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Paula Kolbusz[1]

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THE USE OF THE SIX SIGMA METHODOLOGY IN A PROJECT IMPROVING THE MANUFACTURING PROCESS

WYKORZYSTANIE METODOLOGII SIX SIGMA W PROJEKCIE USPRAWNIAJĄCYM PROCES PRODUKCYJNY

Abstract

In the current, full of technological novelties, companies that want to maintain their position on the market are obliged to implement continuous improvement of their operations. A frequent and recently popular phenomenon is the creation of workplaces in organizations for specialists in the field of continuous improvement. Improvement is a laborious and long-lasting process. The activities of the company that create added value for the customer should be improved, in other words they increase the competitive advantage on the market, then they will be effective for the company. The article presents the possibility of using the Six Sigma methodology to improve the efficiency of the production process of a rubber product on one of the production lines. To achieve the intended goal, qualitative and quantitative research methods were used to analyze the results obtained as part of the company's case study. In addition, the statistical analysis of the obtained results allowed to identify factors in the areas affecting the efficiency of the manufacturing process and to determine the action plan identifying the actions that should be implemented to improve the production process.

Keywords: improvement of the production process, DMAIC, Six Sigma

Streszczenie

W obecnych, pełnych nowinek technologicznych firmach, które chcą utrzymać swoją pozycję na rynku, zobligowane jest do ciągłego doskonalenia swojej działalności. Częstym i ostatnio popularnym zjawiskiem jest tworzenie w organizacjach miejsc pracy dla specjalistów z zakresu ciągłego doskonalenia. Doskonalenie jest pracochłonnym i długotrwałym procesem. Działania firmy, które tworzą wartość dodaną dla klienta powinny być doskonalone, czyli zwiększają przewagę konkurencyjną na rynku, wtedy będą efektywne dla firmy. W artykule przedstawiono możliwości wykorzystania metodyki Six Sigma do poprawy efektywności procesu produkcji wyrobu gumowego na jednej z linii produkcyjnych. Aby osiągnąć zamierzony cel, zastosowano jakościowe i ilościowe metody badawcze do analizy wyników uzyskanych w ramach studium przypadku firmy. Ponadto analiza statystyczna uzyskanych wyników pozwoliła zidentyfikować czynniki w obszarach wpływających na efektywność procesu produkcyjnego oraz ustalić plan działania określający działania, które należy wdrożyć, aby usprawnić proces produkcyjny.

Słowa kluczowe: doskonalenie procesu produkcyjnego, DMAIC, Six Sigma

1. Introduction

In the automotive industry, an often heard term is "striving for the highest quality". The 70s of the twentieth century were abundant in ideologies and strategies for improving the level of quality and productivity in enterprises. The topics of the concepts in question were focused on the foundations of competitiveness, including: quality indicators, production costs of the final product and timeliness of deliveries. The growing pace of technology development, increasing customer requirements not only as to the quality of the product offered by the company, but also the time of production and delivery, are aspects that the management of enterprises is currently struggling with. Many institutions have been obliged to work at a high level of quality (Bogdanienko, 2011).

In the last century, mass production was developed, which is associated with a greater possibility of production errors, which resulted in an increase in demand for quality control of products. The very term of the word perfection derives from the Latin word "perfectio", which literally means "to do something, to do to the end", that is, it defines "accomplishment,

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[1] Paula Kolbusz, Politechnika Rzeszowska, Szkoła Doktorska Nauk Inżynieryjno-Technicznych, Al. Powstańców Warszawy 12, 35-959 Rzeszów, ORCID: 0000-0002-6058-041X.

finishing". This idea was extended by Tatarkiewicz and defined perfection as "that which fulfills all its proper functions and that which has achieved its goal, something that is simple, uniform, non-complex". The term improvement is replaced by "improving, modernizing, changing.

Six Sigma was implemented in the mid-80s by Bill Smith and Bob Galvin at Motorola, for which the American Quality Award was received, the methodology was used as a production training program in organizations (Watson and DeYong, 2010). This approach was initially based on areas in the electronics industry, only later reached many other sectors (Arnheiter and Maleyeff, 2005). Six Sigma spent years developing until it evolved into a comprehensive quality management system, called TQM (Green, 2006). Over the past twenty years, the methodology has become more common as its principles have also been implemented in service industries in the context of the supply chain (Wei et al., 2010), as well as hospitals, local governments and the public sector (Arnheiter and Maleyeff, 2005).

As a project-based approach to management, the scope of Six Sigma implementation now also includes continuous cost reduction in the company by reducing losses resulting from insufficient quality. In order to determine this method, customer expectations were examined in order to determine critical values for and goals for individual levels of company management were defined (Kwak and Anbari, 2006).

The aim of this study is to analyze the use of the Six Sigma methodology to improve the efficiency of the production process in a selected enterprise. The structure of the article is as follows: Chapter 2 presents the research methodology, Chapter 3 presents the Six Sigma tools used for a specific case study. However, the conclusions are set out in Chapter 4.

2. Purpose and methodology of research

2.1. Six Sigma in practice

The foundation of both ideologies and productivity improvements in the company is the practice of activities according to the management philosophy, which is focused on the quality of the product or service (Total Quality Management), while others focus on the entire restructuring of processes in the enterprise (Business Process Reengineering, Just In Time). The activities of another group of concepts were focused on reducing and finally completely eliminating waste (Lean Management) or on increasing the stateof seriousness in processes focused on the critical characteristics of the finished product (Six Sigma). The last two methodologies were combined into one in this way, obtaining Lean Six Sigma (LSS).

In a recent review of the literature, it will distinguish the spread of LSS in four important sectors of the economy: manufacturing, healthcare, finance and education. It will also presentthe critical barriers and benefits of implementing this methodology. A companies using Lean Six Sigma must be awareof the challenges and success factors when implementing LSS in various sectors of the company, such as production, finance, human resourcese. The effects of the use of LSS are, among other things: reduction of waste, defects and improvement of the process, which in turn ensures high-quality products at minimal cost, and this leads to customer satisfaction, which ultimately raises the standard of social life.

The economy have been forced to retaliate by becoming more aware of sustainability and the requirements for environmentally friendly products to reflect on their business operations. In most countries, traditional methods of producing and using fossil fuels have been adopted in industries. Manufacturing industries in developed countries release four times less dioxideto coal compared to emerging countries. Therefore, for the sake of society and environmental protection, the industrial sector is obliged to take into account green technologies and in its activities. Over the past tenyears, many ideas and approaches have developed, such as Lean, Green, Six Sigma to produce the highest quality products.

