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Analysis of Solutions Dedicated to Non-Conformity Prevention

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Abstract:

Purpose: *The purpose of the work is to analyze the use of solutions aimed at preventing incompatibilities and assess the effectiveness of these solutions to minimize the risk associated with the quality of manufactured products. The analysis presented in the work is based on the Poka-Yoke error prevention concept used in the selected enterprise. The paper presents the state of the company before and after the introduction of Poka-Yoke method.*
Approach/Methodology/Design: *The research methods used in the paper were the analysis of company data, analysis of literature states, as well as methods using the Poka-Yoke concept. The company was surveyed in 2017/2018 during the system implementation.*
Findings: *The results on the control card for nonconforming units of type "p" were also presented, where the analysis showed that the introduction of the Poka-Yoke system to the company reduced the number of nonconformities by 6.69%.*
Practical Implications: *Implementation of the Poka-Yoke system will allow enterprises to create conditions in which an error cannot happen, or will be immediately visible. The result of such an action may be distracting operators from repetitive operations, reducing the number of deficiencies and induce immediate action when a problem occurs.*
Originality/Value: *Showing how the use of the Poka-Yoke system affects the prevention of inadvertent error in enterprises, by determining the differences between the state of the enterprise before and after the introduction of the Poka-Yoke system, there is an opportunity to improve the economy and contribute to the social and economic sphere.*

Keywords: *Quality, quality control, management system, Poka-Yoke solutions, divergence.*

JEL classification: *O14, P42, P51.*

Paper Type: *Research study.*

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1. Introduction

Quality is a feature of products, services or processes that determines its suitability for the customer and his satisfaction. Quality management is a field of science which is equipped with a wide range of methods and tools useful for obtaining, maintaining and improving the economically justified quality of products and services. It is used not only in the production process zone, but also in pre-production and post-production zones. This is due to the fact that quality analysis plays an extremely important role in product design and testing. The main area of quality research is still the production company. The production process zone is traditionally considered to be the key to the quality of life of society, determined by the quality of products and services offered. According to this, manufacturers are responsible for the quality of design and production process, and the aim of all their activities is to achieve optimum quality. The focus of these activities is on the final product and basic technological processes. At the production stage, the research should focus on achieving optimal quality under specific production conditions, taking into account economic factors, i.e. quality costs. In trade and sales, the research focuses, among other things, on the opinions of customers, which should be the basis for improving the product quality. In the operation phase it is important to check the usefulness and reliability of technical facilities, services and maintenance, which is the basis for further improvement of the quality of certain processes, products or services. Such requirements must be associated with properly trained employees and technical personnel in the quality management zone defined in the quality rules (Sałaciński, 2015).

Specialists, through access to appropriate guidance and tools, can control the quality of the product and collect and analyze information to efficiently prevent possible non-compliance (Feldmann, 2015). Guided by appropriate quality management methods can be a way to achieve the basic objectives of the company, which can be an increase in product profitability, in market share and income growth. Product quality management processes use appropriate models that contain and characterize the criteria and mechanisms for improving quality processes (Lisiecka, 2013).

Many quality problems have their origin not only in production process or executive functions, but also in marketing, service or finance, as well as in human resources and administrative functions (Basiarti, 2018). The wrong approach is one that speaks of quality as an isolated inspection service that is located at the end of the production process. The quality of the products that meets the customer's requirements must be designed throughout the production system and at the same time be anchored in the employees' awareness (Bauer, 2017). The concept of quality management is the result of several decades of knowledge and experience gained by organizations around the world. They had to meet the growing demands of the customer, which was in opposition to the traditional concept of quality management (Lock, 2002). The quality management philosophy puts the customer first, subordinating all areas of the organization's operation to his requirements. The approach to the problem of quality improvement, which is still used today, was formulated several decades ago by Shewhart, Deming and others (Hamrol, 2004; Więcek, 2007). The quality of a product or service is therefore the result of a number of activities forming the so-called product life cycle. It is worth noting that the main factor influencing the quality of the offered product is man. It is his knowledge, skills and experience used in practice that allow him to produce a product of the quality expected by the customer (Emami, 2019).

The research was conducted in a selected research entity, whose factory is located in the area of the Lower Silesia Province. The research was conducted on the basis of data received from the company. The analysis of the received information allowed to determine the number of advertised parts before and after the introduction of the Poka-Yoke system on the assembly line on which the hydraulic equipment is produced.

The aim of the publication is to present the benefits of the Poka-Yoke error prevention concept. The paper presents the state of the company before and after the introduction of this method. The research methods used in the paper were the analysis of company data, analysis of literature states, as well as methods of using the Poka-Yoke concept.

