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# Application of Lean Manufacturing Methods in the Production of Ultrasonic Sensor

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**Abstract:** The paper deals with the use of lean manufacturing methods for ultrasonic sensors production optimization. The company where this case study was applied is part of a group that is one of the most important suppliers in the automotive industry. It is necessary for companies to constantly improve and innovate their production environment to remain competitive in the market. The current car manufacturers' demands include the pressure to increase production efficiency which can be achieved by implementing lean management. Production processes are never perfect and need to be improved and optimized to achieve the ideal state. The optimization focuses on the part of the sensor production line where the cap and seal are fitted. The ultrasonic sensor is used for measuring the oil level and temperature in a narrow area. The case study aims to optimize the fitting process problem and the resulting product of this process because it does not meet the quality requirements.

**Keywords:** automotive; defects; lean manufacturing; optimization; Poka-Yoke

## 1 INTRODUCTION (INTRODUCTORY REMARKS)

Currently, increasing demands are on companies and their competitiveness. If a company is to be successful, it must pay maximum attention to the customer's requirements and the quality with which it meets the requirements. Introducing lean management is an effective way to achieve maximal quality in all sectors. Manufacturers still look for ways how to increase the efficiency of their production and their competitiveness. This can be achieved in several ways: purchasing new technology, improving services and quality, or reducing waste [1, 2].

Over the last twenty years, the introduction and implementation of lean manufacturing principles have had a significant impact on the manufacturing company. Experience shows that lean manufacturing methods and tools are not equally applicable to large and small businesses. The lean thinking concept, which was also successfully implemented in medium-sized companies, arose after implementation in large companies belonging to the automotive sector. Small businesses have been ignored for a long time [3].

One of the industries that fall under lean management is process optimization. Individual processes are never perfect, and to achieve the ideal state, it is necessary to improve and optimize the processes to satisfy the customer as much as possible [4].

## 2 BASICS OF METHODOLOGY

Nowadays, if a company wants to be successful it must be lean already or use Lean Management methods. A company that uses Lean Management methods strives to improve continuously as an organization (all employees strive to improve, regardless of job position) in all areas (production, processes, administration, logistics, etc.) and strives to avoid waste. For a lean company, the customer is a priority, and the company strongly focuses on satisfying the customer's needs [5].

Lean Manufacturing is a branch of Lean Management that applies production management methods. Lean Manufacturing focuses on maximizing added value for the customer. Lean is a way to make a business minimize waste and produce more, have lower costs, and make more efficient use of space and production resources. Waste means everything that increases the costs of a product without increasing its value. Fig. 1 shows typical examples of waste in production [6, 7].

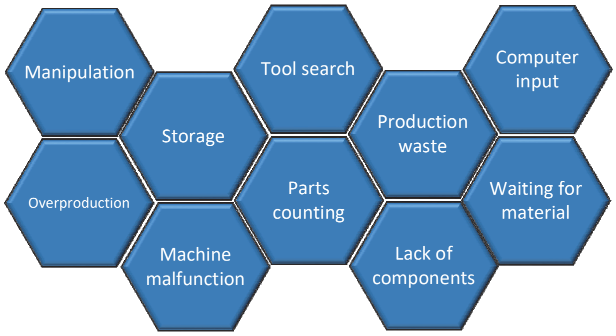



**Figure 1** Waste in production [8]

### 2.1 Poka-Yoke

The name of the Poka-Yoke methodology is based on the Japanese words POKA (error) and YOKERU (avoid). As the name suggests, the principle of the Poka-Yoke method is to prevent human error or an error before it occurs. The method is used in production as a preparation that prevents the worker from making a mistake very often. Implementing Poka-Yoke is not costly, and the costs that Poka-Yoke saves due to error prevention are considerable [9].

When an error occurs during production, it is common for management to assign the cause of the error to the operator and solve the problem by retraining the operator. The Poka-Yoke methodology does not blame the operator for the mistake but assumes that if one operator could have caused the error, anyone else can cause it. Finding a way to prevent the error from recurring is a resolution to this issue [8, 9].