The composition of GLS consists of three unique approaches, i.e. Green, Lean and Six Sigma, through which the dynamics of profitability are increased by reducing emissions, waste and reprocessing. Combined Green Lean Six Sigma is able to produce a product that is not only of high quality and cheap, but also friendly to environment. GLS combines Lean and Green waste in the defining phase of the DMAIC Six Sigma methodology. Ubecomes and investigates the causes of process-related waste and emissions. Then, possible solutions are sought for improvements in different dimensions of organizational sustainability. The next stage is to wdrożenie the best solution to it, and the performance is used for further development.

In the history and industrial revolutions of the last three centuries, it highlights the transition from power sources through automation, information technology and automated manufacturing, to connectivity. Industry 4.0 has been defined by the World Economic Forum as the latest industrial revolution that revolves around the so-called cyber-physical era, with this revolution occurring with the integration of the physical and digital worlds through the proliferation of sensors and devices forming a connected ecosystem. Froma customer-centric product cycle approach to a customer-centric experience cycle, it has been implemented as a result of the fourth revolution. This means that the customeris involved in the product life cycle from concept to post-purchase feedback, and customer experience has been included as the key to the success of companies, in every sector. In the literature, the term Industry 4.0 means a profound change in many sectors: from production to use. Industry 4.0 is able to create value throughout the life cycle of a product, process or service. For the reasons described above, the effect of this revolution can be an object, but also a service designed for the end user, the development of which is driven by innovation in several areas: IT, mechanical engineering, embedded systems, manufacturing, automation technology and all these combined to provide the more complex systems that are known today. The automotive industry is experimenting with new challenges and frontiers with so-called autonomous and connected vehicles, which are "smart" and completely connected to the rest of the world thanks to internet technologies.

2.2. Description of the company covered by the case study

The research was carried out in a company that has been active in the Automotive industry for years. The main goal of the group is to create products that are comfortable, safe and at attractive prices for the user. The expertise of the corporation includes such industries as:

- Sealing of the structure,
- Precision tightness,
- Fluid flow monitoring,
- Materials and structures,
- Anti-vibration systems,
- Transmission systems.

The selected company specializes in the tightness of structures and in the automotive industry. It is a market full of stringent requirements and specific requirements. The advantages of these products include: comfort of use, energy result and protection. The products met are: reduction of pollutant emissions and the level of energy consumption, acoustic result, proper management of thermal consequences, optimization of mechanical force, weight reduction and reduction of dimensions without compromising the quality of manufactured products. The activity of the company in which the case study was examined dates back to the second half of 2017 and the manufactured products are thermoplastic seals and rubber seals. The production area of rubber processing, which is the production line, was selected for the analysis. Which includes: extruders, metal accumulators, furnaces, mastic machine, rubber profile transporters, cutting machine, welding machines. The analyzed area is the finishing operation performed after extruding the rubber profile, which consists in stiffening the area of the trunk gasket.

2.3. Research problem

The main problem of the process under study is the increased percentage of non-compliant parts. This is due to the fact that insufficiently strong connection of the gasket was observed or incorrectly glued together at the site of the incision, which is used to stiffen it. The consequence is the disposal of poorly prepared final product, increased working cycle time and greater - than expected - consumption of production components. This contributes to the overall increase in the cost of production of the finished product. The increase in production costs causes the weakening of the company's role on the market, in addition, it may happen that an inadequately prepared final product will not be stopped at the final inspection, it is tantamount to a complaint from the customer and his dissatisfaction, and thus in the future may have an impact on reducing the company's market share.

Therefore, the following research problem was defined: identification of factors affecting the high and unstable percentage of recoil of the part – during the final inspection after the stiffening process for the trunk gasket. Part of the analysis of the problem was also to definition actions that should be identified and then validated in order to improve the described process.

2.4. Description of the manufacturing process of the case study

The production process of rubber processing products is a complex process. The production of products is a large number of stages during which the presence of specialists is necessary: from designers, CAD specialists through technologists, process engineers, people responsible for material, employees responsible for machines, to the quality department and production line operators. The beginnings of production are already in CAD programs, where a drawing with functional characteristics and dimensional tolerances was created. On the basis of the customer's drawing, was designed with the appropriate extrusion mold, thanks to which he will give the gasket the desired shape that meets the drawing requirements with an accuracy of 1 mm. When all machines and tools were prepared along the production line, this was initiated proces of manufacturing under the supervision of a team of specialists.

The metal was stretched using a roller system, which is the skeleton of the gasket cross-section. At the same time, rubber compounds were taken from the containers for extruders under the set pressure and temperature. The rubber is transported through the moulds and the seal is given the right shape. The next step is an alternating vulcanization process in furnaces and cooling in cooling baths. Thanks to such operation, the correct properties of the product were obtained. After verification that the vulcanization process was successful, the product is subjected to laser firing of vent holes and in the laser printerit burns the appropriate identification print. Then, using the special cut machine with programm the product was cut into pieces of appropriate length. The final stages are thermal bonding of the product, final inspection and packaging.

One of the profiles belonging to the design of products from the Z group requires an additional operation, which is the stiffening process, called the process X. This product is called with the Y profile and it is a gasket for trunk doors. Due to its purpose, it has a longer dimension than other profiles, which is why it requires strengthening. For this purpose, in a defined place, a special tool is made about the incision. Previously prepared with a stiffening element, for this purpose cut by it into drawing lengths and glue it at one end, which allows it to be placed inside the product. In addition, it is a solution that facilitates the process X. The process X itself requires manual skills and precision. The stiffening element islocated through the cut hole, then with the appropriate material it is dried at the incision site and glued together with quick-drying glue. The final stage is visual inspection and packaging of the gasket into serial packaging according to the defined packaging instructions of the finished product.

2.5. Research methodology

The start in Six Sigma began with a start with measurements and collecting the results of analyzes obtained from them. First of all, it is necessary to determine: parameters, places and methodology of measurements. These are the decisive points for the quality, process and cost of the organization. Methodology is a meticulous representation of the actual state. Collecting the results from the measurements is the basis for the analysis of the process in the verified research project. The conclusions drawn on the basis of the assessment are a factor for the implementation of corrective actions and then a plan for continuous improvement. The continuous duration of this process is due to the repetitive circus of the stairs (Fig. 1).

To analyze the research problem, the Six Sigma methodology based on the phases of the DMAIC cycle, i.e. Define, Measure, Analyse, Improve and Control, was used.

