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Serious game for lean layout planning: a proposal for involving company staff within the design process

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Abstract: planning the layout of a company directly affects the performance of a production system. To generate an effective layout solution, it is fundamental to involve both design experts and company staff at all stages of the design process. This paper presents a novel lean layout planning system to engage company staff in the research of the layout solution. A two-step process was followed: first, a literature-based approach was applied to get a prototype layout, then a strategy to engage the company's staff in the achievement of the final solution was proposed. The article describes the proposed strategy and shows how the layout changes with or without the involvement of skilled staff. A case study of a leather bags manufacturing plant is also presented. The case study results highlight how the proposed procedure can be helpful in achieving a solution that better satisfies workers and makes employees accept working changes.

Keywords: lean layout planning; serious game; facility layout problems; lean manufacturing; lean design; leather bags manufacturing plant.

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1 Introduction

To ensure that a manufacturing company's production maintains a competitive advantage in globalized markets, it is essential to place increasing emphasis on high quality and timely delivery of products at the lowest possible price (Daneshjo et al., 2018; Low et al., 2015). One of the well-known strategies to improve the performance of a production system is to redesign the facility layout optimizing the physical arrangement of workstations, departments, and assets constituting the production plant (De Carlo et al., 2013). This challenge corresponds to a typical "Facility Layout Problem (FLP)" (Singh and Sharma, 2006) and can directly affect the efficiency, safety, and sustainability of the company, as well as the quality and cost of the items produced (Li, 2019; Tompkins et al., 2010). An effective facility layout planning could reduce the operating costs, throughput times, and the cost of transporting and handling materials, while simplifying the resource flows and maximizing the WIP turnover (Allegri, 1984; Drira et al., 2007; Francis and White, 1974).

The output of an FLP is usually a block layout that specifies the relative location of each production department within the plant. Sometimes a more detailed layout can also be obtained by specifying the aisle structure and the disposition of the single machines and process equipment (Singh and Sharma, 2006).

One of the existing approaches to solve FLP is lean layout planning, which consists of designing the layout of a company by applying the lean philosophy and the approach of waste minimization (Zhenyuan et al., 2011). The goal is to solve an FLP by combining lean thinking with traditional layout design approaches, such as systematic layout planning (Muther, 1973). Lean layout planning attempts to develop a layout that generates smooth resource flow, minimizes handling distances and costs, reduces walking distances and work-in-progress (WIP), improves the work environment, avoids excessive inventory, and improves visibility for effective operations management (Joseph, 2006; Li, 2019). Previous studies (De Carlo et al., 2013) have shown that lean layout planning gives excellent results when designing the layout of high variety and low volume (HVLV) companies.

Two critical issues related to lean layout planning are as follows.

1. To eliminate waste as much as possible and realize the essence of lean thinking, the principles of lean manufacturing should be applied throughout all the business activities, from the company design stages (**lean design**) to the management phases (**lean production**) (Jones and Womack, 2016; Womack and Jones, 2003). However, as stated by (Li, 2019), while the literature offers

many papers concerning the research and application of lean production, the investigation on lean design is less mature. Indeed, a relatively small number of case studies of lean layout planning were developed compared to the multitude of works related to the application of lean philosophy in management areas like maintenance (Mostafa et al., 2015), production (Cullinane et al., 2014), warehousing (Abushaikha et al., 2018), and so on.

2. Since the lean design approach can give rise to different layout alternatives, to choose the best option is essential to involve experienced company staff at all stages of the design process: from the first step of collecting information about the company to the final step of choosing the right layout alternative (Muther, 1973). According to (Ali Naqvi et al., 2016; Yang et al., 2000), most of the existing methods involve the staff in the preliminary design phase (when general data concerning the company and the production process are collected), but do not consider their feedback in the remaining design activities.

Here, an attempt is made to address the identified criticalities, therefore two consecutive aims are set in the present work. First, to propose a novel approach to engage companies' staff and consider their input throughout the whole layout design process. Then, to show a case study application of the proposed lean layout planning system (which is lean design) to a company.

The case study chosen is a plant that produces leather bags and operates in the luxury fashion industry. Such an HVLV company has recently purchased a new building where it wants to transfer its production. The change of location and the redesign of the factory layout are exploited to reduce the current efficiency issues.

The proposed method starts with the lean strategy shown by (Li, 2019), which is applied to obtain a prototype layout. Subsequently, the planning system is extended by proposing a serious game which is a simulation-based interaction with operators to exploit their know-how in modifying the prototype and defining the final solution. Events are simulated according to accelerated time and scaled spaces. Then, repeating the simulation several times, the layout is modified with an iterative process, verifying that after each change the new alternative is more effective than the previous one both for the staff and the lean expert. By applying the proposed lean layout planning system, a solution is achieved which maximizes business performance, better satisfies employees, increases morale and productivity, and makes staff embrace layout changes (Botti et al., 2017).

Besides describing how to implement the novel approach, through the results of the case study, this article demonstrates how the layout solution changes with or without the involvement of experienced staff, and how important it is to involve area experts to generate the optimal layout alternative. The proposed method can be useful for designing the layout of a company that has limited resources in terms of budget and time to complete the project.

The remainder of the present paper is organized as follows: after a preliminary literature review on lean layout planning (Section 1.1), in Section 2 the functioning of the proposed methodology is described. In Section 3 the case study of lean layout planning is presented. Finally, in Section 4, a discussion regarding the case study results and some conclusions are provided.

1.1 Literature review

FLP is a relatively old problem and has received considerable attention over the years. It was first mentioned by Koopmans and Beckmann in 1957 (Koopmans and Beckmann, 1957). Then, it has gained importance in recent decades (Chakraborty and Das, 2020; Djassemi, 2007; Guan et al., 2019; Jiang and Nee, 2013). The scientific literature on layout planning has been greatly expanded. Indeed, the benefits which can be achieved by planning the layout of a company and the significance of the FLP both at the industrial and academic level are attested by numerous references. Some papers focus on the description of approaches to solve the FLP (Georgiadis et al., 1999; Hassan and Hogg, 1987; Meller and Gau, 1996), some offer literature reviews (Hosseini-Nasab et al., 2018; Singh and Sharma, 2006), and others describe case studies (Fahad et al., 2017; Li, 2019).