Today, especially in the automotive industry, the Poka-Yoke methodology is a matter of course. Tab. 1 lists the most common human errors with examples of situations they can cause. The Poka-Yoke methodology tries to prevent the given errors and eliminate them thanks to simple modifications in the process or its preparations [10].

**Table 1** The most common errors and advantages of Poka-Yoke [9]

| Human error | Error example | Poka-Yoke advantages |
|---|---|---|
| Forgetfulness | Skipping an operation | Minimising or avoiding errors and mismatches. The operator can focus on operations that add value to the customer, rather than wasting time thinking about how to prevent errors. Improving quality and eliminating the source of errors. Easy and inexpensive to implement. |
| Misunderstanding, miscommunication | Poor manufacturing/assembly | |
| Misidentification | Incorrect advantage of the situation | |
| Lack of experience | Missing part, poor manufacturing | |
| Deliberate disregard for standards | Wrong part | |
| Negligence, inattention | Incorrect execution of operation | |
| Slowness, clumsiness | Unset device | |

The Poka-Yoke methodology can best be understood through examples. The first example is how computers (laptops) and their ports are manufactured, which are designed so that the relevant connectors can only be plugged in one correct direction into the relevant port. All ports and their respective connectors have different shapes and colours to avoid the mistake of the wrong connector being plugged into a given port. Another example would be sockets and electrical wiring. Sockets are designed to be plugged in one direction only. Similarly, electrical wiring uses colour differentiation to prevent possible errors [8, 10].

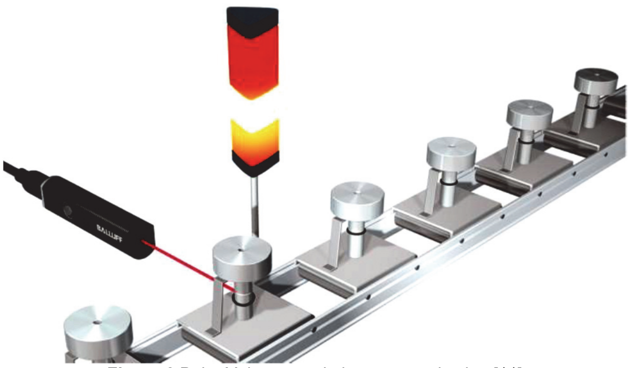


**Figure 2** Poka-Yoke example in mass production [11]

An example of the use of Poka-Yoke in mass production is the use of various sensors and transducers. In the case of the operator setting up the wrong part, the sensor detects the difference from the programmed standard and reports an error (Fig. 2). The operator then checks the error and production can continue. If the sensor reports incorrect information, nothing has happened, and the production has only stopped for a few seconds. On the other hand, if the sensor detected a defective part, it prevented the production of a defective piece, damage to the machine or even loss to the customer to whom the defective piece could have been sold [9].

## 3 CASE STUDY FOR DETERMINATION OF BOTTLENECKS AND PROBLEMS

This case study focuses on the production optimization of an ultrasonic sensor used to measure oil level and temperature. To identify the bottlenecks, it was first necessary to conduct a detailed analysis of the sensor itself and its production process on the assembly line. This sensor is manufactured in three height and design variants, where the visible difference is mainly in the sensor height and the change in the design of the lower part (housing). The sensor consists of many components that are further combined into larger units. The manufactured versions of the sensor and its most important components, which are necessary for the production process of the problematic line, are shown below (Fig. 3) [12, 13].

