

Layout design for efficiency improvement and cost reduction

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Abstract. In a reality of global competition, companies have to minimize production costs and increase productivity in order to boost competitiveness. Facility layout design is one of the most important and frequently used efficiency improvement methods for reducing operational costs in a significant manner. Facility layout design deals with optimum location of facilities (workstation, machine, etc.) on the shop floor and optimum material flow between these objects. In this article, the objectives and procedure of layout design along with the calculation method for layout optimization are all introduced. The study is practice-oriented because the described case study shows how the layout of an assembly plant can be modified to form an ideal re-layout. The research is novel and innovative because the facility layout design and 4 lean methods (takt-time design, line balance, cellular design and one-piece flow) are all combined in order to improve efficiency more significantly, reduce costs and improve more key performance indicators. From the case study it can be concluded that the layout redesign and lean methods resulted in significant reduction of the following seven indicators: amount of total workflow, material handling cost, total travel distance of goods, space used for assembly, number of workers, labor cost of workers and the number of Kanban stops.

Key words: facility layout design, lean method, efficiency improvement.

1. Introduction

Among the growing market globalization, where customer demands are changing continuously, enterprises have to improve efficiency and focus on cost reduction and profitability in order to increase their competitiveness. Therefore, the application of efficiency improvement methods is essential for such companies. This is the reason why the topic of the study is highly important and relevant. Manufacturing systems have to become more complex and flexible in order to respond to the rapidly changing economic environment. The resources required in manufacturing (materials, machines, labor force, space and other facilities) are limited. Therefore, it is very important for manufacturing companies to produce cost-effective and high-quality products, which can be achieved by maximized utilization of resources and minimized production costs.

Facility layout design is one of the most important and frequently used efficiency improvement methods, since it can lead to significant reduction in the operational costs of companies. Therefore, this method is used by more and more manufacturing companies and service providers. Facility layout design means the process of finding an optimum arrangement of facilities (objects: department, workstation, machine, equipment, etc.) on – in this particular case – a manufacturing shop floor. Additionally, the layout of the manufacturing facilities in a plant has to be adjusted from time to time to fit changing production plans and processes.

The main objectives of facility layout design are to improve the performance of the production process, minimize the total

distance for the flow of materials and workers between facilities, and minimize the material handling cost and lead times in the manufacturing process. There are two types of facility layout improvement: new facility design and redesign of an existing layout.

In the study, the objectives, the procedure of layout design and the calculation method for layout optimization are all introduced. The article is relevant and practice-oriented because besides the introduction of theoretical background, a practical efficiency improvement method is also introduced for redesign of the layout of an assembly plant in a case study.

The research is original and unique because two efficiency improvement methods are combined in the case study. The classical facility layout design method is used as the basis, but four lean methods (takt-time design, line balance, cellular design and one-piece flow) are also applied. The goal of the application of lean methods is to form a more effective re-layout, meaning that costs will be reduced and KPIs (key performance indicators) will be improved.

In the case study the combination of the two methods resulted in significant reduction of the following seven indicators: the amount of total workflow, the material handling cost, the total travel distance of goods, the space used for assembly, the number of workers, the labor cost of workers and the number of Kanban stops. Consequently, the case study also confirms that the combination of facility layout design and lean methods is an effective tool for process improvement.

2. Literature review

There are numerous tools and methods for improvement of production processes. The most frequently used efficiency improvement methods are simulation, lean method and facility

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layout design [1, 2]. These methods are often applied at companies in many sectors to increase competitiveness. In this article, facility layout design will be introduced in detail.

The reasons for design/redesign of facility layouts are the continuously changing customer demands, which lead to poor utilization of machines, labor force and facilities [3]. Facility layout planning means the allocation design of facilities in a manufacturing shop floor. A facility is an entity that facilitates the performance of any job [4].

Optimum location of facilities in a plant has a massive impact on the system performance, e.g. manufacturing costs, lead times, productivity and amount of work in process (WIP). A well-designed manufacturing layout can reduce the operating cost by up to 50% [5] and minimize material handling costs while considering any physical restrictions on such arrangement [6, 7].

The facility layout problem (FLP) involves a given number of facilities in order to minimize the total cost of moving the required amount of material between the facilities [8–10]. A number of theoretical methods exist for designing and optimizing FLPs, both for new facility design and for redesign of an existing layout [11, 12]. Layout problems can be classified in different ways, depending on the workshop characteristics, general problems to be solved and the static or dynamic nature of the layout problems to be solved [13, 14], among others. The facility layout problem has been modelled in the literature as a quadratic assignment problem, quadratic set covering problem, linear integer programming problem, mixed integer programming problem, graph theoretic problem, etc. [5, 13]. Relevant publications on this topic mainly focus on mathematical solutions of theoretical models, rather than on real-life practical layout problems.