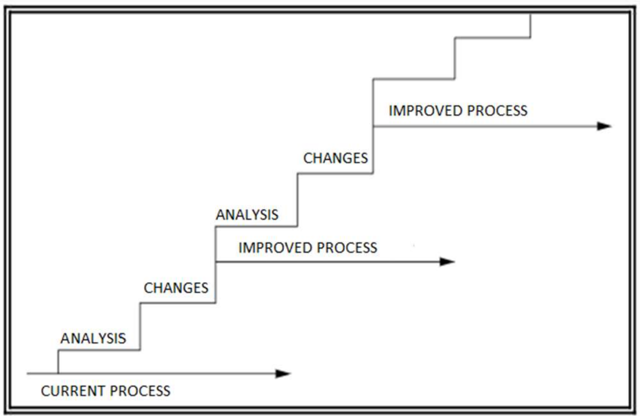


Figure 1. Map of the way of improvement.

In the first of these phases:

- a project card has been prepared to define the problem,
- the process under investigation has been identified on the basis of the SIPIOC method,
- milestones and project costs have been established.

In the next phase:

- a data collection plan has been defined,
- a preliminary analysis of the collected data was carried out,
- it has been checked whether the current measurement system is functioning correctly.

The Analysis phase of the Six Sigma project concerned:

- from defining the current process capacity,
- identification of the root cause when using various Six Sigma tools.

In the fourth phase of the SS project under discussion:

- initial improvements to the process in question have been made,
- a plan of corrective actions has been developed,
- FMEA analysis of potential improvements was performed.

During the Control phase:

- an audit plan has been drawn up,
- re-collected from the process,
- the implemented improvements were assessed on the basis of the current capacity of the process.

3. Implementation of the Six Sigma methodology for process analysis – case study

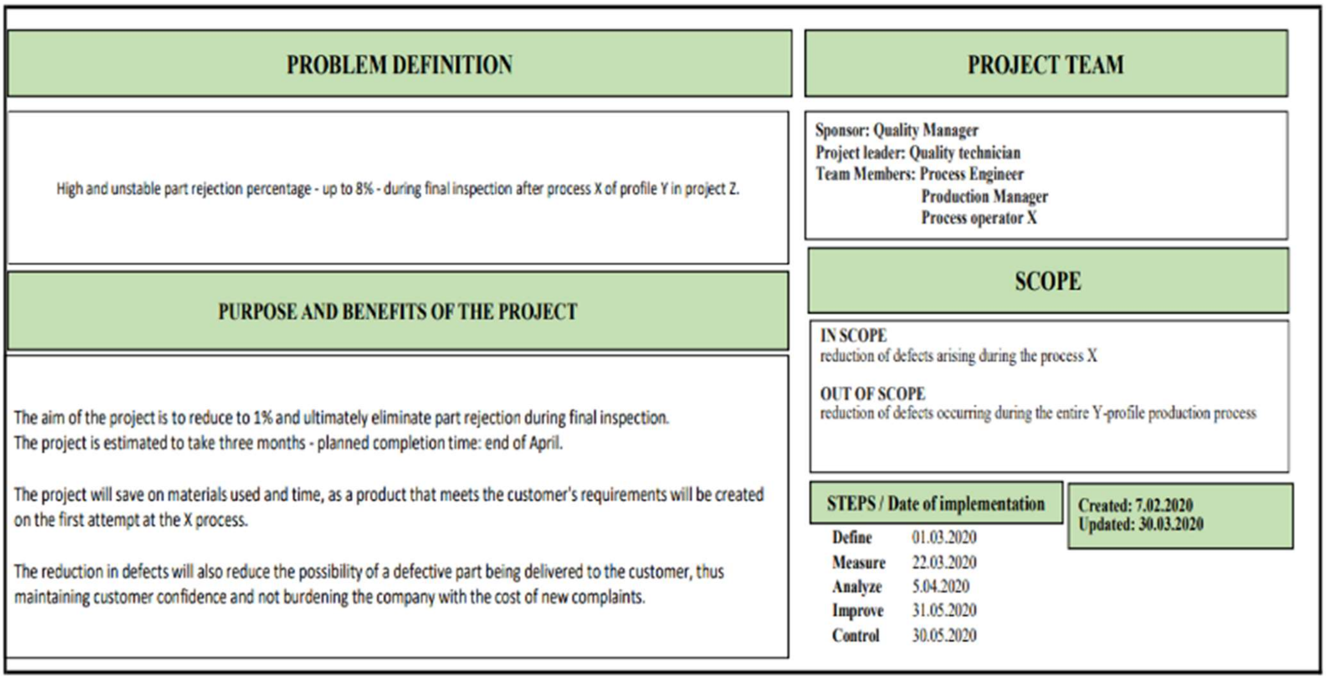
3.1. The Six Sigma Project – faza definition

The first activity of the project team was to define the problem to be faced – the preparation of a Project charter. Project charter, otherwise known as the

Project Charter, is a description of the problem in a way that everyone can understand, facilitates communication between team members as well as other interested parties who may have their share in the project. The project charter should be as precise as possible. It consists of the following elements (Fig. 2):

- define a problem,
- define a specific goal,
- setting the expected goals,
- define constant process with which the problem is associated,
- selection of appropriate team members,
- define project milestone amine.

During the first phase of the DMAIC cycle was also defined SIPOC, in which individual letters are an abbreviation of English words, successively: suppliers, inputs, process, outputs, customers. This tool illustrates the process that has been analysed and will enable team members to unanimously define the results and aspects that can have an impact in the search for strengths and weaknesses in the research project (Figure 3).



PROBLEM DEFINITION

High and unstable part rejection percentage - up to 8% - during final inspection after process X of profile Y in project Z.

PURPOSE AND BENEFITS OF THE PROJECT

The aim of the project is to reduce to 1% and ultimately eliminate part rejection during final inspection.
The project is estimated to take three months - planned completion time: end of April.

The project will save on materials used and time, as a product that meets the customer's requirements will be created on the first attempt at the X process.

The reduction in defects will also reduce the possibility of a defective part being delivered to the customer, thus maintaining customer confidence and not burdening the company with the cost of new complaints.