2. Analysis of the Company's Activities

The company manufactures hydraulic equipment for equal machines on a daily basis. In connection with its production activity, many incompatibilities could be distinguished in its processes, which hindered the proper functioning of the company. At the turn of 2017/2018 it decided to introduce the Poka-Yoke system, because the most frequent nonconformities appeared in the following areas:

- installation of seals,
- the selection of the Cardan shaft,
- number of housing washers.

The time of introduction of the changes was 1 month and immediately they could observe an improvement in the functioning of the company.

2.1 Analysis of the Number of Accepted Complaints before the Introduction of the Non-Compliance Prevention System Poka Yoke

Table 1 presents the three most frequent causes of product complaints. The first reason was a badly installed casing seal resulting in hydraulic oil leaks, which contributed to a decrease in the unit's efficiency. The second factor causing an increased number of complaints was an incorrectly selected cardan shaft being an element of another product manufactured on the same assembly line. The next source of complaint was due to a wrongly selected number of pads on the housing cover.

Table 1. *Comparison of total costs and real costs of removing the effects of risk factors*

Reasons for complaint / Month	Wrongly fitted seal		Incorrect selection of the cardan shaft			Insufficient number of housing washers	Sum of non-compliance in individual months
	Number of non-compliance	non-compliance of an item in relation to the total number of non-compliance [%]	Number of non-compliance	item in relation to the total number of non-compliance	Number of non-compliance	non-compliance of an item in relation to the total number of non-compliance [%]	Number of elements
08.	62	38%	20	12%	82	50%	164
09.	75	40%	16	9%	97	52%	188
10.	143	53%	11	4%	114	43%	268
11.	165	57%	33	11%	93	32%	291
12.	101	42%	23	10%	115	48%	239
01.	87	32%	36	13%	153	55%	276
02.	81	34%	29	12%	127	54%	237
03.	69	27%	12	5%	173	68%	254
04.	118	50%	10	4%	108	46%	236
05.	142	53%	8	3%	120	44%	270
06.	139	40%	29	8%	183	52%	351
Sum	1182		227			1365	

Sourse: *Own.*

During the first two months of the study a similar level of defects was found, the following months were accompanied by an increase in product complaints. However, the peak of the defects reported by the recipients coincided with the increasing scale of production process, which took place in March and April. As orders dropped, the intensity of failures decreased.

2.2 Elements of the Poka-Yoke System, which Reduce the Occurrence of Incompatibilities

In order to minimise the occurrence of faults in its products, which consequently lead to product complaints, XYZ has introduced the Poka-Yoke system on its hydraulic equipment production line. The assembly line has been equipped with infrared sensors that scan the code of a given component, and then an appropriate computer program processing the information received shows where and in what order the component is to be installed. Figure 1 shows the sensors installed at each component on a strip next to the containers.

Figure 1. *Position of infrared sensors on the mounting line*

Source: *Own.*

The system, by lighting a green light next to each part, indicates which part is to be included in the finished product (Figure 2A). If the fitter does not take the part marked with the green light, it will not be able to move on to the next production process stage, because the system will become blocked. The system will only allow further assembly if the fitter cuts the beam from the sensor in the right place. When the part is taken from the right place, the green light goes out. If the operator turns off the LED by mistake, it can check whether the part should be in the finished product through the information contained in the computer program. The screen shows the structure of the product that is currently being manufactured.

Figure 2. *Diodes to inform about the selection of parts. A) Green LED indicating the order of assembly of the parts, (B) Red LED indicating incorrect part selection*

A) B)

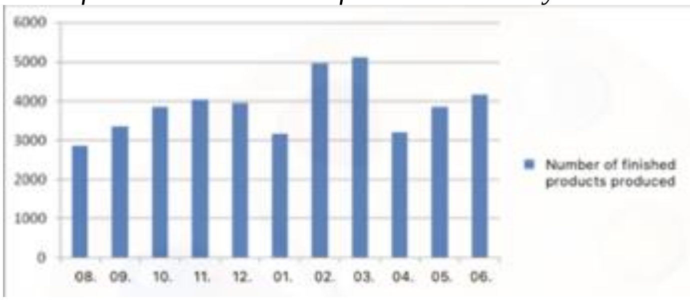
Source: *Own.*

When an assembler reaches for a component, the program saves it. If the operator reaches for a bad component that cannot be found in the product, a red light is lit (Figure 2B). This system allows to immediately determine whether there is a production process error. Additionally, selected actions are controlled by the vision system. It checks with the camera, illuminator, and processor that all existing components have been properly installed. If it detects a defect, it will not allow the operator to proceed to the next stage of installation. The installer activates the video system with the button at which the sensor is located. If the sensor detects a defect in the manufactured part, the operator must correct the part.