According to (Fu and Kaku, 1997; Georgiadis et al., 1999), FLP can be solved using two categories of methodologies: algorithmic approaches and heuristic approaches. Algorithmic approaches are quantitative methods and involve writing and solving an objective function while respecting some design constraints (Peters and Yang, 1997; Yang and Peters, 1997). On the other hand, heuristic approaches are based on both qualitative and quantitative inputs and allow the achievement of qualitative and quantitative objectives. Such methods imply splitting the design process into several sequential steps (Apple, 1978; Muther, 1973) and, for this reason, are also known as procedural approaches. Heuristic approaches can generate more than one layout alternative as a result, so the quality of their outcome is closely related to the experience of the layout designer who must be able to select the best alternative. Generally, heuristic approaches are preferable when dealing with multi-objective layout problems (Yang et al., 2000). Lean layout planning is one of the existing heuristic methods.

Lean manufacturing is a production system born in Japan at Toyota Motor Company after the Second World War. As a general purpose, it pursues to remove inefficiency from all areas of a production system and reduce costs to increase the profitability of a company (Liker, 2007). It is a multidimensional approach pioneered by Taiichi Ohno (Toyota's chief engineer), through which the operations and processes constituting a production system are divided into three kinds of activities: non-value-added activities, value-added activities, and wastes. The goal is to minimize waste and non-value activities, so as to eliminate everything the customer is not willing to pay for (Karlsson and Ahlström, 1996; Salleh and Zain, 2012). According to the classification proposed by (Ohno, 1988), waste in a manufacturing company can be traced back to seven categories: waiting, overproduction, rework, motion, processing, inventory, and transportation. By implementing a continuous never-ending development process and using a wide variety of management practices - Just In Time (JIT), quality management, teamwork, and so on (Low et al., 2015) - the lean approach typically results in increased efficiency, and quality of production processes (Comm and Mathaisel, 2000).

As already mentioned, the lean manufacturing strategy can be used both to design and to manage a plant. When it is used to design the layout of a company, it is called “**lean layout planning**” and concerns defining the physical arrangement of the company process equipment according to the 11 key principles identified by (Koskela, 1992). Such principles (listed in Table 1) correspond to the application of the 5s rules in the case of layout planning (Gupta and Chandna, 2020). The lean layout planning system seeks the elimination of wasteful space and the creation of a layout with minimal risk to business opportunities and possible future changes (Salleh and Zain, 2012).

Some successful applications of lean layout planning are shown in the literature concerning different domains including the healthcare sector, fashion industries, and the automotive sector. In fact, to improve healthcare services, the layout of machines, beds, and other resources in emergency departments was improved (Wang et al., 2015), and the hospital layout was also customized to be aligned with the needs of patients and physicians (Nicholas, 2012). Regarding the fashion industry, (De Carlo et al., 2013) showed how to redesign the layout of a felt hats production line, demonstrating how in the case of HVLV companies, the lean layout planning technique gives preferable design results compared to other tools such as discrete event simulation and SLP. Finally, for the automotive sector, (Savino and Mazza, 2015) focused on the study of the layout of a semi-automated assembly line for automotive components with an O-shaped configuration.

As reported by (Wang et al., 2015), most applications of lean layout planning are based on the creation and analysis of a Value Stream Mapping (VSM), a popular visualization tool to map the entire production process, especially underlying the flow of transformation of raw materials to final products, and seeking waste in terms of times and movements (Jeong and Phillips, 2011). Usually, a representative VSM of the initial process (current state map) is realized. Then a new map is made after redesigning the plant layout (future state map), thus visualizing the effects of change (Sa'udah et al., 2015). Regarding the use of VSM for lean layout design, just a few literature examples are as follows. (Jasti et al., 2019) shows how to reduce different kinds of wastes in the auto-ancillary industry, while (Neubert et al., 2010) measures and optimizes production performance parameters, reducing hidden costs in a manufacturing system.

In addition to the use of VSM, other supporting tools were used for lean layout planning purposes. Among these, the simulation was mainly used to validate the layout solutions before physically implementing them in the company (Abdulmalek and Rajgopal, 2007). The Kanban technique was implemented to optimize production facilities, generating pull processes (Savino and Mazza, 2015), while Spaghetti Charts were used to increase the safety of industrial plants (Cantini et al., 2020a). Among the most innovative applications of lean layout planning, are those that adopt artificial intelligence to identify waste and improve layouts (Neubert et al., 2010).

The literature also offers lean layout planning approaches based on serious games. Some examples are provided by (Bloechl and Schneider, 2016; de Carvalho et al., 2014). In addition to these, it is also possible to use cardboard models, performing layout simulations with cardboard templates that reproduce the dimensions and shapes of assets on a real scale (Nguyen and Do, 2016). According to (Ali Naqvi et al., 2016), despite involving company staff in the layout design process, most of the existing methods do not fully exploit their know-how to improve the final solution. Staff should be involved in all stages of the design process because, by daily working inside the plant, they can identify critical elements for improving the final solution. However, many methods interview staff in the preliminary design phase, but ignore their feedback in the remaining design activities (Yang et al., 2000). This is the starting point of this paper, in which a serious game is specifically designed to solve FLPs by considering the requests and suggestions of company personnel throughout the entire layout design process.

2 Methodology: lean layout planning system

To apply the lean layout planning system, typically a two-steps procedure is followed (Li, 2019; Zhenyuan et al., 2011): first, the 11 principles in Table 1 are applied to get a prototype layout (step 1), then, the solution is evaluated and eventually modified to achieve an optimal result (step 2).