In contrast, in this publication I wish to use a real case study to confirm that facility layout design is an effective method which can be widely used in practice for process improvement at manufacturing companies and service providers. Therefore, my article is practice-oriented, because in addition to the introduction of theoretical background, the layout redesign of an assembly plant is introduced in a case study and its effectiveness is calculated. The results of the facility redesign were obtained successfully at an assembly plant within the framework of an R&D project.

3. Definition and objectives of facility layout design

Definition of facility layout design: optimum arrangement of facilities in a manufacturing site and optimum flow of materials from one facility to another, which minimizes material handling costs. A facility may be a department, workstation, machine, equipment, etc.

The facility layout problem is a fundamental optimization problem encountered at many manufacturing companies and service providers. Solving FLPs requires mathematical expertise and competences which are computationally intensive and time-consuming. There are two types of facility layout design: 1) new layout design, and 2) redesign of an existing layout.

The main objective of facility layout design is to design more effective workflow and improve productivity of the manufacturing process by improving the flow of materials and workers between machines in the manufacturing area to minimize the total distance of goods flow, the material handling cost and the time spent in the manufacturing system. Optimum facility layout provides higher utilization of resources and cost reduction.

Generally, an efficient facility layout should attempt to meet the following objectives:

- to maximize utilization of resources (space, facilities, labor force, etc.),
- to increase productivity of the company,
- to minimize material handling cost,
- to minimize the movement of goods, workers and equipment,
- to minimize overall production time,
- to minimize investments in equipment,
- to create a safe and comfortable work environment,
- to maintain the flexibility of operation (changes in the layout to introduce new products or production technology).

4. Optimization method for facility layout design

In the facility layout problem, a non-overlapping planar orthogonal arrangement of n rectangular workstations has to be defined within a given rectangular shop floor of size $L_x \times L_y$. During the optimization, all of the possible alternative facility layouts/re-layouts are defined taking design constraints into consideration. After that the optimum layout/re-layout is selected, based on the objective function (1).

4.1. Objective function. Material flow efficiency is a frequently used term for the description of the amount of workflow that should be minimized. A typical formulation of the optimization problem can be as follows:

$$\min E = \sum_{i=1}^n \sum_{j=1}^n f_{ij} d_{ij} \quad (1)$$

where n is the number of facilities in the layout, f_{ij} is the amount of material flow from facility i to facility j , d_{ij} is the rectilinear distance between their centroids and $f_{ij} d_{ij}$ is the material flow efficiency realized by material flow between facility i and facility j [UL.m, etc.] (UL is a unit load, which can be a pallet, box, etc.).

Material flow matrix:

$$\underline{F} = \begin{matrix} & \begin{matrix} 1 & \dots & j & \dots & n \end{matrix} \\ \begin{matrix} 1 \\ \vdots \\ i \\ \vdots \\ n \end{matrix} & \left[\begin{array}{ccccc} & & & & \\ & & & & \\ & & f_{ij} & & \\ & & & & \\ & & & & \end{array} \right] \end{matrix}$$

f_{ij} : average amount of material flow from facility i to facility j per hour or shift [pieces of goods (pcs), pieces of unit loads (UL), etc.].

Distance matrix:

$$\underline{D} = \begin{matrix} & 1 & \dots & j & \dots & n \\ \begin{matrix} 1 \\ \vdots \\ i \\ \vdots \\ n \end{matrix} & \left[\begin{matrix} & & & & & \\ & & & & & \\ & & & & & \\ & & & d_{ij} & & \\ & & & & & \\ & & & & & \end{matrix} \right] & \begin{matrix} d_{ij}: \text{ distance} \\ \text{between the} \\ \text{centroids} \\ \text{of facility } i \\ \text{and facility } j \text{ [m].} \end{matrix} \end{matrix}$$

4.2. Constraints. Constraints for optimum allocation of facilities in a manufacturing shop floor can be the following: architectural limitations, space requirements of facilities, foundation of machines (fixed position or moveable), relations of the facilities (e.g. order of machines), vibration and noise effects, relation with internal and external transport paths, etc.

5. Combination of facility layout design and lean methods

The research is novel and unique because facility layout design and lean methods were combined in order to improve efficiency to a more significant extent, to reduce costs and improve more KPIs. The combination of the two methods is advantageous because the essence of the layout design is the optimum arrangement of n workstations on a given shop floor, while the lean methods provide the possibility of reducing the number of workstations.