2.3 Analysis of the Number of Accepted Complaints after the Introduction of the Poka-Yoke Error Prevention System

Figure 3 shows the numerical information relating to the quantity of parts produced after the system has been put in place, preventing non-conformity. The comparison includes the same intervals as for production process before the introduction of the Poka-Yoke system.

Figure 3. *Number of "Orbital X" hydraulic motors produced in 2017-2018 in particular months after the introduction of the Poka-Yoke system*



Source: *Own.*

Table 2 contains numerical information on the occurrence of defects in the advertised product after the introduction of Poka-Yoke procedures. In order to assess the effectiveness of the system, the same structural elements of the product, which were the biggest problem during production process without its use, were checked.

Table 2. *Number of product complaints due to the most frequent inconsistencies in 2017-2018 in particular months*

Reasons for complaint / Month	**Wrongly fitted seal**	**Incorrect selection of the cardan shaft**	**Insufficient number of housing washers**	**Sum of failures in individual months**
August	8	0	22	30
September	13	1	36	50
October	23	0	43	66
November	26	1	37	64
December	8	3	25	36
January	18	2	21	41
February	35	0	55	90
March	38	1	63	102
April	29	1	5	35
May	21	2	33	56
June	16	0	63	79
Sum	**235**	**11**	**403**	

Source: *Own.*

It can be observed that the sources of complaints appeared in the company not cyclically. The largest number of complaints was in March 2018, while the smallest in December 2017. Therefore, in this case, there is no difference in regularity. The largest number of complaints was reported with insufficient number of housing pads. However, the smallest number of complaints referred to incorrect selection of the gimbal shaft.

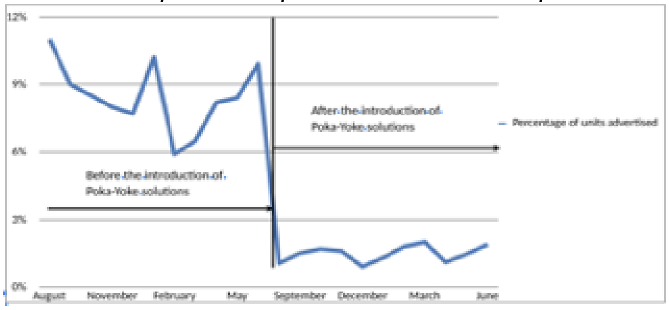
3. Analysis of the Results of the Impact of the Poka-Yoke System

The percentage share of product complaints was analysed in relation to the number of the most frequent discrepancies to the production process volume in particular months. These values refer to the situation before and after the introduction of the Poka-Yoke error prevention system. Figure 4 presents a graph of the relationship between the percentage share of complaints taking into account the analyzed product inconsistencies in individual months. In the period from August to June, the curve refers to parts before the introduction of the Poka-Yoke solutions on the assembly line for hydraulic motors, while in the following months, the situation shows the percentage share of equipment returns after the implementation of the Poka-Yoke solutions. In the first months before the introduction of the Poka-Yoke solutions there was a downward trend. In January, the percentage share of the advertised units increased. Then, the trend was downward until February. Between March and June, the curve increased in value.

As you can see, during this period the trends are unstable. The values of the percentage share are changing very quickly. After the introduction of Poka-Yoke solutions, the tendencies remain more stable. There were not very big differences between them. From August to October, the trend increases, then it decreases until December. This period is followed by an increase in the trend, which lasts until March. In April, the percentage decreases. In the following months until the end of June the trend increased.

The percentage of product complaints with regard to inadequate assembly of the housing seal to the production process volume in individual months was analysed. These values refer to the situation before and after the introduction of the Poka-Yoke error prevention system. Figure 5 shows a graph of the percentage share of units complained about only including parts with a poorly installed seal before and after the introduction of Poka-Yoke solutions. The change in the percentage reduction has been achieved by introducing solutions such as a vision system, which controls and checks the position of installed seals. If the installer detects an abnormality in the installation, the fitter will not be able to proceed to the next assembly stages. The fitter needs to correct the position of the gasket only then will be able to move on to other operations. The vision system signals the problem by blocking the product and displaying a message on the computer screen. The vision system consists of camera, illuminator and processor. It is able to detect the lack of a seal where it should be. It also detects the incorrect position of the seal.