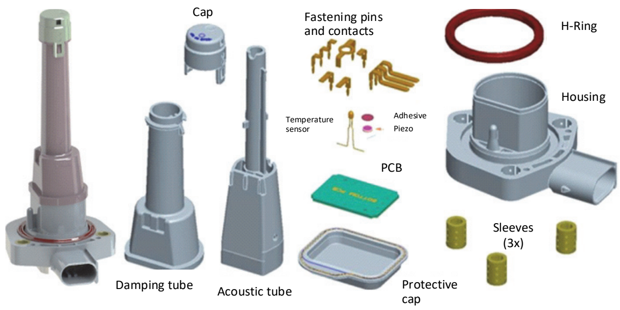



**Figure 3** Overview of ultrasonic sensor versions and components [11]

The complete ultrasonic sensor manufacturing process consists of several technological operations, while only the cap and seal assembly sub-process were important for the subject of this study. The entire manufacturing process starts with the preparation of all contacts and subsequent injection moulding of the housing. Next, leak tests are performed along with evaluation. Other technological operations of the manufacturing process are curing, piezo potting, dispensing of heat-conductive paste, seating and welding, pressing, and laser welding of the housing. After calibration, testing, and drying, there is a sub-process of cap and seal fitting, which will be further discussed in this case study as it is a bottleneck [12].

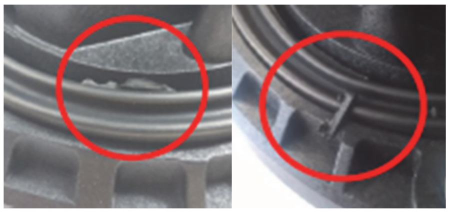
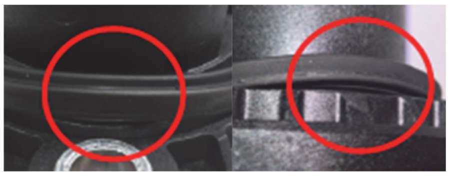
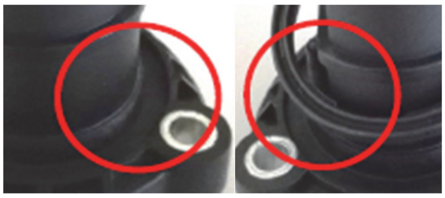
The device has a total of four positions on the turntable. In each position there is a bed (composed of three parts) which contains the Poka-Yoke elements (Fig. 4). A cap is placed in the left part, a seal in the middle and a housing on the right side [8].

- Position 1 - installation of the input components in the bed.
- Position 2 - fitting the cap to the housing.
- Position 3 - seating and pressing the seal into the housing; includes a sensor that checks the correctness of seating.
- Position 4 - removal of OK product.

**Figure 4** Bed with Poka-Yoke elements [11]

The bottleneck in the ultrasonic sensor manufacturing process is the cap and seal assembly station. In particular, the constant complaints from operators about the failure rate of the station, the high rejection rate, and the inability to meet production schedules pointed to this. The reason for the failure to meet the plans is mainly due to the high Cycle Time, which is a problem of the equipment, and the failure rate, which is a problem of position 3. The high scrap rate can be attributed both to the cause of the failure rate and to the station control program. The table below (Tab. 2) describes and characterizes each problem [11].

**Table 2** Device detected problems [11]

| Significant problems | | | |
|---|---|---|---|
| **Number** | **Name** | **Description** | **Visual display** |
| 1 | Shards | Frequent unacceptable burrs on the seal. Poor tolerance setting and low-quality input material. The burrs impair the seating process, are large, resulting in ripples, chipped edges, etc. |  |
| 2 | Torn or chopped flag | Torn or chipped part of the seal (inside). Cut, damaged, or cut flag inside the H-Ring. Poor quality input material, speed and method of fitting, misalignment and inaccuracy, groove/edge design. |  |
| 3 | Ripple | Frequent non-pressing of the seal (wavy), necessity of manual pressing. Wrinkling is when the seal is seated all the way around, but in a certain part, the seating is not ideal. |  |
| 4 | Partial fitting | In some places, the seal is not fitted at all. Partial seating is when a gap can be observed under the seal where the seal is not seated. |  |
| 5 | Without fitting | The seal is missing or not fitted at all. Rare case where the seal is not fitted and the product is not detected as a NOK and is passed on to the next operation as an OK piece. |  |
| 6 | Cycle time | Cycle time is considerably high, up to 18 seconds. | - |
| **Minor problems** | | | |
| **Number** | **Name** | **Description** | |
| 7 | MES | Long and difficult communication with the MES program. After pressing the START button, there is a communication delay of 1-3 seconds between the machine and the MES program. Furthermore, incorrect writing of MES program values into the system, which then evaluates the product as NOK, while it is OK. | |
| 8 | Sensor for control | The sensor to monitor the inserted components (Poka-Yoke) to prevent the machine from starting is missing. Poka-Yoke elements fail, and the machine starts the already inserted product again in the insertion process. | |
| **Details (possibilities for improvement)** | | | |
| **Number** | **Name** | **Description** | |
| 9 | Nonstrength of the bed | Occasional pulling out of the bed to insert components and products due to tight alignment and friction forces. | |