PROJECT TEAM

Sponsor: Quality Manager
Project leader: Quality technician
Team Members: Process Engineer
Production Manager
Process operator X

SCOPE

IN SCOPE
reduction of defects arising during the process X

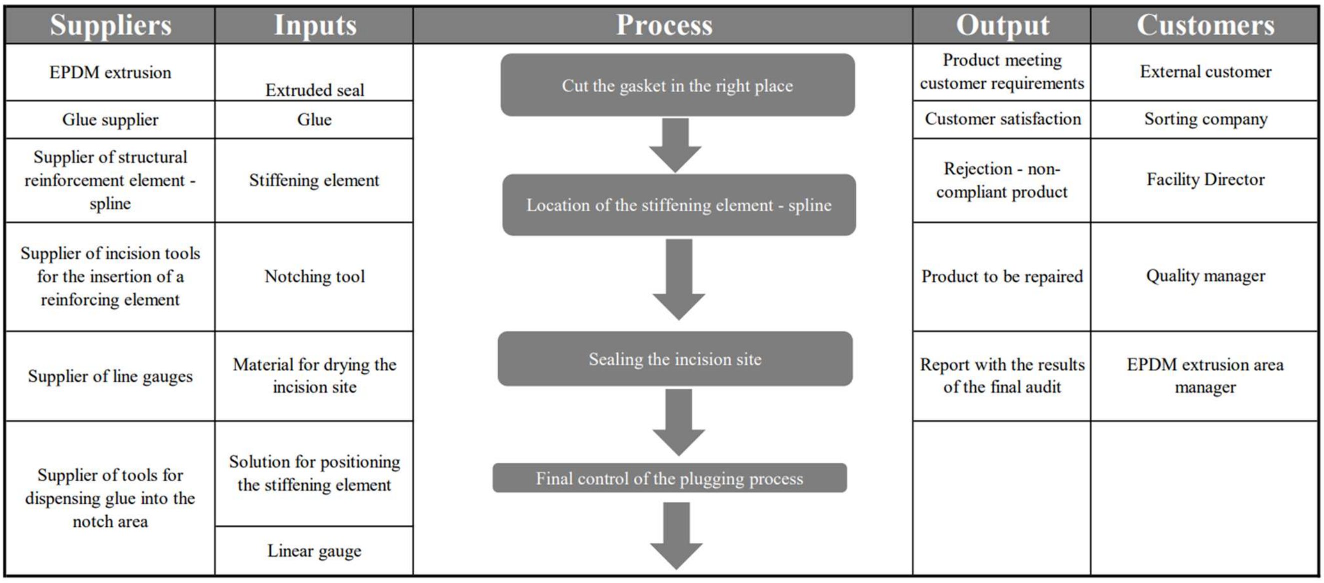
OUT OF SCOPE
reduction of defects occurring during the entire Y-profile production process

STEPS / Date of implementation

Define	01.03.2020
Measure	22.03.2020
Analyze	5.04.2020
Improve	31.05.2020
Control	30.05.2020

Created: 7.02.2020
Updated: 30.03.2020

Figure 2. Project card for the issue under consideration



Suppliers	Inputs	Process	Output	Customers
EPDM extrusion	Extruded seal	Cut the gasket in the right place	Product meeting customer requirements	External customer
Glue supplier	Glue		Customer satisfaction	Sorting company
Supplier of structural reinforcement element - spline	Stiffening element	Location of the stiffening element - spline	Rejection - non-compliant product	Facility Director
Supplier of incision tools for the insertion of a reinforcing element	Notching tool		Product to be repaired	Quality manager
Supplier of line gauges	Material for drying the incision site	Sealing the incision site	Report with the results of the final audit	EPDM extrusion area manager
Supplier of tools for dispensing glue into the notch area	Solution for positioning the stiffening element	Final control of the plugging process		
	Linear gauge			

Figure 3. SIPOC of this Six Sigma project

In the first phase of the streamlining projects, a tool called the voice of the customer was also used. Taking into account that these are opinions of a general nature, it is important to specify the customer's requirements to which these opinions relate on the basis of the collected data. The precise, measurable requirements in question are called CTQ (Critical to Quality), in other words, product properties or process parameters that are critical to the customer – having a significant impact on his approval (Table 1).

Table 1. Defined CTQ in a Six Sigma project

CTQ	
percentage of non-compliant products	Feature of the process
percentage value of products that do not comply with customer requirements	Measure
max 1% of non-compliant products	Target
99% probability that 1% of non-compliant products will appear	Required result

CTQ is also presented using another form – elements in the form of a tree (Fig. 4).

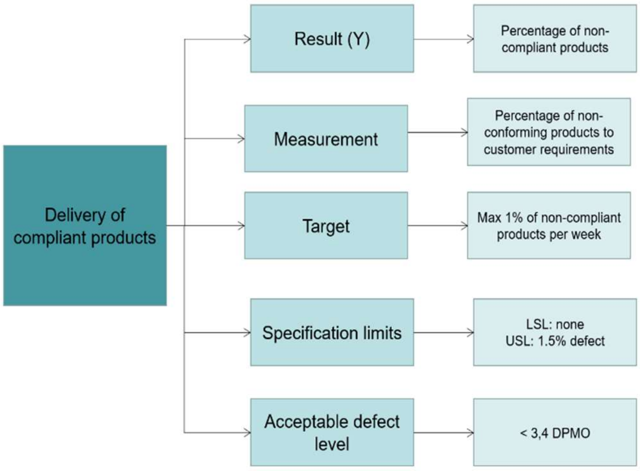


Figure 4. CTQ tree of the improvement project in question

3.2. Six Sigma project – measurement phase

In order to achieve the expected values of the number of non-compliant parts during the final inspection after the X process, data was collected, which was collected from the 39th week of 2020 to the end of this year. On the basis of this information, such defects as: incorrect seal joining, visible metal part, displacement of the edge of the gasket at the place of joining, incorrect gluing of the incision site, impurities, lumps, foreign bodies, gasket deformation, bad identification labels, visible metal part at the place of joining and others were distinguished.

Table 2. Collected data on defects in 2020

% of recoil	71 456	Controled parts	Results
3,18%	2 269	NOK parts	
30,41%	690	Incorrect gasket connection	Defect names
0,00%	0	Visible metal part	
2,51%	57	Offset on gasket connection	
51,17%	1161	Incorrect gluing of the incision	
11,90%	270	Pollution	
0,40%	9	Papules	
0,75%	17	Foreign body	
1,28%	29	Deformed gasket	
0,22%	5	Wrong label	
0,48%	11	Visible metal part	
0,84%	19	Other	

With the help of Pareto-Lorenz diagram, they show that the greatest deficiencies can be observed during the stage of gluing the incision site, necessary to carry out the X process. Thanks to the use of this diagram, the defect that generated the largest number of rejected parts was selected and further design steps were focused on its improvement.

