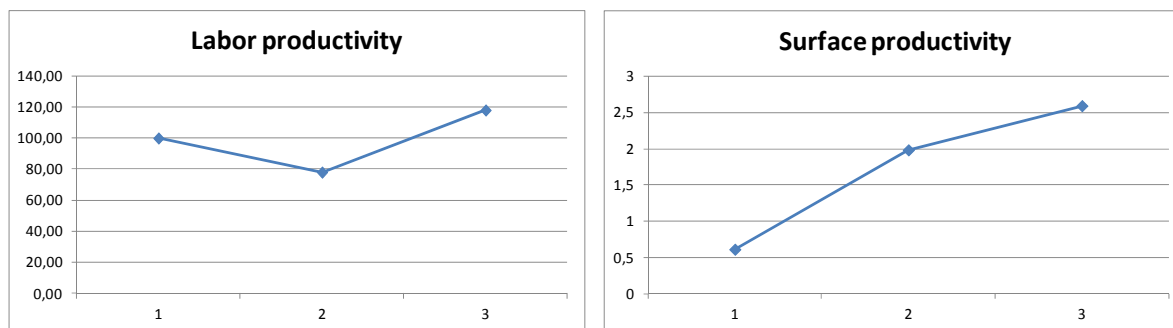


Fig. 4. KPIs evolution.

5. Conclusions and future research.

This research shows the evolution of a manual U-shaped cell in comparison to a traditional robotized line. In addition, it shows that a collaborative robot may be integrated in the working area of a U-shaped assembly cell under safe conditions with no need of extra space and, therefore, keeping the high space productivity of a manual U-shaped cell.

The results presented here, under real production conditions, show that, in a U-shaped cell, a cobot collaborating with human operators may raise labor productivity. These results were even better than a traditional robotized line.

Collaborative robotics opens a new field for automation which was not possible so far: combining the surface productivity achieved by using U-shaped cells with the raise of labor productivity by automating handling tasks.

Future research in this field may focus on the generalization of these results. A potential field would be the analysis of geometrical configurations for U-shaped cells willing to integrate cobots for additional space reductions. Another interesting avenue for future research is the study of emotional implications for operators when collaborating with cobots in the working area.

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