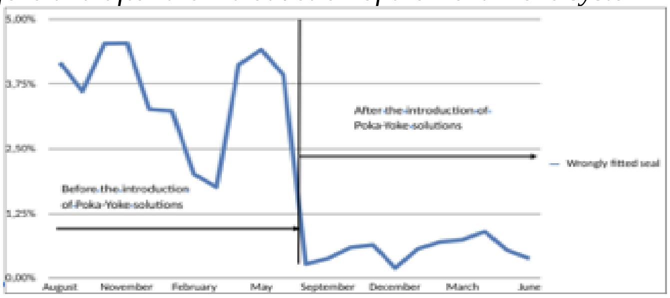
Figure 4. *Chart of the percentage share of units advertised, taking into account analyzed inconsistencies before and after the introduction of Poka-Yoke solutions*



Source: *Own.*

Another Poka-Yoke solution, which allows to reduce the percentage of claimed non-conformances due to a poorly installed seal, is beam sensors. They prevent the wrong type of seal from being taken into the product. If the fitter takes the wrong seal, the system will send a signal to the computer, which will display information about the mistake. The system will also block further assembly of the product until the fitter checks the type of seal. If he does so, he presses the switch that is responsible for restarting the seal check system.

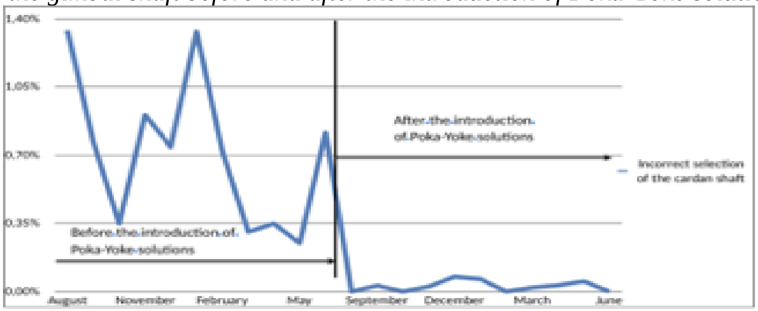
Figure 5. *Graph of the percentage of units advertised including parts with poorly fitted seals before and after the introduction of the Poka-Yoke system*



Source: *Own.*

The percentage share of product complaints in relation to inappropriate selection of the gimbal shaft to the production process volume in particular months was analysed. These values refer to the situation before and after the introduction of the Poka-Yoke error prevention system. Figure 6 shows a graph of the percentage share of units complained about only including parts with incorrect selection of the cardan shaft before and after the introduction of Poka-Yoke solutions. The change in the percentage reduction was achieved by introducing solutions such as beam sensors, position sensors and vision system. The use of beam sensors prevents incorrect selection of the cardan shaft. When the fitter enters the engine model into the computer, a light is lit at the appropriate gimbal shaft to be used. Position sensors determine the correct mounting and size of the gimbal shaft. The vision system also checks the selection of the cardan shaft for the correct model.

Figure 6. *Chart of the percentage share of units advertised including parts with incorrect selection of the gimbal shaft before and after the introduction of Poka-Yoke solutions*



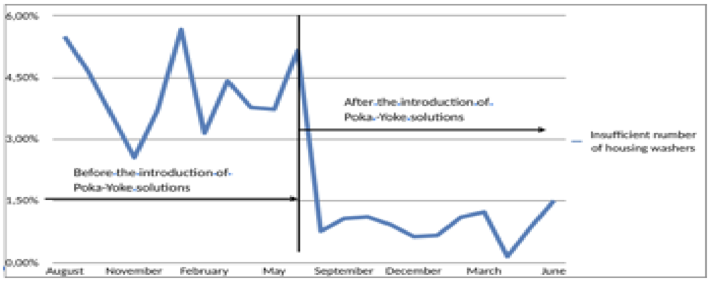
Source: *Own.*

The percentage share of product complaints in relation to the insufficient number of housing pads to the production process volume in individual months was analysed. These values refer to the situation before and after the introduction of the Poka-Yoke error prevention system. Figure 7 shows a graph of the percentage share of units complained of only the parts with insufficient number of enclosure washers before and after the introduction of Poka-Yoke solutions. The occurrence of this discrepancy has been limited by the introduction of counters mounted at the vision sensors, which count the number of washers taken. If the number of shims downloaded does not match the product specification, the system will display a message on the screen about the insufficient number of installed shims.

Figure 8 shows a graph of the fraction of products not complying with the "p". This is a simulation of a control card that is used to control the process. The control card for non-compliant units of type 'p' is an alternative control card. It is used when it is possible to identify further product units and assign them as compliant or non-compliant units. Variable sample sizes are possible. The values shown on the card indicate whether the process is extensive or not. Other examples of alternative cards are (Hamrol, 2013):

- number of non-compliant units in a fixed sample size (e.g. cards of the type e.g.),
- numbers of inconsistencies in the fixed sample size (type u cards),
- number of discrepancies per product unit (type c cards).