## 4 OPTIMIZATIONS IN THE PRODUCTION PROCESS

Based on the analysis carried out to identify the problems, proposals for their solution were described in detail. Then these proposals were implemented together with practical tests. The description and actual implementation of the solution proposals are briefly described in this chapter. For each problem encountered, the tasks and conditions to be tested were defined (Tab. 3). Based on these proposed tasks and testing processes, it was possible to detect the causes of undesirable defects and subsequently determine measures to optimise them [5, 14].

**Table 3** Tasks and testing problems for optimization [11]

| Tasks and testing problems for optimization | | | |
|---|---|---|---|
| **Number** | **The Problem** | **Tasks/tests** | **Terms and specifications** |
| 1 | Shards | Dimension test | Verification that the dimensions of the seals in the drawing are identical to the actual drawing. |
| | | Test of 2 types of seals | Test fitting of two types of seals and comparison<br>100% visual inspection when inserting input elements<br>Execution of the test by one operator. |
| 2-5 | Severed flag<br>Ripple<br>Partial fitting<br>Without fitting | Friction test | Testing 3 types of seals and comparing them. |
| | | Lubrication test | Trying out 2 types of lubrication and comparing them. |
| | | Setting speed test | Testing two types of speed and comparing them. |
| | | Ironing test | Testing 4 types of ironing and comparison. |
| | | Test of the new tool | Testing the tool and comparing it with the original. |
| | | Test with reduction | Test fitting with reduction on 2 seals. |
| 6 | Cycle time | MES program communication | Debate with the programmer about possible changes in MES communication and reduction of communication time. |
| | | Automation of position 2 | Position 2 automation solution with supplier. |
| 7 | MES | Data logging | Debate with the programmer about correcting error data logging. |
| 8 | Sensor for control | Sensor installation | Solution with the supplier to install and program sensors for input elements. |
| 9 | Nonstrength of the bed | Adding a bed fuse | Resolve with the supplier to add a fuse to the beds. |
| | | Drawer for beds | Solution with the supplier adding a drawer to the beds. |

## 1) SHARDS

A total of 200 pieces were selected for the burr tests and then used for a second test of 2 types of seals. For the first dimensional test, 15 samples were randomly selected; this test was only a control test in terms of dimensions. Each measurement was taken 10 times and the resulting values were the average of the given values. The test results were positive, all values were within tolerance, but the seal was measured without burrs. If burrs are present, all dimensions may increase by up to 0.2 mm, and the values will be out of tolerance. Whether burrs are problematic was confirmed by a second test.

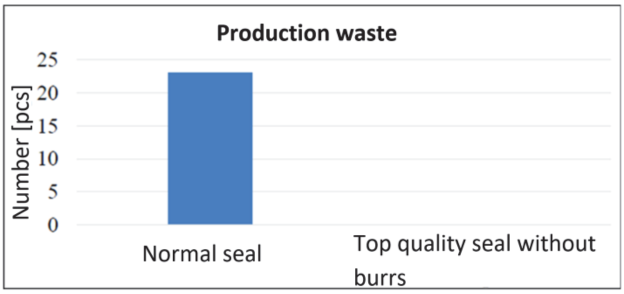



**Figure 5** Scrap rate by seal quality [11]

The test of two types of seals was carried out for normal seals (100 pieces) and top-quality seals without burrs (100 pieces). The results of the test are presented in a graph showing the percentage of nonconforming pieces (Fig. 5), which clearly shows that the highest quality seals without burrs performed significantly better. The rejection rate for the seal was zero, while for the conventional seal it was as high as 23 % [11].