Step 1) The search for a prototype solution is carried out by performing two sub-phases.

a) **"Preliminary design phase"**. This phase mainly concerns the collection of key information, such as the area and shape of the available spaces, the physical dimensions and typology of the facilities, the nature and quantities of the manufactured parts, the production process flow, the closeness relationships between different production departments and, finally, the pains and gains of the company staff. Once the preliminary design phase has been completed, the database needed to define the new plant layout is obtained. In this phase, typically, some tools such as VSM and "relationship diagram" are used to graphically represent the collected information (Ante et al., 2018; Jasti et al., 2019).

b) **"Layout design phase"**. Based on the established database, an ideal layout is built, then the desired solution is fitted within the building planimetry. The machines are arranged by applying the 11 principles of Table 1 and considering the relationships between production departments. In this way, the prototype layout is outlined. Similar to other heuristic approaches (i.e., Systematic Layout planning - SLP), the lean layout planning system does not require high mathematical or computer skills, rather it applies common-sense thoughtware in an orderly way (Muther, 1973). For this reason, lean layout planning does not provide a unique solution, but it can generate different layout alternatives based on the experience and ideas of the design team and a number of subjective decisions that are made (Bock and Hoberg, 2007). The more skilled the design team is, the more successful will be the selected prototype solution.

Step 2) "Evaluation and optimization design phase". Since the layout alternative chosen at the end of step 1b is not necessarily the best possible, during step 2, the solution is examined and modified to generate the optimal result. The prototype layout is evaluated through qualitative and quantitative methods to verify whether it meets the company's needs and eliminates waste or not. If the solution is satisfactory, then it is suggested as the final layout solution, otherwise it is modified. Many evaluation methods have been proposed in the literature: simulation, analytic hierarchy process, fuzzy evaluation method, and expert scoring method (Li, 2019).

As stated by (Li, 2019), to select the best layout alternative - which is functional, lean, and satisfying for the company's staff - it is essential to involve both lean experts and the company workers in the whole design process. Only a knowledgeable cross-functional team can identify the solution that meets the technical requirements of waste elimination while avoiding obstacles or problems for production. However, the approaches for solving lean layout planning problems offered by the literature usually involve consulting staff and gathering information in the first procedural phase (step 1a) through interviews and inspections (Ali Naqvi et al., 2016). Sometimes, the staff is also engaged in the assessment of layout alternatives (step 2). However, the operators' contribution is limited to the prioritization of conflicting aspects or the choice of weight factors to apply methods such as AHP (Yang et al., 2000) or fuzzy TOPSIS (Sharma and Singhal, 2017). In this way, it is not exploited the company know-how of those who daily face production problems, and less information is obtained than what could really be useful. Hence, it is necessary to find an effective way to draw on the knowledge of experienced workers, which hardly ever emerges during interviews. The evaluation approach here proposed fulfils this need. It is a serious game, performed after the layout design phase (step 1b), aimed at simulating, evaluating, and modifying the layout prototype through the involvement of company staff. In the simulation, operators can describe themselves and represent their tasks. The benefit here is that when an operator describes himself, he finds it easier to present to his co-workers the issues that affect production. The following section provides a description of the serious game.

Figure 1 summarizes the lean layout planning system proposed in this paper. First, the literature-based strategy by (Li, 2019) is applied to get a prototype layout (step 1), then, the serious game is performed to improve the result (step 2).

2.1 Serious game for involving company staff in the evaluation and optimization design phase

The serious game proposed to engage the company staff in the evaluation and optimization design phase (step 2) is based on the following concept. By showing the prototype solution to the company staff, simulating a typical working day, and asking the area experts to describe the production problems that usually arise, valuable ideas are collected to improve the solution. Then, by iteratively re-adjusting the layout prototype based on staff requests, it is possible to outline a solution that is lean, capable of maximizing business performance, and hopefully free of all organizational and operational problems that have emerged (Cantini et al., 2020b).

The following resources are required to apply the serious game:

- a large working surface;
- planimetry (in scale 1:50 if a single department layout is designed or 1:100 if the entire plant is considered);
- a token (game piece) in scale for each:
    - working machinery
    - company worker involved in the simulation (it is recommended the presence of at least one expert for each company's production department)

    - shelving unit
    - logistic transfer device (trolley, roller conveyor, etc.)

  The tokens can have a stylized shape (i.e., a rectangle), but they must reproduce the overall dimensions of the machine.

- some scaled tokens to represent vans and trucks dedicated to the procurement of raw materials and the distribution of finished products;
- a big wall clock.

The functioning of the serious game is as follows. The planimetry of the plant is laid out on a large surface. Inside the planimetry (within the available space), the lean designer arranges the tokens representing the machinery and the shelves to reproduce the prototype layout (obtained at the end of step 1b). In this way, the faithful representation of the overall dimensions of machines according to the prototype solution is obtained.

A panel of experienced operators with different roles is assembled, selecting at least one person from each production department. The more numerous and varied is the panel, and the more reliable the simulation will yield. All the workers involved in the simulation are provided with a token that represents them or the materials they handle during their daily work (crates, pallets, etc.). Then, each participant is asked to place his token in the production department to which he belongs to represent the beginning of a typical working day. In this way, in addition to the prototype arrangement of machines, also the typical arrangement of operators and materials at the beginning of the working day is faithfully reproduced.

A timestep is established based on the organization of the work (i.e., a marching time of 30 minutes), and the time is scanned with this time advance unit. Using the clock to represent the passage of time, a typical working day is simulated by advancing the time based on the chosen cadence. As time progresses, the staff is asked to move the tokens according to the production flow to represent the movements of materials/workers within the system. The tokens are moved starting from the area upstream of the production process and then, gradually, following the resource flows. Although the timestep is constant, the simulation is performed at a variable time. Indeed, after each movement, the simulation is temporarily stopped, and the staff is asked to describe what happens to the production. Through these interviews, the pains and gains of the workers are examined in-depth (more than in step 1a). Since the simulation of a typical working day begins by moving resources upstream of the production process, the first interviews will be with the operators responsible for receiving raw materials and for starting the manufacturing process. Simulating the movement of tokens, each operator can provide detailed information on what they perceive as positive aspects of the current layout, or what they know (based on experience) will hamper their work. Through interviews, operators can also suggest possible changes to the layout to satisfy their needs.

During the whole process, the lean layout designer verifies logistic flows, WIP, waste, throughput time, and all the parameters that need to be optimized. Whenever problems are detected (by the lean designer or experienced operators), the lean expert modifies the layout prototype. Then, through an iterative process, the action is simulated again to check if the new arrangement solves the issues and the principles of Table 1 are respected.

Once the entire working day has been simulated, the result is a new lean layout alternative that is more satisfactory for the staff. By repeating the simulation several times, it is possible to find the optimal solution.