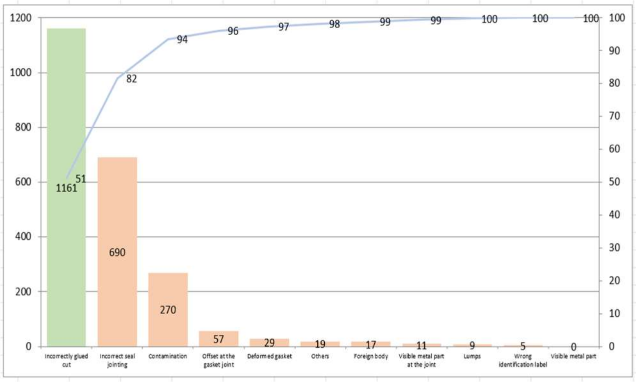
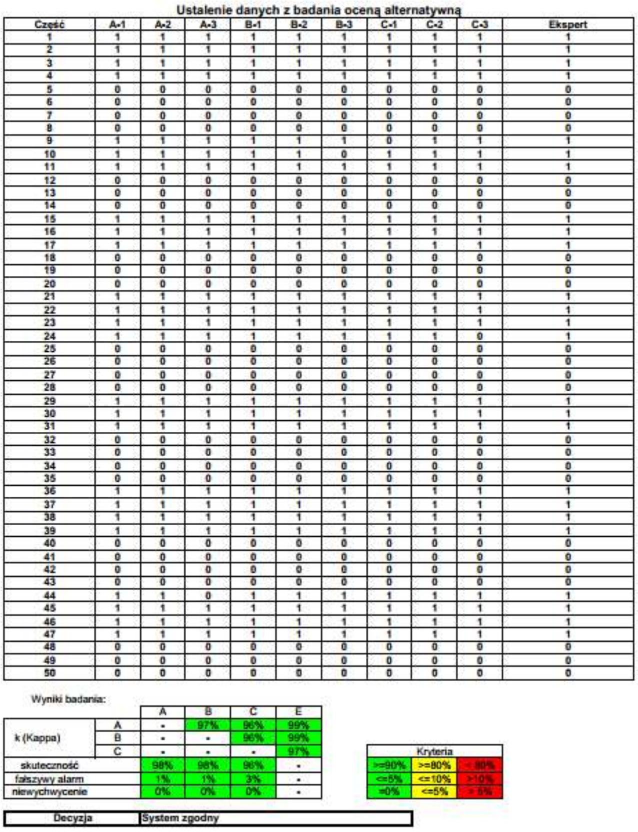


Chart 1. Pareto diagram – Lorenz defects during process X for results from the second half of last year

In order to go through this stage of analysis and then process improvement, it was necessary to verify whether the current measurement system, which is the pattern control of defects, works correctly. For this purpose, a system analysis was carried out using the Kappa method of MSA testing for attribute data. The studywas attended by 3 operators and an expert. Each member of the study had the task of verifying 50 finished products on a NOK/OK basis by visual inspection, assuming that half were OK and the other half were NOK. The products were given three times for inspection in random order. Then, the results of the operators were compared with an expert (Table 3).

Table 3. Results of MSA analysis by Kappa method



Ustalenie danych z badania oceną alternatywną

Część	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	Ekspert
1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	1	1	1	1	1	1	0	1	1	1
10	1	1	1	1	1	0	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	0	1
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	1	1	1	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1	1	1	1
31	1	1	1	1	1	1	1	1	1	1
32	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0
36	1	1	1	1	1	1	1	1	1	1
37	1	1	1	1	1	1	1	1	1	1
38	1	1	1	1	1	1	1	1	1	1
39	1	1	1	1	1	1	1	1	1	1
40	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0
44	1	1	0	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	1	1	1
46	1	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	1	1	1
48	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0

Wyniki badania:

		A	B	C	E
k (Kappa)	A	-	97%	96%	99%
	B	-	-	96%	99%
	C	-	-	-	97%
skuteczność		98%	98%	96%	-
fałszywy alarm		1%	1%	3%	-
niewychwycenie		0%	0%	0%	-

Kryteria		
>=90%	>=80%	< 80%
<=5%	<=10%	>10%
=0%	<=5%	> 5%

Decyzja	System zgodny

The success of a streamlining project depends mainly on the definition of the method of conducting the research, its appropriatebymeasures and procedures. All attributes used must be adequate to the assumed improvement of the critical feature. To this end, it will draw up the so-called Data Collection Plan taking into account the elements in question (Table 4).

Table 4. Data collection plan for the implemented improvement project

CTQ	Adequate % of non-compliant products during process X
Variable	% of product waste
Measure type	N/A
Data type	Quantities of NOK pieces, attribute data
Operational definition	Daily data at the process station X collected every day, on each shift, the number of PIECES OF SAI for each container with 88 pieces is stored
Measurement procedure	Visual assessment of the ART OF NOK/OK Measurement is made by each change – measurement is made after operation X – measurement is made by the person responsible for the final control – the measurement is recorded on the data collection sheet
Measuring system	The measurement is made by visual method by the final inspection operator at the X operation station
Measurement unit	Pieces OK./NOK
Sampling time	Period of 6 months – from week 39
Sample size	Any process X
X	The operator who evaluates the attribute data. The change on which the attribute data is collected. The date on which the data was retrieved.

Having confirmed the effectiveness of the measurement system, it was determined that the data will be collected after the improvements for the next 8 weeks according to a team-defined data collection sheet.

3.3. Six Sigma Project – Analysis Phase

The following are the results of the % recoil of non-compliant parts in the weeks in which the production process of the Y-profile took place (chart 2).

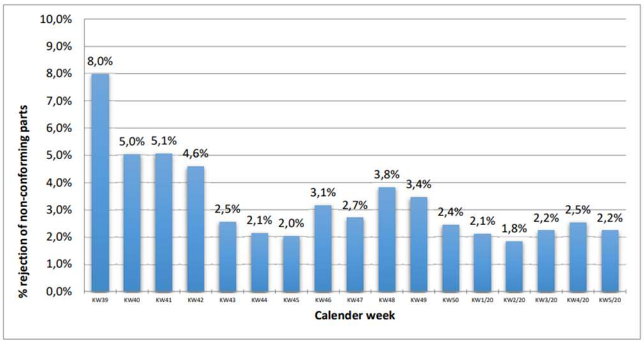


Chart 2. Weekly final inspection results during process X for results from the second half of last year

During the eight-week inspection, decrease in the level of recoil was observed compared to week 39, but it is still not a target value, as it fluctuates between 1.8% – 3.8%. Taking into account the results so far, the current capacity of the process was calculated. To calculate it with the attribute CTQ, use:

- Sample size: 71456, i.e. 812 containers of 88 pieces in each,
- Measures of process capability:
  - ✓ % defects = 3.18%,
  - ✓ Number of critical characteristics per unit = = 11,
  - ✓ DPU = 8,8,
  - ✓ DPMO = 31754,
  - ✓ Process Sigma Level = 3.4.