## 2-5) SEVERED FLAG, RIPPLE, PARTIAL FITTING, NO FITTING

A total of six tests were performed for these defects (Fig. 6 and 7), for which a total of 775 pieces were selected and tested according to specifications.

**Friction test** - the results show that the best values were achieved with the highest-quality seals without burrs and therefore it makes sense to use only seals without burrs. The test also confirmed that there is no need to change the seal supplier.

**Lubrication test** - was stopped in the middle and it was decided that there was no point in continuing the test because the lubrication of the seals had a visible negative effect on the seating process, and it is not recommended to lubricate the seals in any way.

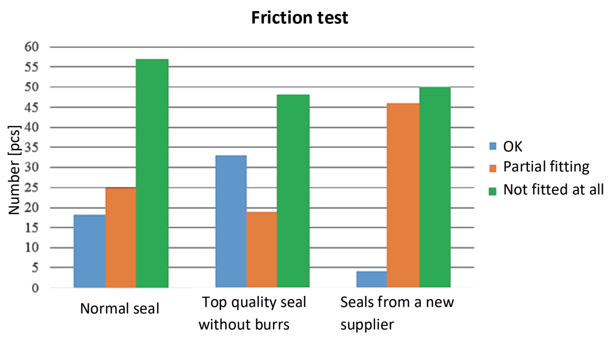



**Figure 6** Graphical representation of the friction test results [11]

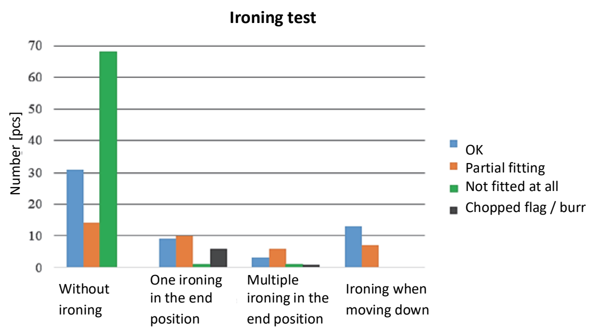



**Figure 7** Graphical representation of the Ironing test results [11]

**Setting test** - the test showed that the setting speed has no effect on the cut-off flag, and there is no point in adjusting the setting speed.

**Ironing test** - the ironing test showed that the best solution is to iron while moving downward, where the start of the ironing will be just before the problematic edge. Ironing in the end position is not recommended with a seal.

**New tool test** - for this test, 10 pieces were observed and then the test was discontinued, as it was already proven that changing the tool had no positive effect on the improvement of fitting.

**Reduction test** - this test confirmed that the edge is indeed causing the problem with the cut flag. The solution is therefore to change the design to round the edge or use a reduction. A total of 3 reducers were made for this test, the first was made on the 3D printer (a), the second reducer was supplied by the supplier (b), and the last type was made in-house (c) implementing the flaws that were found after a quick test with the reducer from the 3D printer [11].

### 6) CYCLE TIME

To reduce the cycle time, it was necessary to change and automate position 2. The entire machine was taken to the supplier where the required changes were made. On this occasion, the communication with the MES program was discussed with the programmer. The entire program was checked from the ground up, fine-tuned, and the cycle time was reduced due to the optimization of the program. Part of the automation of position 2 was the addition of a vibratory feeder, which now automatically feeds the caps that are replenished at the back of the machine. The automation of the cap has eliminated one of the loading elements, reducing the time required for the operator and the cycle time. The bed change after automating position 2 is shown in the figure (Fig. 8). The resulting cycle time was reduced from the original 18 seconds to 8.9 seconds due to the optimization and automation of position 2 and communication with the MES.