Advantages of combining the two methods:

- the operational cost of the company can be significantly reduced,
- the performance of the production process can be improved,
- many KPIs can be improved.

The classical facility layout design and 4 lean methods [1 – takt-time design, 2 – line balance, 3 – cellular design, and 4 – one-piece flow] are combined and applied in a case study (described in section 8) in order to improve efficiency and reduce costs to a more significant extent.

Theories, general characteristics and calculation procedures of the above-mentioned 4 lean methods are described in section 6. The application of these methods is introduced in a real case study in section 8.3.

6. Application of 4 lean methods

The aim of the lean philosophy is cost reduction by means of eliminating non-value added activities [2]. The focus of the philosophy is to improve quality, decrease wastes and optimize the cost of production processes.

6.1. Takt-time design method. The scheduling of production is determined by the customer. Takt-time is the average time in which a final product needs to be produced in order to satisfy customer demand [16, 17].

Takt-time can be calculated by:

$$T_{takt} = \frac{T_a}{D} \left[\frac{\text{sec}}{\text{unit}} \right] \quad (2)$$

where T_a is the net time available to work [work time per shift: sec], D is the customer demand [final products required per shift: unit].

Activities at workstations that require more time than takt-time form bottlenecks in the manufacturing process. These bottlenecks can be identified very easily with the help of this analysis. Activities at workstations that require less time than takt-time are also critical, because the unutilized resources (labor force, equipment) are also wastes in the process.

6.2. Line balance method and calculation of the number of operators and workstations. The next step is to define how many workers and workstations are required to run the assembly work cell.

Assembly line balancing deals with reconfiguration (balancing) of the size of the line and assignment of workers on the assembly line. The aim is to create task groups that minimize the idle time of workers and machines and result in high utilization of human work and machines. This can be achieved if the time consumption of the task groups is approximately equal, close to takt-time. The required number of operators can be calculated by:

$$N_{oper} = \frac{T_{total}}{T_{takt}} \quad (3)$$

where T_{total} is the time consumption to make one final product on the assembly line [sec], and T_{takt} is takt-time [sec].

Line balancing means levelling the workload of all processes in the assembly cell to eliminate bottlenecks and free capacities. On the assembly line, every operator and machine is doing the same amount of work over time, no one is overloaded and no one is underloaded.

6.3. Cellular design and one-piece flow methods. Traditional process layout can be changed by means of cellular layout and moveable workstations can be organized into a U-shaped cell. Cellular manufacturing has lots of advantages [16–17]. The goal of the cellular design is to achieve perfect goods flow allowing one-piece flow on the assembly line.

The main benefits of the U-shaped cellular layout are the following: continuous one-piece flow and balanced workstations can provide fast flow of goods inside the assembly process. Productivity can be increased, lead times can be reduced, and the compactness of a cell minimizes the space needed for the assembly process. Additionally, the amount of work in process stock can be minimized.

7. General steps of layout redesign in practice

The main objective of facility layout redesign is to achieve effective workflow, improve productivity and reduce total material flow in the shop floor.

The main steps of facility layout redesign are the following:

Step 1: Define the objectives of the facility design.

Generally, the main objectives of facility layout planning are to minimize the total distance of goods flow, the material handling cost and the time spent in the manufacturing system.

Step 2: Define the main and supporting activities of the manufacturing process.

Constraints and requirements relating to the activities (e.g. workstations), human resources, equipment and material flows all have to be specified.

Step 3: Determine the space requirements for all activities

Space requirement for all objects and material flow paths has to be calculated.

Step 4: Create alternatives for facility layouts.

Variations of layouts have to be formed that consider alternative facility locations and material flow paths.

Step 5: Select the most effective facility layout.

The elaborated layout alternatives have to be evaluated and compared based on the objective defined in step 1.

Step 6: Implement the best layout.

The best facility plan has to be selected and implemented.

In the following sections of the paper a real case study will be introduced that employs a layout redesign method.

8. Case study for layout redesign

8.1. Problem formulation: original layout. The original layout of the assembly plant to be redesigned can be seen in Fig. 1. The examined company carries out manual assembly of electronic products. The size of the shop floor is $12.5 \text{ m} \times 20 \text{ m}$. The assembly process includes 11 workstations. The location of the workstations and the material flow between these are depicted in Fig. 1. Two of the workstations (No. 1 and No. 3) are in a fixed position, while the others can be moved.

The component supply to the stations is completed based on JIT (just-in-time) principles (Kanban). The loading-in and loading-out of raw materials and components are performed in 3 steps of the Kanban circle.

