The use of Lean Manufacturing principles to improve production processes by better designing of assembly cells

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Abstract. One of the pillars of Lean Management is continuous improvement of production processes. Thus, while designing new workstations, it is worth taking into account the requirements resulting from this management philosophy. The question remains how to formulate these requirements, at what design stage to use them and how to do it. A very important aspect of work stations' design is their ergonomics. Considering the ergonomics of a workplace, we should adapt it to the human anatomical and psycho-physical capabilities. The use of takt time to determine the production capacity of the assembly cell makes it easier to organize tooling, working hours and other factors necessary for effective production. After determining the takt time, it is possible to settle the number of assembly stations we need to achieve the required performance in the analysed time horizon. Another important aspect of Lean Manufacturing is enabling continuous flow of materials between successive production processes. Continuous flow at the assembly stage is ensured by the layout of work stations in accordance with the order of technological operations and thoughtful arrangement of production equipment. This will facilitate further acceleration of production orders, elimination of activities that do not add value, and reduction of labour consumption in the assembly process. In accordance with the aforementioned Lean Management recommendations, a conceptual design of an assembly cell for an example product from the electronics industry was developed. In the case of the analysed product, the idea to ensure continuous flow was to build the assembly cell at the stage when the product design was completed and its trial series produced.

1. Introduction

Before designing a new assembly station, it is necessary to specify the requirements that the work station must meet to function effectively in the production system. By meeting certain rules and requirements, it will be easier to integrate the designed station into the manufacturing process. One of the pillars of Lean Management is the continuous improvement of production processes, including the work stations participating in them. In order to implement Lean successfully, it is necessary to sequence the implementation tasks [1, 2]. Therefore, while designing new workstations, it is worth taking into account the requirements resulting from this management philosophy. The question remains how to formulate these requirements, at what design stage to use them and how to do it.
The main features that distinguish assembly cells include:

- most often, one-piece flow of a product,
- limiting transport routes to a minimum,
- shortening operation times by adapting equipment to a dedicated product,
- employees trained in the assembly of the product group,
- characteristic shape of the assembly cell, most often U-shaped.

1.1. Workplace ergonomics

A workstation is a place where a person spends on average up to eight hours a day, so ergonomics is a crucial aspect when designing it. Considering the ergonomics of a workplace, we should adapt it to the human anatomical and psycho-physical capabilities. There are four basic categories of ergonomic requirements:

- physiological - technical objects must be adapted to the physiological characteristics of the man,
- anthropometric - technical objects must be adapted to the dimensions of the human body and its weight,
- hygienic - the working environment must be adapted to the human being in order to reduce harmful environmental factors,
- psycho-physical - technical objects must be adapted to the human for the proper functioning of human senses.

Given the requirements listed in these categories, the assembly station must take into account the dimensions of the human body. The height of the working surface at the workstation should ensure the correct, upright posture (assuming standing work). The correct height of the workplace is usually considered to be 750 - 1100 mm, depending on the type of work performed.

The appropriate dimensions of the work space are an important aspect as well [3]. In the case of an assembly station, the main process takes place in the working area, thus its dimensions must make manipulation with the assembled object possible and take into account ergonomic restrictions. The reach of hands determining the dimensions of the working space is shown in figure 1.

![Figure 1. Normal and maximum reach of hands in the working plane [4].](image)

The most common workstation zones are: a work area, a zone with mounting elements where standard containers will be located, and a zone with work instruments. Hence, we have another,
quite obvious, design tip - the station cannot be designed in isolation from the products to be assembled and should have separate work zones for storing necessary parts as well as tools and equipment.

The location of information and signalling elements should be consistent with human perceptive capabilities. In addition, the employee must be able to place them in a convenient way [5]. In the case of an assembly station, such elements can include boards for workplace instructions or Andon lamps.

In the work environment, the choice of proper lighting is an essential issue. General lighting in the production hall is usually insufficient. Each workplace must be equipped with spot lighting. At the assembly station, the employee must also be able to control the light source, moving it closer to the product while assembling a small element.