The proposed evaluation method works properly if the precepts of "andragogy" are followed and the employees are put at ease. People collaborate when they are in a comfortable and tension-free environment. For this reason, the participation of the company chief in the simulation would be discouraged. Besides, to avoid time pressure, the simulation should not be performed at the end of working hours, but preferably during the last hours of the working day. In addition, in the days before the simulation, the lean designers should be seen and known by the staff to arouse curiosity and trust and stimulate collaboration. During the simulation, the designers should be the first to make the atmosphere welcoming. In this regard, for example, they could put some snacks and drinks on the working table and run the simulation by eating the appetizers together with the staff. The right attitude helps to bring out the company's know-how and contributes to achieving the optimal solution.

3. Case study

To implement a case study of the proposed lean layout planning system, a leather bags company working in the luxury fashion field and producing more than 400 different models of bags was selected.

Initially, the production plant was located on a two-floors building, with an area of about 5000 m^2. After having encountered some production problems, the company purchased a new rectangular shed of 8000 m^2 in which to move the bags production. The idea was to use the change of location and a redesign of the plant layout to reduce the efficiency losses connected to the disposition of the process equipment.

Step 1.a - Preliminary design phase. Performing site inspections and staff interviews, the sequence of activities forming the bags production process was analysed. Figure 2 summarizes the macro-phases of the process using flow charts and ASME notation. Raw materials (leather, textile, supports, boxes for packing finished products, metal accessories, ribbons, and zips) are purchased and stocked in the warehouse, then leather, supports, and textiles are transported to the cutting department and shaped. Once cut, the textile pieces are returned to the warehouse, while leather and support pieces are sent to the preparation department. Here, the thickness of the leather pieces is reduced and uniformed by performing the splitting and fleshing operations. Then, leathers and supports are glued together, and the semi-finished products are crushed with a press that refines the edges. Subsequently, the operations of quilting and inserting plastic reinforcement tubes are carried out. These activities are not executed in all bags. Quilting is used in some bag models to achieve an aesthetic effect on the surface. Instead, piping is carried out only on the pieces that will form the edges of the bag to strengthen the structure of the finished products. At the end of the preparation phase, stamping is carried out to print the logo of the company on the bags. The prepared semi-finished products together with textiles, ribbons, zips, and metal accessories (stocked in the warehouse) are sent to the assembly department. Here, the workers manually colour the edges of the leather pieces, then they sew the linings, handles, and outer surfaces of the bags, and they assemble all components to obtain the finished bags. Finally, the bags are sent to the packing department where they are tested, packed, and stored in the finished product warehouse awaiting sale.

Figure 2 shows that all the operations have to be executed consecutively (they are represented as series activities), except for quilting and piping operations, which can be performed simultaneously (parallel activities). To describe these proximity relationships, a Buff diagram was built (Figure 3). The cutting department should be located near the raw materials warehouse, the preparation department should be close to the cutting department, the assembly department should be near the preparation, and, finally, the testing and packing department should be close to both the assembly department and the finished products warehouse.

The production machines owned by the company were surveyed and information about their spatial dimensions, typology, and production capacity was collected (Table 2). Moreover, the VSM map related to the initial layout of the plant was outlined (Figure 4) to summarise the average duration of the operations forming the production process and show the waste that characterizes the initial situation. Transporting and waiting times are very high and this depends on the fact that the company is in a two-floor building and it is necessary to move several times from one floor to another, but above all, it depends on the fact that machines are arranged in a messy way and two consecutive production departments are not always placed close to each other. Figure 4 also shows the waste of time caused by the repetition of certain processes (such as splitting or fleshing) and linked to a non-linear flow of materials.

For the construction of the VSM, it was considered the most produced bag model of the plant. Both value-added operations (processing times) and non-value-added operations (transporting and awaiting times) were considered. The numerical results used to build the map were partly derived from the available databases and partly measured manually (by applying a red label on a bag, following such bag throughout the production process, and measuring the duration of operations in real time). The measure units used to quantify time were seconds (s) or days (d). In the maps, for operations that were performed at once, the duration was written above the timeline. On the other hand, for operations that were executed twice, the time of the first operation was written above the timeline, while the time needed to bring the piece back to the machine and execute the second operation was written below the line. In the case of non-value-added times, the total duration was indicated as the sum of two times: the time needed to transport the semi-finished products from one department to the next, and the time needed to wait for the next operation to be carried out. Sometimes, in fact, an operation is performed only if the entire batch of bags has completed the previous one.

Finally, the initial plant layout (Figure 5) and its problems were studied. The critical issues that could be solved by redesigning the layout were as follows:

- the time spent by the items in the warehouse was too long;
- the distance between workstations was excessive (causing high material moving times);

- there was no free space to add new machinery and increase production in the cutting and preparation departments (so the HVLV plant was not flexible to demand variations);
- the material flows were not linear. The same product was moved several times (in a messy way) from one production department to another. This made it difficult to carry out visual inspections on the production progress of each bag model. Moreover, within each department, the machines were arranged without criteria, so the production process was decelerated by the presence of bottlenecks.

Step 1.b - Layout design phase. Applying the principles of lean manufacturing, a prototype layout was obtained (Figure 6). The prototype was designed considering three aspects: the company produces according to "pull" logic (Daneshjo et al., 2018), the volume-variety diagram suggests a cellular layout for the analysed company (De Carlo et al., 2013) and, finally, in a lean perspective the flow of materials should be as linear as possible (Joseph, 2006).

In the prototype layout, the production departments were arranged according to work cells and respecting proximity relationships. Comparing Figures 5 and 6, the layout of the departments was completely revolutionized to respect the sequence of activities in Figure 2 and the Buff diagram in Figure 3. This was done for several reasons including:

- to reduce the distances that personnel and logistic devices must travel to move products from one department to the next;
- to obtain a linear and straightforward flow of materials, and a WIP that moves in a single direction (from the plant entrance to the exit), without ever going back;
- and, consequently, to allow production progress to be controlled at any moment, reducing the time spent by items in the warehouses.

The raw materials warehouse was placed at the entrance of the plant to facilitate the receipt and storage of incoming goods from suppliers. At the same time, this warehouse was placed near the cutting department, so that the warehousemen could easily deliver the daily work to the cutting machines.