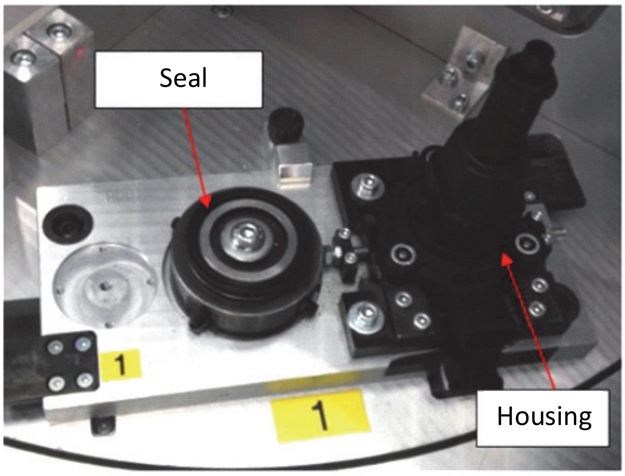



**Figure 8** New type of bed (without cap) [11]

### 7) MES

The problem with the MES has already been partially solved in the previous problem during the automation of the device (the lengthy wait after pressing the START button has been eliminated, thanks to the optimization of the program by an external programmer). Several monitorings of the day were performed, but with no positive result. Although the moment when the program did not write a value was caught, the cause and reason why it happened could not be determined. The data logging problem therefore persists.

### 8) SENSOR FOR MONITORING

The Poka-Yoke input elements have been updated and improved to avoid mis-foundation issues. A SICK sensor has been added to ensure that the correct version is founded and to check the presence of a cap.

### 9) NON-STRENGTH OF THE BED

When the machine was rebuilt, the aim was to fine-tune all the details already in the supplier, so the beds were improved to prevent accidental pulling out due to frictional forces, and a bed drawer was added.

**Adding a bed lock** - a locking screw has been added to all beds to prevent accidental pull-out due to frictional forces at position 4. This simple solution cost a minimum of money.

**Adding a drawer for bunks** - previously bunks were stored in a free space at the back of the unit. With the automation of position 2, a vibratory feeder was added, and that free space was filled. For the new location, a drawer was made and placed at the bottom of the machine. The drawer was secured with a lock that only maintenance, production managers, and technicians have access to.

## 4.1 ALTERNATIVE SOLUTION PROPOSALS

As alternative solutions, options are presented that, although too costly in terms of money or time, could lead to a solution to the problem.

### a) MACHINE DESIGN CHANGE

The cap and seal fitting process is not only carried out in the Czech Republic but the same process is used in plants in China and Hungary. The designers have devised the fitting process differently. For example, in China, instead of manipulating the seal, they manipulate the housing. The seal is firmly set on the bed and centred. The housing is then seated on the seal and seated using pressure. Once the seal is seated, the manipulator rotates the housing, and the process continues with the next steps of seating the cap (Fig. 9).

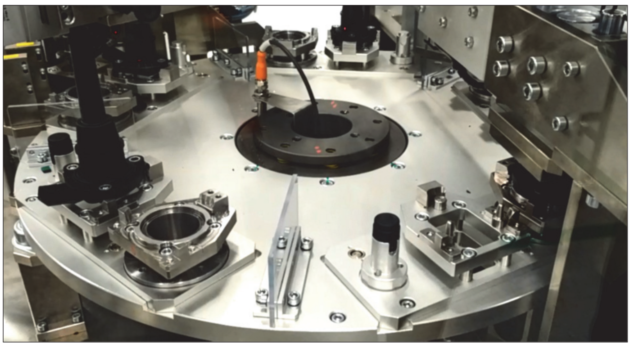


**Figure 9** Cap and seal fitting process in China [11]

Another country with a similar concept is Hungary. There, the settlement process is based on a very similar principle as in China. The seal is firmly set on the bed and centred. The housing is then seated on the seal and seated using pressure (Fig. 10).

**Figure 10** Sealing process in Hungary [11]

According to the available information, the process works without problems in both countries and therefore, in case of investment in a new machine, one could take inspiration from foreign designers, as handling the housing seems to be a better solution than handling the seal.