Reasons for applying facility layout redesign in the case study:

- the company has to produce a new type of final product,
- assembling the new final product requires new assembly lines, which requires more free space on the shop floor ($\sim 75 \text{ m}^2$),
- the space dedicated to the original assembling activity should be reduced by means of layout redesign to provide free space on the shop floor.

Goals of facility layout redesign in the case study:

- to provide free space for establishment of new assembly lines,

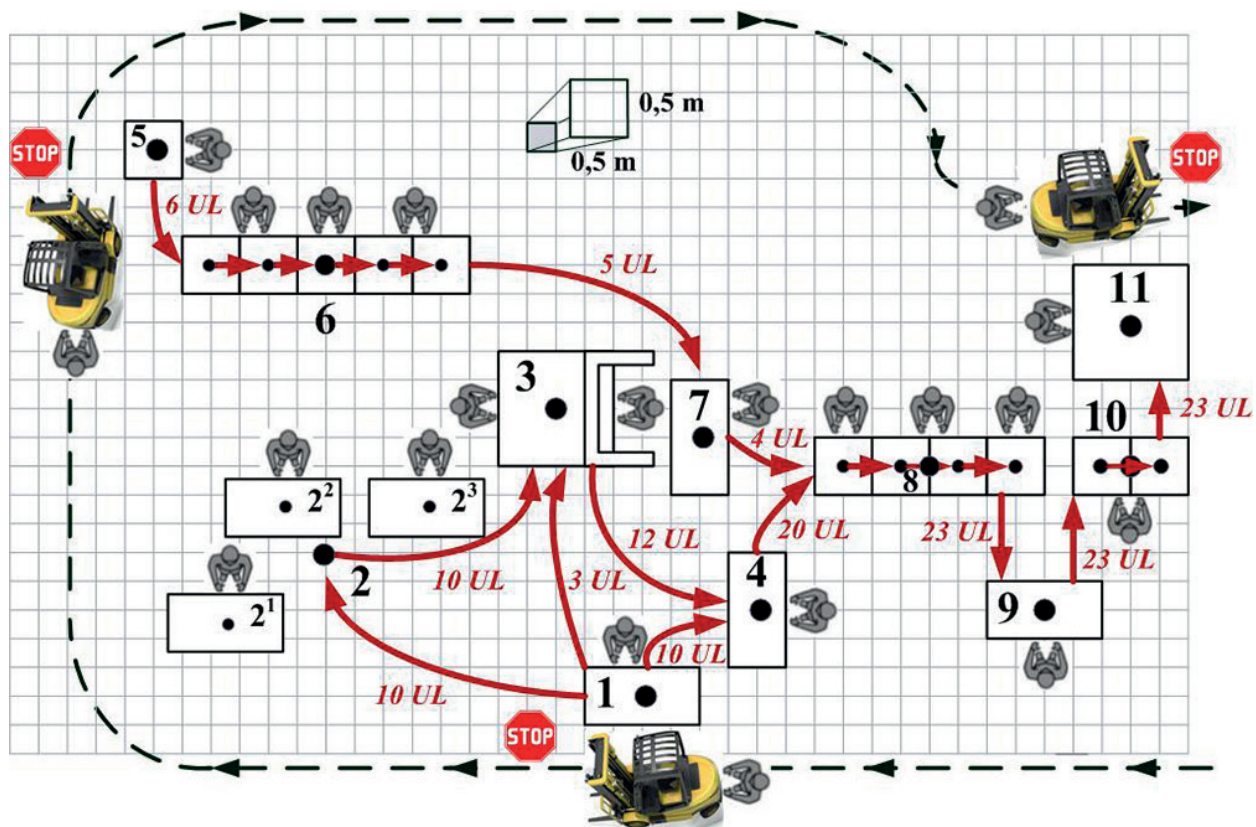


Fig. 1. Original plant layout

- to arrange the workstations on the shop floor in an optimum manner,
- to minimize total distance of flow of materials and workers between facilities,
- to minimize the material handling cost,
- to reduce lead times and increase productivity,
- to reduce the number of workers (reduce labor costs),
- to create a safe and comfortable environment for the workers.

8.2. Procedure for layout redesign in the case study. Most variants of facility layout problems are known to be hard combinatorial problems, therefore global optimum solutions are difficult or virtually impossible to compute within reasonable time [4].

Because the number of re-layout alternatives is almost infinite, the formation and comparison of all possible alternatives is impossible also in this case study.

Therefore the number of alternative re-layouts has to be reduced by a method of choice (described in section 8.3).