Then, workstations and machines were arranged to optimize their production capacity, reduce bottlenecks, and decrease throughput times. Based on the principles of lean layout planning (Table 1), machines with the same production capacity were disposed in parallel, while the remaining were arranged in series (positioning first the fastest machines and then the slowest ones). For example, since manual cutting machines have a lower production capacity than automatic ones, the automatic machines were arranged first and then the manual ones were arranged in series. For the same reason, since the splitting machines have double production capacity (200 pieces per day) compared to the fleshing machines (100 pieces per day), the splitting machines were arranged first (according to Figure 2) and, in series, for each splitting machine, two fleshing machines were arranged in parallel.

After the piping department, a warehouse was placed for storing semi-finished products to be stamped. Since all pieces must be stamped (even those arriving from subcontractors), the stamping machines and the aforementioned warehouse were placed near an opening to the outside. After stamping, instead, a warehouse was set up to store semi-finished products ready to be coloured and assembled.

In addition, the equipment was arranged to leave three aisles. A central one for moving forklifts with semi-finished products, quality inspectors, and production supervisors, and two lateral aisles for moving forklifts, baskets containing work orders, and defective materials to be reworked (reverse engineering).

Finally, in the cutting and preparation departments, free space was left (approximately 90 square meters) to give the company the opportunity to buy new equipment and expand production.

Step 2 - Modelling and simulation phase. Applying the serious game described in Section 2.1 and involving in the simulation 16 company workers, the prototype layout was iteratively readjusted. As shown in Figure 7, the game pieces needed to perform the simulation were partly obtained by using well-known board game tokens (to represent workers and logistics transfer devices), and partly produced by cutting out coloured cards (to represent the machines and their scaled dimensions). Figure 7 also shows that the principles of andragogy were applied to run the simulation and a comfortable atmosphere was created by providing snacks and drinks.

Repeating the simulation several times, the final layout was obtained (Figure 8). The staff interview generated some ideas for further improvements (shown in bold in Figure 8).

- To manage the scrap generated by the process, a trash storage department was added.
- The cutting department was divided into two zones: one for automatic cutting machines and one for manual machines. This was done to separate the flow of precious materials (crocodile, python, and iguana) from the cheapest one (cow), allowing better production control and reducing bottlenecks.
- A splitting and a fleshing department were added downstream of the gluing area because the staff reported that sometimes the semi-finished products had to be refined after the gluing operation.
- Finally, the testing and packing departments were moved closer to the factory exit. In fact, the bags are expensive objects and the staff said that, sometimes, customers' quality managers want to personally check the finished products. Therefore, these departments should be located in areas that are easily accessible from the outside.

The repetition of the simulation with the support of 16 experienced operators directly constituted the validation approach of the layout solution. In fact, by punctuating the time with small time intervals, by making the staff identify themselves with the simulation (as if they were carrying out their daily work), and by asking the staff to move the tokens, different resource flows were obtained in the several simulated scenarios. In this way, possible traffic jams, non-linear flows of resources, accumulations of semi-finished products, difficulties in movements, or other problems were highlighted and solved. Then, the final solution was achieved only when, by repeating the serious game five times, neither the operators nor the lean designer detected criticalities.

Figure 9 shows the VSM obtained after changing the location of the plant and implementing the final layout. Compared to Figure 4, Figure 9 helps understanding the benefits in terms of time and waste reduction achieved by applying the proposed lean layout planning system. The redesign of the layout generated a substantial reduction in non-value-added time: the total transport time is decreased of 42 seconds, and the total time spent by items in the warehouse is reduced of almost 10 days (862.137 seconds). Table 3 summarises the growth in performance obtained by modifying the layout and demonstrates how the final layout is advantageous compared to the initial one. Having measured an initial throughput rate of 212.50 bags/hour and a final throughput rate of 222.68 bags/hour, knowing the processing and transport times of a bag (Figures 4 and 9) and using Little's law to determine the WIP, the change of layout results in a halving of WIP, throughput time and workers' moving time. It also leads to an increase in productivity of almost 5%.

Finally, a linear flow of materials is achieved, thus avoiding the backward movement of semi-finished products from one workstation to the previous one, and reducing the distances travelled by workers to reach production departments.

4. Discussion and conclusions

Planning the layout of a company using a lean perspective is a good way to improve its performance by minimizing wastes, reducing production costs and time, and simplifying resource flows. For truly realizing the essence of lean thinking it is fundamental to involve the company's staff in all phases of the design process. This aspect is little investigated in the extant body of literature, where a structured approach is lacking to enable corporate staff to collaborate and express opinions in all steps of the layout design process. Hence, the lean layout planning system proposed in this article fills this gap. The functioning of the proposed system is as follows: first information about the company is collected. Then a prototype layout is designed based on (Li, 2019). Finally, the solution is iteratively improved through a novel serious game which is a simulation-based interaction with operators useful to exploit their know-how for generating improvement ideas.

In addition to describing the functioning of the suggested lean layout planning system, an application of the methodology to a case study of an HVLV company working in the luxury leather goods sector is also shown. The case study demonstrates that the suggested methodology is a viable way to solve real-world layout design problems. As shown in Figure 9 and Table 3, compared to the initial layout, the final layout reduces the problems associated with non-value-added operations, linearity of flows, high storage times and long distances to move objects. The throughput time and the workers moving time are halved, the number of units produced per hour is increased (+4.79%), the total waiting time for items in the warehouse is decreased of almost 10 days, there are no rework operations and backward material flows, and finally the WIP is reduced (-52,23%). The comparison between the prototype layout (Figure 6) and the final solution (Figure 8) demonstrates the importance of consulting the staff to generate new ideas to improve the result. In fact, both solutions (with or without staff involvement) reduce waste and solve the main production issues. However, the final layout is preferable because it also solves problems related to garbage, finishing operations, and tests carried out by external customers.