### b) TOOL MADE OF ANOTHER MATERIAL (RUBBER)

Another suggestion to solve sealing problems is to make the seating tool of rubber or a softer material than iron. This hypothesis could solve the cut-off flag problem and theoretically other problems as well.

### c) DESIGN CHANGE

As the tests in the previous chapters suggest, the problem will already be in the initial design of the seal and therefore it would be ideal to make a design change to the seal. Attention should be paid to the internal flags when redesigning, as they are likely to fail to perform their intended function and impair the seating process. [11]

## 5 CONCLUSION

The main objective of this paper was to retain customers and meet their expectations by optimizing the production of the ultrasonic sensor for oil level and temperature measurement. Customers had previously focused on the seal and cap seating process and requested improvements to the process.

Failure to improve the process could endanger relationships with the customers concerned. By optimizing the process and significantly reducing cycle time, customer requirements were met, and the cap and seal fitting process was audited and accepted, with the remaining deficiencies to be corrected in the future.

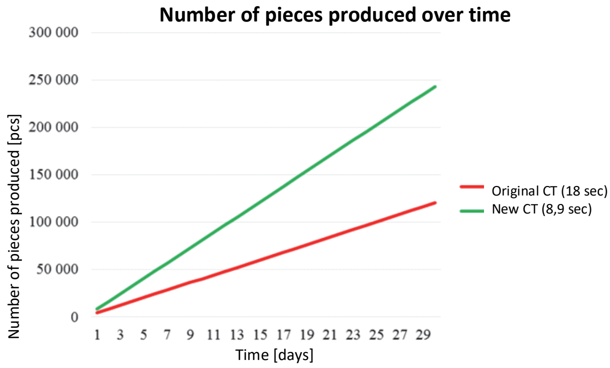



**Figure 11** Comparison of the number of units produced over time [11]

Another benefit for the company is the cost savings due to the reduction of NOK pieces and the improvement of the quality of the final product, thanks to the removal of burrs and the final visual inspection. By reducing the cycle time to half, twice the amount of product can now be produced than before, and this will lead to higher yields (Fig. 11). As a final benefit to the company, the process is simplified and less demanding on the operator, due to the reduction of input components.

**Table 4** Summary of the solved problems [11]

| Number | Name of the problem | Solution description* | |
|---|---|---|---|
| 1 | Shards | - add an operator to production<br>- removal of permissible burrs in seals | ✓ |
| 2 | Severed flag | - change the method of the ironing process | ✓ |
| 3 | Ripple | - persistent problem<br>- add an operator to production | × |
| 4 | Partial fitting | - significant improvement, but the problem persists<br>- add an operator to production | - |
| 5 | Not planted at all | - combination of improved ironing and burr removal | ✓ |
| 6 | Cycle time | - automation of position 2 and process optimization | ✓ |
| 7 | MES | - problem with lengthy communication solved<br>- the problem with bad writing persists | - |
| 8 | Sensor for monitoring | - adding components to the device | ✓ |
| 9 | Nonstrength of the bed | - adding components to the device | ✓ |
| * resolved (✓), partially resolved (-), not resolved (×) | | | |

Most of the defined problems have been solved or at least improved to an acceptable state (Tab. 4). However, there was also a problem that has not yet been solved. A Six Sigma project team was assembled towards the end of the solution to address this problem and to focus on fine-tuning the process. Considering the state in which the facility was before optimization, overall process optimization can be judged as a success

The results have shown that the defined steps and their verification allow one to implement quality tools in production and thus eliminate the problems that occur in the production process. The engineering company involved in this study confirmed the relevance and success of the project based on the implementation of Poka-Yoke and other quality tools in the production process.

This contribution fulfilled the philosophy of lean manufacturing. It is about efficient production, where there are no unnecessary losses. This philosophy aims to produce products in the shortest possible time with minimum costs and, of course, also to meet customer requirements regarding the quality of the produced products.

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