With this, eight alternative re-layouts (most suitable for implementation) are selected, evaluated and compared (section 8.5).

The layout redesign was achieved based on the steps in section 7. During optimization, the ideal re-layout (Fig. 3) was selected, based on objective function (1), and then suggested for implementation.

The results of numerical comparison of the original layout and the new facility re-layout are described in sections 8.6–8.7.

8.3. Method for the formation of re-layout alternatives.

The goals of the layout redesign, design constraints, technical requirements and practical applicability were taken into consideration during the formation of potential re-layouts (placement of workstations).

The main aspects of the method for the formation of re-layout alternatives were the following:

- The primary aim of the redesign was to provide fixed- shape continuous free space (75 m²) for the establishment of new assembly lines. Therefore the best arrangement of workstations was to be achieved on the remaining shop floor (175 m²).
- The following relevant design constraints were taken into consideration:
 - relations of assembly processes and workstations are defined by the order of technological processes,
 - foundation of machines (fixed position or moveable),
 - space requirements of workstations (including work table area, operational space of workers and area of WIP storage),
 - direction, width and space requirement of material flow paths between the workstations,
 - direction, width and space requirement of Kanban material flow path; location and space requirements of Kanban stops,
 - architectural limitations, e.g. locations of roof supporting pillars,
 - budget constraints of the redesign.
- Four lean methods (takt-time design, line balance, cellular design and one-piece flow) were applied for creation of the

re-layouts, therefore the described layout redesign is novel and unique. For example, in this case study the cellular design was one of the most important lean methods because during the redesign the traditional process layout was changed to cellular layout. The moveable workstations (No. 5–11) were organized into a U-shaped cell, which has lots of advantages [15]: improving productivity by perfect and fast goods flow, reducing lead times, reducing WIP and minimizing the space needed for the assembly.

8.4. Application and calculation methods of 4 lean methods.

The above-mentioned 4 lean methods were applied to create the re-layouts.

Bottlenecks and unutilized resources were identified in the examined real assembly process by using the lean methods (section 6).

Cycle times of the different assembly processes at workstations are listed in Table 1 (original cycle times and new balanced cycle times of workstations). Bottlenecks and unutilized resources are highlighted in red in Table 1.

Table 1
Data relating to the original and new balanced assembly processes

Workstation	Original cycle times (before) [min]	New balanced cycle times (after) [min]
1	5.6	5.6
2 ¹	3.7	6.6
2 ²	4.7	6.6
2 ³	4.8	0
3	6.1	6.1
4	5.5	5.5
5	4.1	5.5
6	7	5.6
7	5.8	5.8
8	6.6	6.6
9	6.2	6.2
10	5.4	5.4
11	6.1	6.1
	71.6	71.6

● **Takt-time design and line balance methods**

Net available time is the amount of time available for assembly including break times. The net available time to work is 7.5 hour, which is equal to 450 min/shift. The real customer demand is 68 units/shift. Takt-time can be calculated by (2):

$$T_{takt} = \frac{450 \text{ min}}{68 \text{ unit}} = 6.6 \left[\frac{\text{min}}{\text{unit}} \right].$$

Line balancing is the levelling of the workload for all processes in the assembly line to eliminate bottlenecks and free capacities.

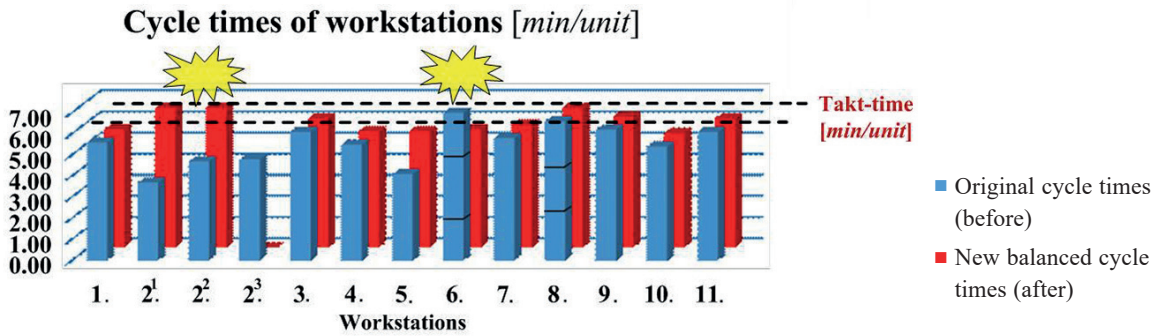


Fig. 2. Original and new balanced loading of workstations as compared to takt-time

The cycle time of assembly processes at workstation No. 6 is longer than takt-time (Table 1, Fig. 2). As a result of this bottleneck, the customer demands are not fulfilled in a timely manner.