The proposed lean layout planning system is useful for redesigning a firm's layout while having limited budget and time resources. The advantages of such an approach are as follows. First, it allows to iteratively improve the layout and to choose the optimal alternative. It can be used in any type of company and its application is quick and simple. Starting from step 1a of collecting data, up to step 2 of generating the final solution, less than 4 hours of work were required to complete the whole layout design process. Secondly, the adoption of the proposed serious game does not preclude the use of other tools, such as discrete event simulation, to validate the layout (Sa'udah et al., 2015). Indeed, the accuracy of model validation could be improved by using computer-based simulation to reproduce the final layout, then observing how it performs. The simulation allows investigating in detail the impact of the serious game implemented in leather manufacturing without physically changing the plant layout. However, logistic simulation, while being an excellent approach to solution validation, is time-consuming and resource-intensive (Razavialavi and AbouRizk, 2013). In terms of time, while building, validating, and using a logistic simulative model may require several working days (König et al., 2011), the proposed serious game took approximately 1,5 hours to be applied. Moreover, the computer-based simulation does not use the company's know-how to select the optimal layout alternative, which, instead, was a focal point of this article. For these reasons, it is believed that the new validation approach may be interesting when applying lean layout planning.

In addition, the proposed lean layout planning system provides a solution that is satisfactory both for company staff and lean designers. Based on the study by (Jalalianhosseini et al., 2020), to understand staff's level of satisfaction with the design of the final layout (Figure 8) and the one of the prototype layout (Figure 6), two questionnaires were distributed to each worker involved in the serious game. The first questionnaire was administered before performing the serious game. In this case, we asked to rate on a 5-point Likert-type scale (i.e., -2= very unsatisfied, 0= neutral, and 2= very satisfied) the prototype layout, assessing the disposition of machinery and assets in each department. The second questionnaire, on the other hand, was administered to the same workers after carrying out the serious game. In this case, the final layout solution was evaluated according to the same criteria and rating scale as before. The comparison of the questionnaire results (Figure 10) shows that the average assessment of the departments' layout is better in the final layout than in the prototype layout. An exception is made in the case of the assembly department, where the two layout alternatives received an equal average score.

When changing the arrangement of workstations, sometimes the acceptance of the new layout can be a problem for operators. Instead, as shown in Figure 10, engaging the staff in the design process results in a faster generation of a satisfactory solution and makes it more likely to be accepted. A solution achieved by combining the skills of lean experts with that of production experts will satisfy workers, increase morale and productivity, and make employees embrace working changes quickly (Botti et al., 2017; Levary and Schmitt, 1986).

In conclusion, the proposed lean layout planning system gives the opportunity to generate more or less detailed layouts according to the company's needs. In fact, during the serious game, the tokens representing machinery, shelves, and other production equipment are moved. Hence, at the end of the simulation, the final layout can be represented either in a macroscopic way, illustrating the disposition of the departments (see Figure 8), or in a detailed way representing the position of each production machine. The system will give valid results in both cases if the precepts of andragogy are respected when applying the serious game. In fact, an oppressive atmosphere prevents workers from expressing their know-how and ideas. As a result, the entire work and the overall layout are compromised.

Figures and tables

Table 1: 11 key principles of lean layout planning identified by (Koskela, 1992).

Principle	Description
1	Reduce the waste and the share of non-value adding activities
2	Increase output value through systematic consideration of customer requirements
3	Reduce variability
4	Reduce the cycle time
5	Simplify by minimizing the number of steps, parts, and linkages
6	Increase output flexibility
7	Increase process transparency
8	Focus control on the complete process
9	Build continuous improvement into the process
10	Balance flow improvement with conversion improvement
11	Benchmark

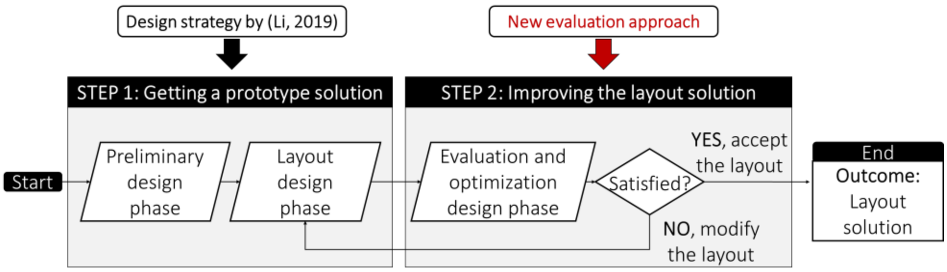

Figure 1: procedural steps of the lean layout planning system.

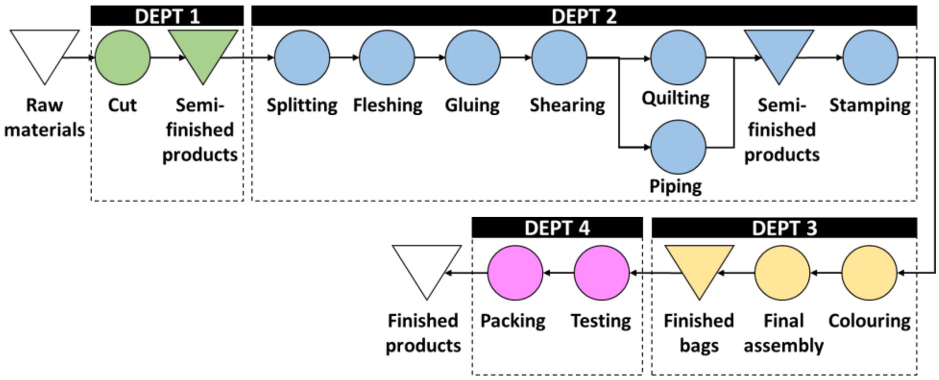

Figure 2: sequence of activities forming the leather bags production process. The alternation of colours highlights the different production departments (DEPTs) of the plant.

Figure 3: Buff diagram. The diagram shows the relevance of the proximity relationships between production departments (DEPTs) of the plant. The relevance levels are as follows: absolutely necessary (A), especially important (E), important (I), ordinary (O), unimportant (U), and undesirable (X).

Table 2: extract from the list of production machines owned by the company. The table refers to some assets placed in DEPT 4 and, for each asset, provides an identification code (ID), a description, and information on the production capacity and spatial dimensions (width and length).