Summing up the requirements of workplace ergonomics, it can be stated that the workplace should guarantee the employee health protection, well-being, facilitate his work and ensure his safety.

1.2. Continuous flow

A crucial aspect of Lean Manufacturing is enabling continuous flow of materials between subsequent production processes. The lack of such a flow in places where it is possible means a waste of time connected with waiting for the transition to the next process [6]. The very concept of Lean Manufacturing is defined in the subject literature in a number of different ways and the names of this philosophy are used interchangeably [7, 8], describing it as Lean Management or Lean Production.

The term Lean Manufacturing (LM) was proposed in 1988 by John Krafcik, who first used it as the term for an alternative system for popular mass production [9].

Continuous flow at the assembly stage is ensured by the layout of work stations in accordance with the order of technological operations and thoughtful arrangement of production equipment. Splitting of the process into technological operations should ensure even workload for fitters and give an opportunity to synchronize their work. The even division into technological operations enables smooth product transfer to the next stage. It is important to provide small process batches (preferably one piece flow) to increase the flexibility of the production system and reduce the associated inventory costs.

The design of the assembly station should ensure the possibility of delivering materials from the outside, e.g. through Milk Run. This solution has numerous advantages but the most important thing is to enable deliveries without interrupting the work of the assemblers.

The space between the positions in the assembly cell must be limited to eliminate waste of traffic and prevent unwanted accumulation of work in progress. When arranging workstations in the "side to side" cell, we must also ensure that there are no vertical obstacles between them, then the flow of one piece passed over the worktop between the workstations will be possible.

Ensuring a continuous flow of components between subsequent assembly stages is the main task in the design of the assembly station. This will speed up the execution of production orders, eliminate activities that do not add value, reduce the labour consumption of the assembly process, and the production cycle time also be shortened as well.

1.3. Takt time

The number of products manufactured should be equal to the number of products ordered by customers. In other words, the sales cycle time should be equal to the production cycle time. In order for the product-oriented cell to work properly, demand must be high enough for a single product. The takt time is calculated based on the following information:

- time available for production in the same period of time,
- customer's requirements.

The use of the takt time to determine the volume of production facilitates the organization of tooling, working hours and other factors necessary for effective production. After determining the takt time, it is possible to settle the number of assembly stations we need to achieve the required performance in the analysed time horizon. Sets of patterns for calculating takt time are already widely available in the literature.
2. Production process
The production process is shown in figure 2 below. The process model was prepared using extended BPMN notation [10].

The device consists of forty-nine unique elements. The first stage of the production process is SMT (Surface Mount Technology) soldering. After soldering, in the second stage, containers with surface-soldered boards are transported to an automatic inspection device. Visual inspection is carried out in a special chamber equipped with cameras and sensors. Then the operation of individual electronic components is checked.

In the event that any discrepancy is found, such a board must be repaired by manually soldering inoperative or missing components. After repair, the elements are checked again in the automatic inspection device.
In the third stage, printed circuit boards are manually soldered using THT (Trough-Hole Technology) technology. Then the final assembly is conducted.

Final assembly takes place in three steps. At the first station, the lower housing subassembly is mounted, which contains three boards manufactured at previous stages and connecting elements. At the second station, the upper housing subassembly is mounted. Mainly it is the device screen and elements enabling data entry. At the last stand, two components are assembled into the finished product.

At the penultimate stage, the finished product is checked for proper functioning and the ability to work in different operating modes. The instrument is then connected to the computer for calibration.

At the last stage, the finished product is transported to the packaging area, where it is placed in a box together with accessories and documentation.

3. LM tools that affect the shape of the assembly station design

In order to facilitate the work of operators at work stations and control of the production process, Lean Manufacturing tools are most often used. Each of the tools has its own specific purpose and affects the way the production process is carried out in a different manner.