Assembly processes at workstations No. 2¹, No. 2², No. 2³ and No. 5 are below takt-time, the labor force and equipment resources remain unutilized, and a lot of waiting and free capacity can be observed.

Following line balancing, the operation of workstation No. 2 (earlier including 3 workplaces / No. 2¹, No. 2², No. 2³ / and 3 operators) can be achieved by 2 operators at 2 workstations after the redesign. Meanwhile, workstations No. 5 and No. 6 can be joined and the workload of these two stations can be achieved by 2 operators (instead of 4 operators) at a smaller area.

The result of takt-time design and line balancing is that the time consumption of task groups on the assembly line is approximately equal (Fig. 2 – New balanced cycle times).

The total assembly process can be carried out by 16 workers instead of the 19 operators previously required to do the same amount of work. The utilization of resources can also be maximized.

• Cellular design and one-piece flow methods

During facility layout redesign, the traditional process layout was changed to cellular layout.

Workstations No. 1 and No. 3 are in a fixed position, but the other moveable workstations can be freely rearranged on the shop floor. Most of the moveable workstations (No. 5 – No. 11) were organized into a U-shaped cell (Fig. 3).

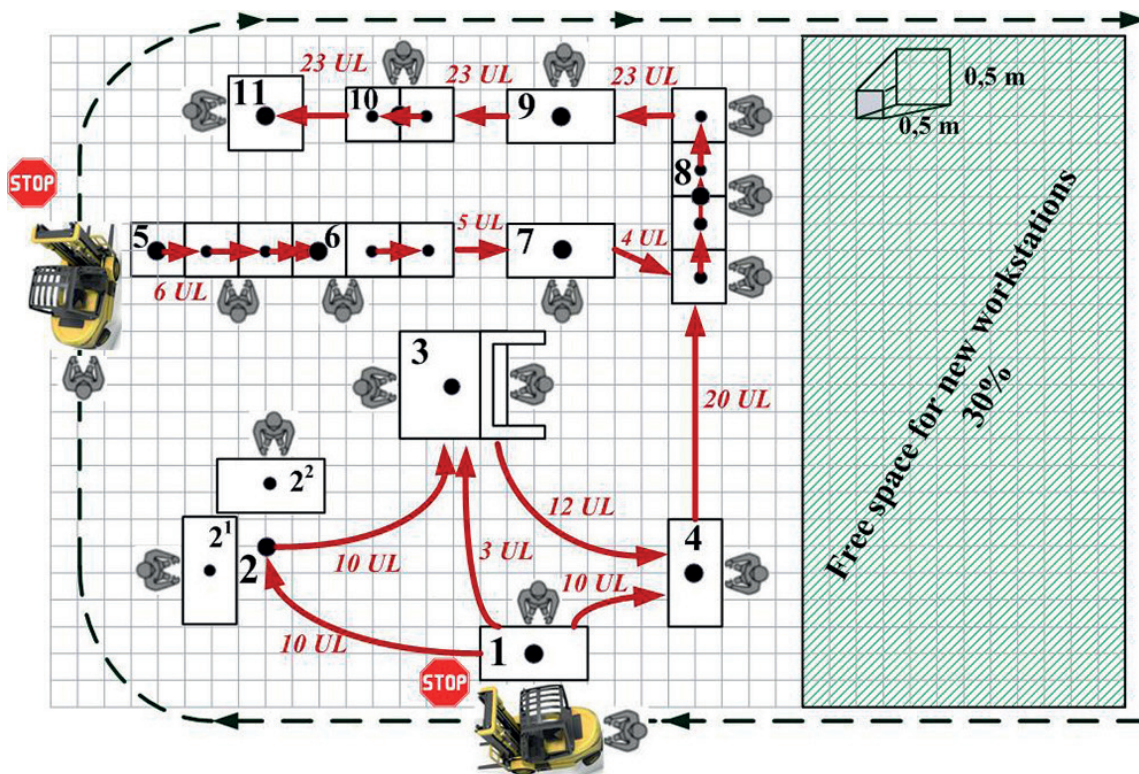


Fig. 3. New ideal re-layout of the plant

The main advantages of the new U-shaped cell: free space can be provided on the shop floor and risk to the component supply can be minimized.

Due to line balancing, one-piece flow can be realized, which results in the reduction of WIP in the assembly process.