Production department	**Asset ID**	**Description**	**Production capacity [items/minute]**	**Dimensions [meters]**
DEPT 4 Testing and packing	C1	Material support bench	-	0,8x4
	C2	Box binding machine	6	0,8x1

C3	Packaging table	-	1,5x2
C5	Material support bench	-	0,5x0,8
C6	Shelf	-	1x2
C7	Shelf	-	1x2
C8	Box binding machine	6	0,8x1
C9	Material support bench	-	0,8x4

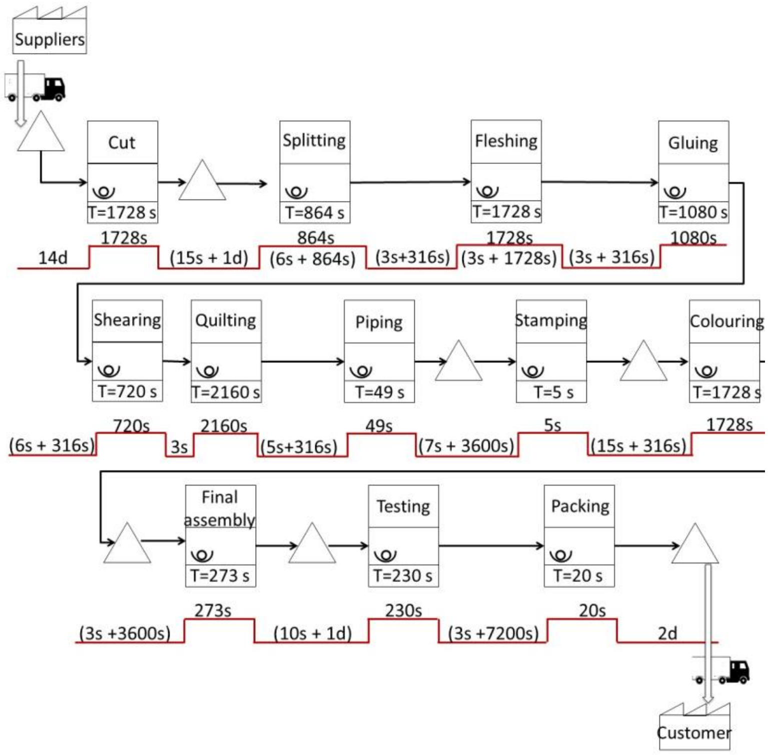

Figure 4: value stream mapping related to the initial layout of the plant.

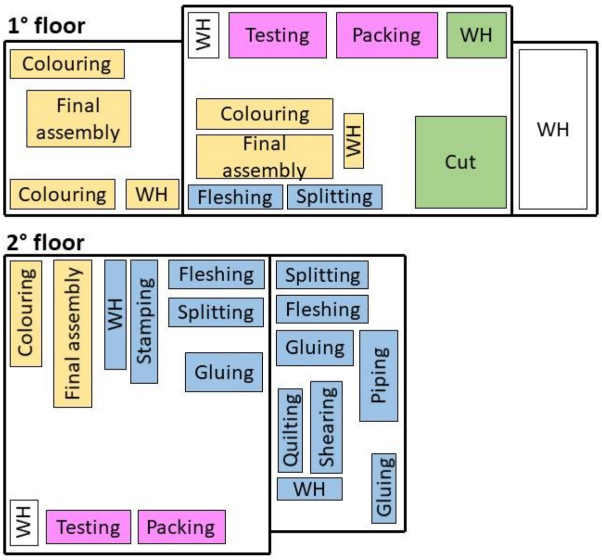

Figure 5: initial layout of the plant. The different colours (like those introduced in Figure 2) underline the physical arrangement of production departments.

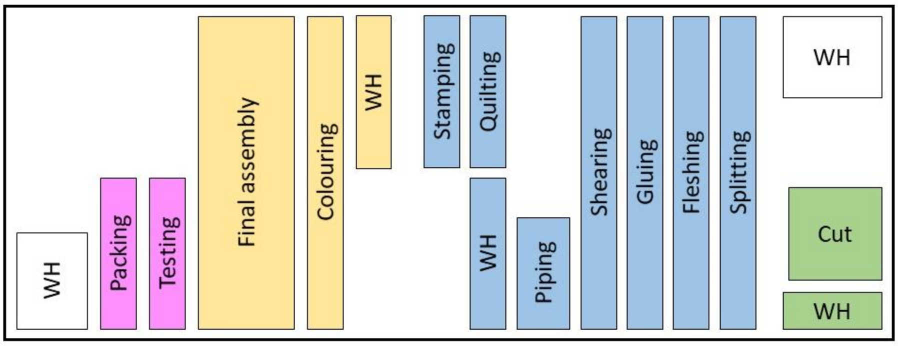

Figure 6: prototype layout obtained at the end of the "layout design phase" (step 1b). The different colours (like those introduced in Figure 2) underline the physical arrangement of production departments.

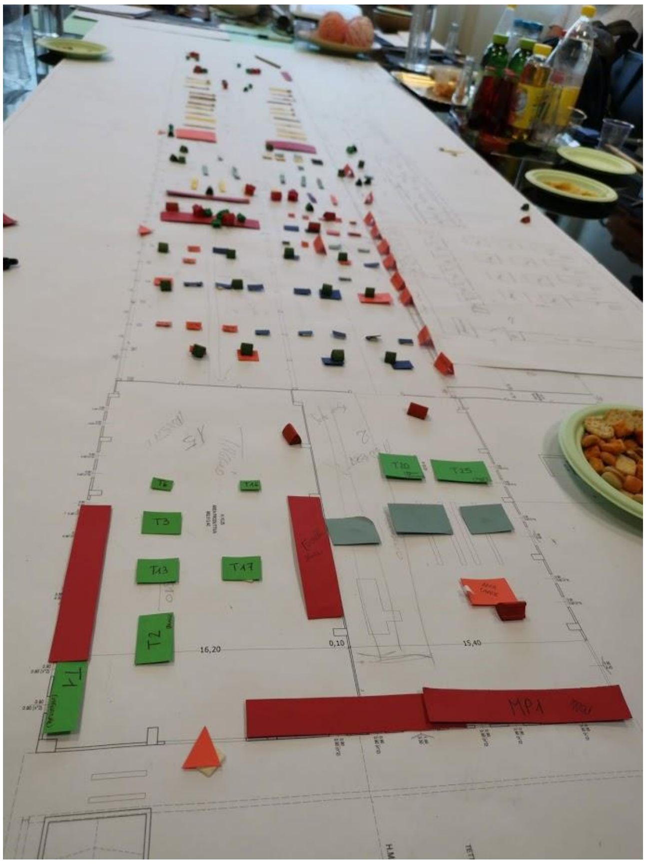

Figure 7: photograph of the performed serious game.