In this step a project team was organized in order to brainstorm the root causes of the problem.

The Ishikawa cause and effect diagram, otherwise known as "fish bone", is a popular quality management tool that allows you to learn about the inconsistencies occurring at the workplace in question and specify the root cause of the problem. Project teams often use them because it standardizes thoughts – the schematic fish bone graphically presents the relationships between the causes and their hierarchy, which results in a chronological and logical ordering of the factors causing the problem. This diagram should be handled using the following steps:

1. Defining the problem.
2. Determination of the category of causes.
3. Brainstorming the factors in each category.

Actions should begin with the collection of data on the occurrence of a defect or deviation in the process. This is a necessary operation to identify the root cause of the problem. An inherent element of this tool is the selection of a working group that will jointly analyze this problem, including operators who deal with the manufacturing process on a daily basis – this will facilitate accurate and clear determination of the sub-incompatibility.

In this improvement project based on an earlier analysis using the Pareto-Lorenz diagram , it is known that the largest percentage of rejected parts during the final inspection has a disadvantage: incorrect gluing of the incision site. It is understood as: a cracking incision place, or an unsightly gluing of this place – an excess of glue. Ishikawa's diagram (Fig. 5) showed that this problem is influenced by many different aspects. By giving the reason a weight according to the scale: 8, 6, 4, 2 and 1, with the assumption that each digit can be used once, the project team assigned them to the reasons, as follows:

8 – do not dry the gasket at the incision site
6 – glue stored in inappropriate conditions
4 – failure to act according to the standard of work
2 – inappropriate method of gasket incision
1 – lack of employee control during operation X

Thanks to this classification, the project team was able to focus improvement activities on those root causes that have the most significant impact.

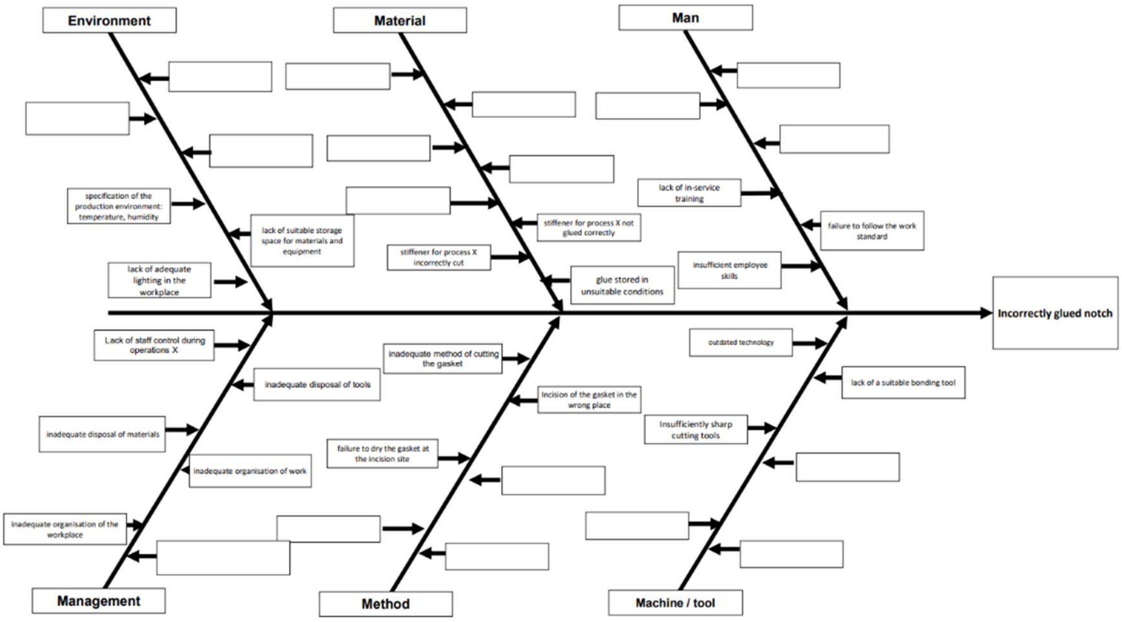
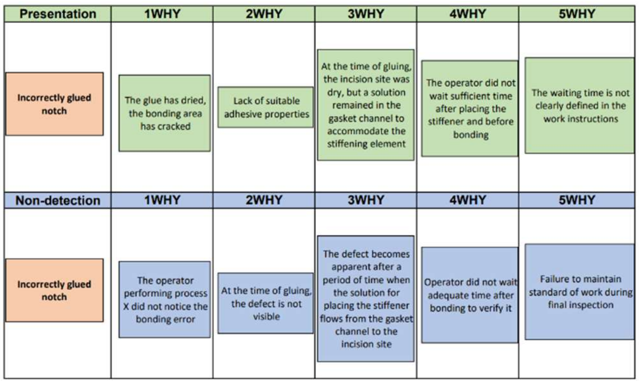


Figure 5. Ishikawa cause-and-effect diagram

After the Ishikawa cause-and-effect diagram was completed, an analysis was performed using a technique called 5WHY. The statement should be based on two grounds, i.e. the cause of the occurrence and the reason for not detecting the error. The firstfactor defines the reason why the defective product was manufactured, so the technological approach was used in this case. The second factor concerns the method of control, the group examining the case wonders why, despite the supervision of the process, the error was not detected in the standard procedure.

A similar scheme of action was used in the discussed research problem, which is why the nextyear was to use the 5WHY technique to understand why the defect, which is the incorrect gluing of the incision, arose. This problem was considered in two planes, i.e. in the aspect of the occurrence of errors and then in the sphere of not finding this error during visual inspection (Fig. 6). During the use of the 5WHY technique, it was shown that source deficiencies were found already in the work manual and the standard of work performed by the final control operator.