8.5. Evaluation of the elaborated re-layouts in order to select the ideal re-layout. Because the number of re-layout alternatives is almost infinite, the number of alternative re-layouts had to be reduced by a method of choice (described in section 8.3).

With this, eight alternative re-layouts (most suitable for implementation) were selected, evaluated and compared.

During optimization, the ideal re-layout was selected, based on objective function (1).

Due to the lack of space, in this paper only the ideal re-layout (Fig. 3) will be presented in detail and numerically compared to the original layout (Table 2).

In our case, the comparison (before/after) was achieved based on the following aspects:

- 1) material flow efficiency,
- 2) material handling cost,
- 3) total travel distance of goods,
- 4) space used for assembly,
- 5) number of workers,
- 6) labor cost of workers,
- 7) number of stops in the Kanban circle.

8.6. Introduction of new ideal re-layout and numerical comparison with original layout – calculation methods. The ideal re-layout (Fig. 3) was selected and suggested for implementation.

The results of comparison of the original and new facility layouts are summarized in Table 2 based on the above-mentioned seven aspects.

Table 2
Result of layout redesign

	Original layout Fig. 1	New re-layout Fig. 2	Difference
1. Material flow efficiency [UL · m]	742	708.5	-4.51%
2. Total material handling cost [%]	100	95.49	-4.51%
3. Total travel distance of goods [m]	67	60	-10.45%
4. Space used for assembly [m ²]	250	175	-30%
5. Number of workers [person]	19	16	-15.79%
6. Labor cost of workers [%]	100	84.21	-15.79%
7. Stops in the Kanban circle [pcs]	3	2	-33.33%

The numerical results and the calculation methods of the examined 7 indicators will be introduced in the next part of this paper.

• **Material flow efficiency**

Re-arrangement of the workstations results in a modification of the material flow distances (d_{ij}) between the stations. The quantity of the material flow (f_{ij}) is constant because the production technology and the amount of final products to be produced are not modified, only the location of the stations changes.

Material flow quantity in the case study (the matrix is the same for the original and for the new re-layout):

$$\underline{\underline{F_{Orig, New}}} = \begin{bmatrix} 0 & 10 & 3 & 10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 20 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 23 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 23 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 23 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{ [UL]}$$

The distances of material flow between workstations in the case of the original layout:

$$\underline{\underline{D_{Orig}}} = \begin{bmatrix} 0 & 8 & 6.5 & 3.5 & 17 & 13 & 5.5 & 9 & 8.5 & 12.5 & 15 \\ 0 & 6.5 & 8.5 & 10 & 5 & 8.5 & 12 & 13.5 & 15 & 17.5 & \\ & 0 & 7 & 11.5 & 6.5 & 3 & 7.5 & 12 & 11 & 11.5 & \\ & & 0 & 18.5 & 13.5 & 4 & 5.5 & 5 & 9 & 11.5 & \\ & & & 0 & 5 & 14.5 & 19 & 23.5 & 22.5 & 20 & \\ s & y & m- & & & 0 & 9.5 & 14 & 18.5 & 17.5 & 15 \\ & m & e & t- & & & 0 & 4.5 & 9 & 8 & 9.5 \\ & & r & i & c & & & 0 & 4.5 & 3.5 & 6 \\ & & & & & & & & 0 & 4 & 6.5 \\ & & & & & & & & & 0 & 2.5 \\ & & & & & & & & & & 0 \end{bmatrix} \text{ [m]}$$

The distances of material flow between workstations in the case of the new re-layout:

$$\underline{\underline{D_{New}}} = \begin{bmatrix} 0 & 7 & 6.5 & 4.5 & 14.5 & 11.5 & 8 & 11.5 & 10.5 & 12.5 & 15 \\ 0 & 6.5 & 8.5 & 7.5 & 6.5 & 11 & 14.5 & 13.5 & 10.5 & 8 & \\ & 0 & 8 & 8 & 5 & 4.5 & 8 & 7 & 6 & 8.5 & \\ & & 0 & 16 & 13 & 8.5 & 7 & 11 & 14 & 16.5 & \\ & & & 0 & 3 & 7.5 & 11 & 10 & 7 & 4.5 & \\ & & & & 0 & 4.5 & 8 & 7 & 4 & 3.5 & \\ s & y & m- & & & 0 & 3.5 & 2.5 & 5.5 & 8 & \\ & m & e & t- & & & 0 & 4 & 7 & 9.5 & \\ & & r & i & c & & & 0 & 3 & 5.5 & \\ & & & & & & & & 0 & 2.5 & \\ & & & & & & & & & & 0 \end{bmatrix} \text{ [m]}$$

Material flow efficiency is calculated by means of (1).