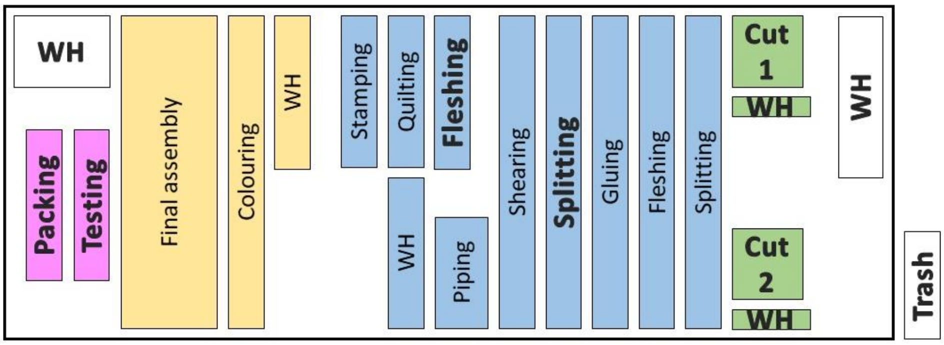

Figure 8: final layout obtained at the end of the "modelling and simulation phase" (step 2). The different colours (like those introduced in Figure 2) underline the physical arrangement of production departments.

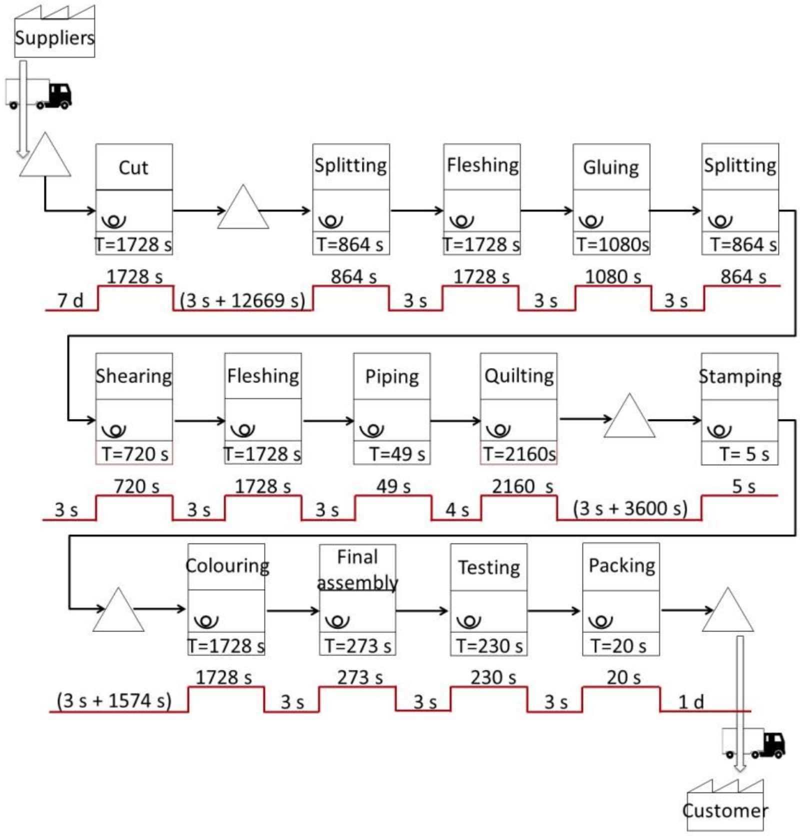

Figure 9: value stream mapping related to the final layout of the plant.

Table 3: performance growth (in percentage) obtained by comparing the final layout with the initial one.

Δ throughput time	Δ throughput rate	Δ WIP	Δ workers moving time [%]
- 54,42%	+ 4,79%	- 52,23%	- 51,22%

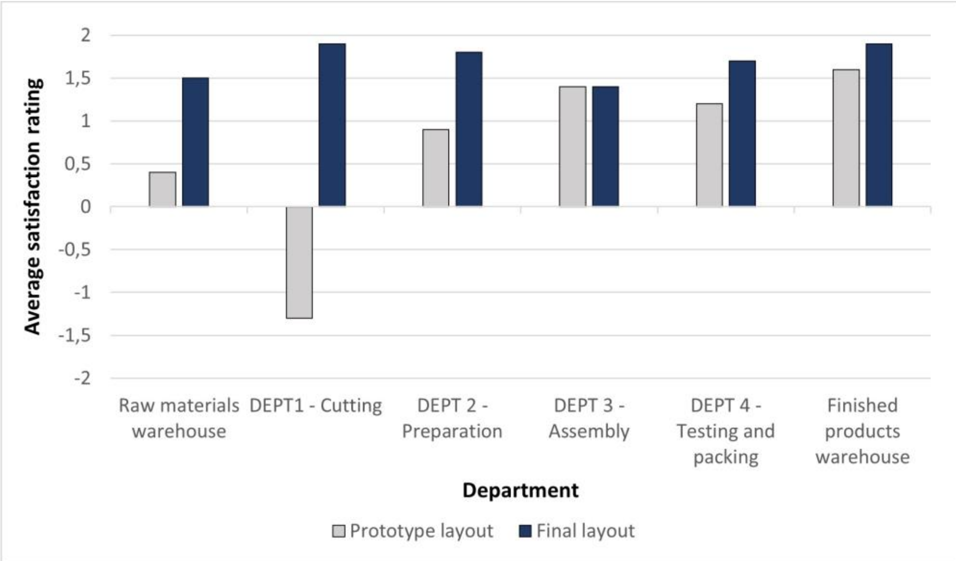

Figure 10: Results of the satisfaction questionnaires administered to the staff before and after performing the serious game. The histogram shows the average ratings assigned by the staff to the departments' layout in the prototype solution (grey) and the average ratings assigned to the departments' layout in the final solution (black).

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