Presentation	1WHY	2WHY	3WHY	4WHY	5WHY
Incorrectly glued notch	The glue has dried, the bonding area has cracked	Lack of suitable adhesive properties	At the time of gluing, the incision site was dry, but a solution remained in the gasket channel to accommodate the stiffening element	The operator did not wait sufficient time after placing the stiffener and before bonding	The waiting time is not clearly defined in the work instructions
Non-detection	**1WHY**	**2WHY**	**3WHY**	**4WHY**	**5WHY**
Incorrectly glued notch	The operator performing process X did not notice the bonding error	At the time of gluing, the defect is not visible	The defect becomes apparent after a period of time when the solution for placing the stiffener flows from the gasket channel to the incision site	Operator did not wait adequate time after bonding to verify it	Failure to maintain standard of work during final inspection

Figure 6. The use of the 5WHY technique for the problem under consideration

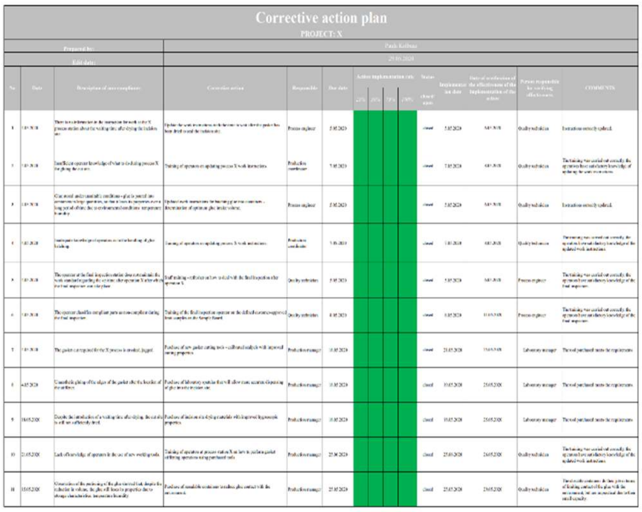
3.4. Six Sigma Project – Improvement Phase

On the basis of the analysis, the following reasons were selected in the improvement process:

- not drying the gasket at the place of incision,
- glue stored in inappropriate conditions,
- lack of compliance with the standard of work,
- inadequate method of incision of the gasket,
- lack of employee control during operation X.

Meetings of the working group allowed forthe organizationof the Planat corrective actions (tab. 5).

Table 5. Corrective action plan for improving process X



Corrective action plan
PROJECT: X

The Corrective Action Plan defines 11 corrective actions to improve process X. The main process activities are the replacement of tools intended for operation X, and then training operators in the standard of work at the workplace using these instruments. In addition, final inspection operators were reminded of the rules and boundary samples categorizing finished products as compliant and non-compliant.

In addition, the FMEA was updated during this phase of the Six Sigma project. This tool allows you to prevent the occurrence of non-compliance in the production process. In addition to identifying errors, it allows you to determine the risk they are burdened with. Errors include both the finished product and the manufacturing process. Knowing the cause that caused the problem, you can limit its occurrence or completely eliminate it. This method can also be used to understand and analyze risks already at the product and process planning stage. Below are the possibilities of using this method:

- development of new projects,
- process optimization,
- start of production in the series,
- elimination of process variability.

The purposeof the FMEA is to constantly look for errors that can occur for both the product and the manufacturing. Knowing the potential threat, preventive actions are taken that will minimize or completely eliminate the cause of the probable error. This results in the continuous improvement of the company's activities in the areas that are covered by the above activities. The essence of using FMEA is to isolate and understand the factors affecting the problematic fulfillment of specificationand technical requirements or the stability of the manufacturing process.

When using FMEA, a group of several people usually from 4 to 8 uses a scheme of action (Fig. 7).

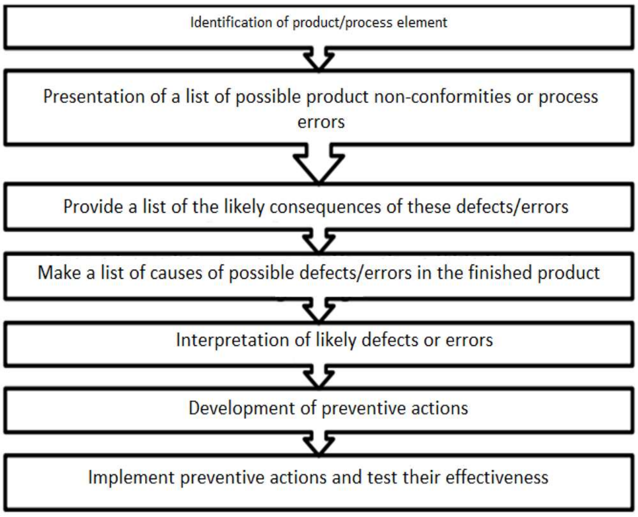
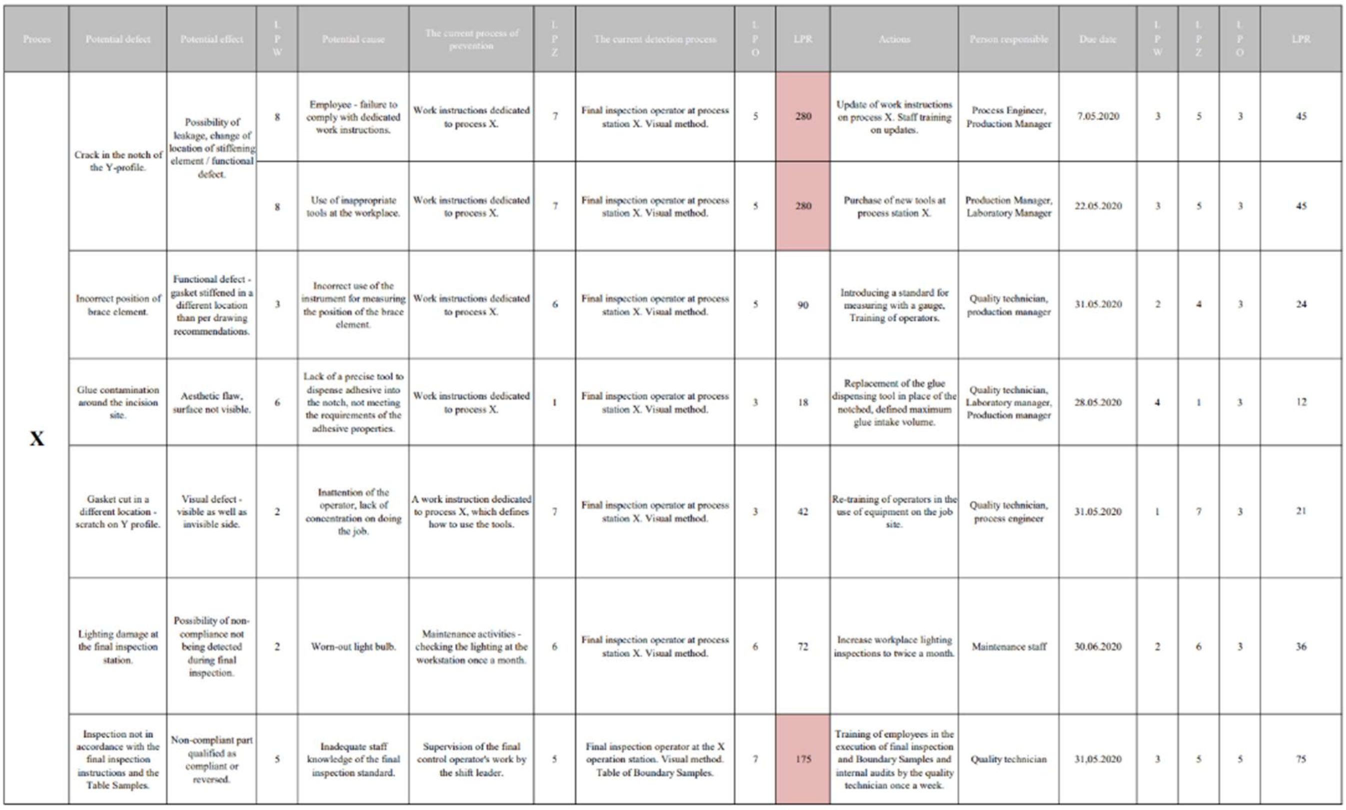