3.1. 5S method

The first step in the introduction of 5S tools at the assembly station is the selection, using the tools’ labels, materials and instrumentation necessary for the implementation of the production process. Such elements include: working tools, containers with elements used for assembly, instrumentation, auxiliary materials, various types of oils and greases as well as workplace instructions.

The second step is to systematize the way of work at the assembly station. The work space elements selected at the previous step are arranged in a way preventing unnecessary movements of the operator during work. The station is most often divided into three zones: working, tooling and the zone for storage of components for assembly. The elements are arranged in the appropriate zones so that those used most often are situated closer to the operator. Also, for visualization purposes, each zone may be marked with a selected colour.

In the next step, cleaning of the workstation at the beginning and the end of the work shift as well as other procedures related to the preparation of the station before the commencement of work are conducted.

The fourth step focuses on maintaining a clean and safe work environment. Sorting and cleaning were carried out before this phase. This phase aims to provide simple, visible tips on how the area should be maintained daily.

The last but not least important step is to provide self-discipline of the employees to ensure that all operations and activities are carried out according to the pre-established rules. This step is considered the most difficult to implement.

When designing a new, subsequent assembly station, information about the necessary and minimized work space or the distribution of working zones is used, after carrying out the 5S procedure in an analogous station. The experience gained while using the 5S method is then used in the design of technologically related new assembly stations.

3.2. Use of Poka-Yoke

When assembling electronic products, it is particularly important to properly connect all components. In the event of a wrong connection, when checking the product, it may turn out that the product not only does not work properly, but has been damaged by the uncontrolled flow of electric current between the components. Committing such errors causes significant costs associated with the production of defective products.

One of the ways to prevent such mistakes may be the use of Poka-Yoke tools that prevent incorrect assembly [10, 11]. A common procedure during the assembly of electronic products is to connect the cables to their dedicated sockets. In order to ensure a faultless connection and facilitate preparation of
the workplace instructions, it is possible to use wires of different colours and mark the wires with a numbering system.

Obviously, when designing assembly stations, some space should be provided for additional elements resulting from the use of Poka-Yoke. The need for them to be used may not result directly from the developed assembly technology.

3.3. Application of Andon

The Andon system enables communication between the operator and the employee responsible for controlling the course of production processes. It is an information management tool that gives a preview of the current state of the production process [12]. Warning signals can be visual and audible, informing about a defect or a problem. Information tools can take different forms: coloured lamps, light panels, information panels or monitors.

In the case of an assembly station, coloured lamps can be used. When the process is carried out in the right way, the lamp lights up green, indicating that everything is fine. When a problem is detected, the employee presses the red button, the lighting of the selected colour lights up; in this case the controlling person is asked to repair the defective element. As a last resort, the production process can be stopped until the fault is rectified. Another case of using the Andon system may be the situation when the assembly components are running low. In this case, the operator uses the blue button and the inspector informs warehouse employees about the need to provide materials.

The design of the assembly cell should immediately provide for the location of Andon in the selected form so as to ensure its good visibility. Its control methods and the means of power supply should also be specified in the design.

4. Implementation of conceptual design

At the conceptual design stage, the focus was on applying the principles listed in the chapter above to a new assembly station for an example product from the electronics industry. In the case of the product being analysed, the idea of ensuring continuous flow was to build the assembly cell at the stage when the product design was completed and its trial series was produced. The schematic diagram of the assembly cell is shown in figure 3.

![Diagram of working zones for the assembly cell along with its main dimensions.](image-url)
The production process of the product began with SMT (surface soldering) of the printed circuit boards and ended with the packaging of finished products and placing them in the finished products warehouse. Initially, there was no continuous flow ensured between any of these production stages. In order to eliminate waiting time for the next stage, a supermarket for soldered and ready-to-assemble tiles was organized, following the surface soldering stage. Continuous material flow was also used at the final assembly stage. Earlier, the assembly took place at three work stations, where the lower housing and the upper housing were assembled and both parts were combined. The ready components waited in the intermediate storage area to be transferred to the overall assembly, and then the finished product waited for the transfer to the next stage of checking and calibration.