Figure 7. *Chart of the percentage share of units advertised only including parts with insufficient number of housing washers before and after the introduction of Poka-Yoke*



Source: *Own.*

Thanks to the control card it is possible to monitor the process, i.e. whether it is possible to predict how it will behave further. The number of non-compliant units was calculated from equation (1).

$$p = \frac{number\ of\ non-compliant\ units}{number\ of\ units\ produced} \quad (1)$$

These figures are for each month. The upper limit of control indicated in the UCL chart was calculated from equation (2).

$$ULC = \overline{p} + 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n_i}} \quad (2)$$

Where:

UCL - upper control limit,

p- - average of the sum of non-compliant units to the sum of units Produced,

n_i -units produced during the month.

The central line marked in the LC diagram was calculated from equation (3).

$$LC = \overline{p} = \frac{\sum number\ of\ non-compliant\ units}{\sum number\ of\ units\ produced} \quad (3)$$

The lower control limit indicated in the LCL diagram was calculated from equation (4).

$$LCL = \overline{p} - 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n_i}} \quad (4)$$

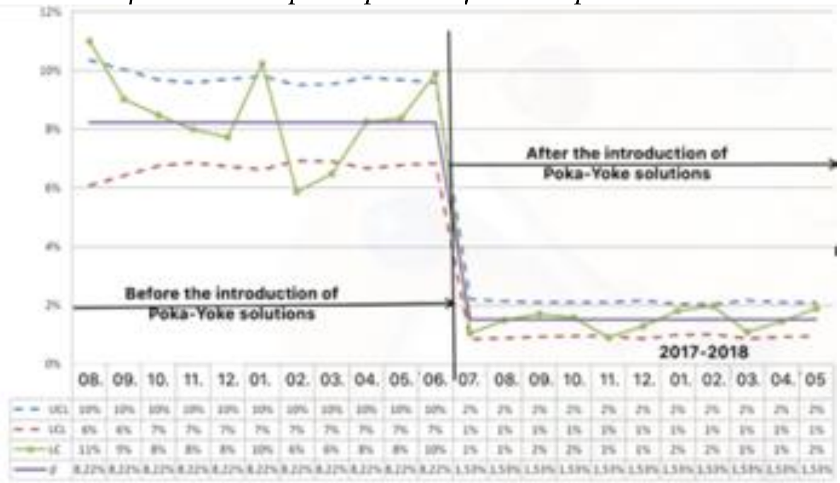
Where:

UCL - lower control limit,

p- - average of the sum of non-compliant units to the sum of units Produced,

n_i -units produced during the month.

Figure 8. *Chart of the non-compliant product fractions p*



Source: *Own.*

The card presents the situation before and after Poka-Yoke solutions. In the first period from August to June, the chart illustrates the situation before the change, while after this period the company introduced Poka-Yoke solutions. The upper and lower limits of the chart create broken curves. This is due to the variability of the number of manufactured products in different months. The difference in the first period between the upper and lower control limit is quite big. This is influenced by the variable number of sample "n" After the change, these limits have decreased their spacing.

The upper limit before and after the change decreased by 8%, while the lower limit changed by about 9%. The percentage of units that did not comply before the change oscillated between 6-11%, while after the change it was 1-2%. After the changes, it can be seen that the percentage of complaints is equally stable, but the fraction of non-compliant units has significantly decreased.

The average of the sum of non-compliant units to the sum of units produced before the introduction of Poka-Yoke solutions was 8.22%, while after changes its value was 1.53%.

4. Conclusion

The paper presents an analysis of the effectiveness of solutions preventing the occurrence of incompatibilities in the examined organization. The paper includes a literature review in the field of quality management with a special focus on the aspects related to the analysis and minimization of risk and on solutions to prevent non-compliance. The organisation in which the research was conducted is presented. The description presents, among others, management systems, which are in force in the company, its structure, products and customers.

The paper presents the problems that occurred at the assembly stations of the finished product and solutions to prevent the occurrence of incompatibilities, which were introduced to the organization. Another aim was to assess the effectiveness of solutions to minimize the risk related to the quality of manufactured products. Individual non-compliant units were analyzed in particular months. The analysis of solutions for a given cause of occurrence of non-compliant units was also carried out. The results on the control card for nonconforming units of type "p" were also presented, where the analysis showed that the introduction of the Poka-Yoke system to the company reduced the number of nonconformities by 6.69%.

It is therefore advisable to introduce systems to improve complaint levels, as they bring great benefits. Research in this area will continue.

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