Total material flow efficiency in the case of the original layout is:

$$E_{Orig} = 742 \text{ [UL · m]}.$$

Total material flow efficiency in the case of the new re-layout is:

$$E_{New} = 708.5 \text{ [UL} \cdot \text{m]}.$$

- **Total material handling cost** can be calculated by means of (4).

In most cases, the cost of transferring material from one machine to another is linearly proportional to the distance covered.

Total material handling cost can be calculated by:

$$C_{hand} = E \cdot c_h \quad (4)$$

where E is the material flow efficiency and c_h is the specific material handling cost [Euro/UL · m].

- **Total travel distance of goods** is the sum of those elements of the distance matrix in which real material flow is realized.
- **Space used for assembly** is not a calculated result; it was an objective of facility layout redesign.
- **Number of workers** is not a calculated value; it was a result of the lean-based process improvement (section 8.4 – Takt-time design and line balance methods).
- **Labor cost of workers** is linearly proportional to the number of workers (section 8.4 – Takt-time design and line balance methods).
- **Stops in the Kanban circle** is not a calculated value; it was a result of the lean-based process improvement.

8.7. Results of facility layout redesign. It can be concluded that the goals of the layout redesign were achieved:

- The required fixed-shape continuous free floor space (-75 m^2) can be provided for the new workstations.
- The material flow efficiency was reduced significantly (-4.51%).
- The material handling cost was also reduced (-4.51%).
- The total travel distance of raw materials and components was reduced due to the ideal re-arrangement of workstations (reduction: -10.45%).
- The layout redesign resulted in the maximum utilization of resources (space, facilities, labor force, etc.). The number of workstations was reduced (Following line balancing, the operation of workstation No. 2 can be achieved at 2 workstations after the redesign instead of 3 workstations. Workstations No. 5 and No. 6 can be joined.).
- The number of workers was also reduced (Following line balancing, the operation of workstation No. 2 can be achieved by 2 operators after the redesign instead of 3 operators. Workstations No. 5 and No. 6 can be joined and the workload of these two stations can be achieved by 2 operators instead of 4 operators (reduction: -15.79%)).
- Labor cost of workers was also reduced (-15.79%).
- The Kanban-based component supply became more efficient; the number of stops was reduced from 3 to 2, (-33.33%).
- Workstations of the assembly process were organized into a cellular layout which has further advantages, e.g. it provides a fast flow of goods inside the assembly process; lead

times and setup times can be reduced; productivity can be increased; the amount of work in process stock can be minimized.

9. Conclusions

The topic of this study is highly important and relevant, because cost reduction and productivity are the main goals of all manufacturing companies in order to increase their competitiveness. Therefore, the application of efficiency improving methods is essential for manufacturing companies. Facility layout design/redesign is one of the most important and frequently used methods which can improve efficiency and reduce the operational costs of companies to a significant extent. It is thus widely used in practice.

Facility layout design means the optimum arrangement of facilities (objects: department, workstation, machine, equipment, etc.) in a manufacturing shop floor and the optimum material flow between these objects, in order to reduce the operational costs of companies and improve the performance of production lines.

In this study, the theoretical background relating to layout redesign was described: the objectives, the procedure of layout redesign and the calculation method for layout optimization. Furthermore, the study is also practice-oriented, because the layout redesign of an assembly plant was described in a real case study.

The described layout redesign is novel and original because two efficiency improvement methods have been combined. The classical facility layout design method was used as the basis but 4 lean methods (takt-time design, line balance, cellular design and one-piece flow) were also applied to define the ideal re-layout.

The goals of the application of lean methods were to make the layout more efficient and improve more KPIs by: 1) reducing the number of workstations and workers; 2) implementing one-piece flow; 3) leveling the workload of all of workstations and human workers; 4) forming a cellular layout.

It can be concluded that the combination of facility layout redesign and the lean methods in the case study resulted in significant reduction of the following indicators: 1) the amount of total workflow; 2) the material handling cost; 3) the total travel distance of goods, 4) the space used for assembly; 5) the number of workers; 6) the labor cost of workers, and 7) the number of Kanban stops.

The above-described facility layout redesign was successfully achieved at an assembly plant as part of an R&D project.

The goal of my future research is to apply further lean methods and tools during layout design/redesign to create more productive and cost effective layouts/re-layouts.

Consequently, the combination of facility layout design and lean methods proved to be an effective method for efficiency improvement at manufacturing companies in order to reduce the total manufacturing cost and provide best arrangement of workstations, ideal movement of goods on the shop floor, maximum utilization of resources and free space for new workstations.

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