The newly designed U-shaped assembly cell will immediately combine two stages (final assembly and checking with calibration). At the first workstation of the assembly cell, the assembly of the lower housing components takes place. At the second, the component of upper housing is mounted and they are joined together. The last workstation will be used to check the product and calibrate it. The components will be transferred to the next station by means of a conveyor belt passing through the outside of the cell. The assembly cell designed in such a way enables:

- shortening the transport route between production stages,
- direct transfer of a single product between stations, ensuring a reduction in the production cycle time,
- reducing the number of work in progress items.

In the next step, while designing the assembly cell according to the principles quoted in the chapter above, the takt time in which the cell should manufacture a ready-to-use product was determined. To this end, the time available for production during one shift was calculated, taking into account the time required by law for employee breaks. Based on completed (for earlier product versions) sales plans, it was assumed what the average monthly demand would be. On this basis, the necessary number of products to be manufactured during one work shift was determined.

The times of technological operations at individual stages enable production with the assumed capacity. This means that they are within the previously calculated takt, in accordance with the customer's needs. It was confirmed that only one such assembly cell would be needed.

The last rule that needs to be met is the requirements for the ergonomics of the assembly cell. Each of the individual stations is adapted to the physiological needs of the man. It should be remembered that a poorly designed workplace can cause young workers to experience problems related to their motor organs. The potential occurrence of the mentioned problems in the longer perspective does not release the designer from his responsibility for the operators' health. All elements such as tools, assembled components and functional elements of the workplace manipulated by the employee must be within the reach of the employee's hands and arranged in designated areas.

An important parameter when designing a workplace in terms of ergonomics are its external dimensions. The work chair must be height adjustable so that the employees have the opportunity to take the position that is the most comfortable for them. The immediate working zone in which the product assembly was carried out must allow the employee to conveniently place the assembled product and facilitate the movements associated with the assembly operations [13]. The following figures 4 and 5 shows the designed assembly cell for a product from the electronics industry in 3D view.
Figure 4. 3D frontal view of the schematic diagram of the assembly cell.

Figure 5. 3D side view of the schematic diagram of the assembly cell.

The cell consists of three stations connected with a belt conveyor. All stations are divided into three zones. In the case of the first two stations, these are: working area (grey), area for containers with elements for assembly (blue) and area for working tools (green). At the last station, the green zone intended for connecting the finished product to the calibration device, the grey zone contains a screen displaying the calibration status. The blue zone contains a calibration device. Each station is equipped with a tablet that the employee can set in a convenient position. This tablet is used to provide the employee with information related to the current order and displays workplace instructions, allowing for a quick transition between the steps of the instruction. Each instruction consists of a table of mounting elements and a description with a photo of the activities performed by the employee in a sequence.

On the right, next to the operating table, there are controllers with two buttons. These buttons are responsible for the functioning of the Andon system and allow you to communicate with the person controlling the production process. The lamps at the top of the station are an essential element of this system.

5. Conclusions
In summary, the use of continuous flow requires adaptation of the structure and shape of workstations in the assembly cell. These requirements include:
stations arranged in a U-shape,
only those technological operations that add value are implemented,
the machines are arranged in the order of the process,
parts are delivered only when needed,
one piece flow (or possibly small batch flow) is introduced,
continuous flow,
supplies of parts carried out by supporters (not operators) from outside of the cell.

Ergonomic requirements translate directly into the shape of the assembly station:
all tools within the employee's reach should be divided into appropriate zones according to their frequency of use,
the worktop for the manufactured item should be at a height convenient for the employee, depending on the type of work performed and the position taken by the employee (sitting or standing),
proper spot lighting should be provided,
all controls or devices are arranged with ergonomics in mind.

Assembly stations and cells designed with the above guidelines bring a lot of measurable benefits to the company, among others: reduced production in progress, which translates into less cost-intensive work, fewer injuries to operators related to work, uninterrupted flow of products, elimination of non-added value movements and immediate information feedback in case of quality problems.

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