Figure 7. FMEA operation diagram

Knowing the area of occurrence of the error, actions were taken to identify other possible defects and their effects. The existing security system was classified in terms of preventing and detecting these potential errors. The FMEA method was used for this purpose. The disadvantages with the highest number of LPR are the crack at the gluing site and the final inspection not in accordance with the standard of work (tab. 6).

Table 6. FMEA for process X

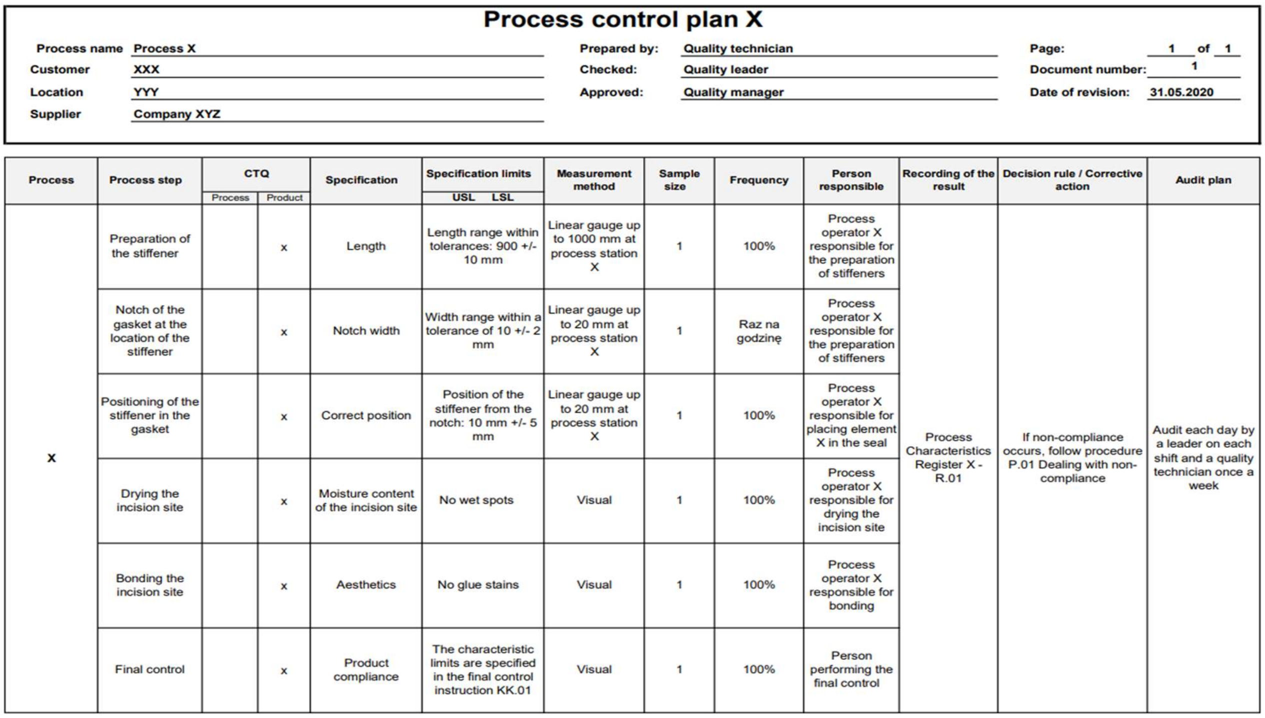


Proces	Potential defect	Potential effect	LPW	Potential cause	The current process of prevention	LPZ	The current detection process	LPO	LPR	Actions	Person responsible	Due date	LPW	LPZ	LPO	LPR
X	Crack in the notch of the Y-profile.	Possibility of leakage, change of location of stiffening element / functional defect.	8	Employee - failure to comply with dedicated work instructions.	Work instructions dedicated to process X.	7	Final inspection operator at process station X. Visual method.	5	280	Update of work instructions on process X. Staff training on updates.	Process Engineer, Production Manager	7.05.2020	3	5	3	45
			8	Use of inappropriate tools at the workplace.	Work instructions dedicated to process X.	7	Final inspection operator at process station X. Visual method.	5	280	Purchase of new tools at process station X.	Production Manager, Laboratory Manager	22.05.2020	3	5	3	45
	Incorrect position of brace element.	Functional defect - gasket stiffened in a different location than per drawing recommendations.	3	Incorrect use of the instrument for measuring the position of the brace element.	Work instructions dedicated to process X.	6	Final inspection operator at process station X. Visual method.	5	90	Introducing a standard for measuring with a gauge. Training of operators.	Quality technician, production manager	31.05.2020	2	4	3	24
	Glue contamination around the incision site.	Aesthetic flaw, surface not visible.	6	Lack of a precise tool to dispense adhesive into the notch, not meeting the requirements of the adhesive properties.	Work instructions dedicated to process X.	1	Final inspection operator at process station X. Visual method.	3	18	Replacement of the glue dispensing tool in place of the notched, defined maximum glue intake volume.	Quality technician, Laboratory manager, Production manager	28.05.2020	4	1	3	12
	Gasket cut in a different location - scratch on Y profile.	Visual defect - visible as well as invisible side.	2	Inattention of the operator, lack of concentration on doing the job.	A work instruction dedicated to process X, which defines how to use the tools.	7	Final inspection operator at process station X. Visual method.	3	42	Re-training of operators in the use of equipment on the job site.	Quality technician, process engineer	31.05.2020	1	7	3	21
	Lighting damage at the final inspection station.	Possibility of non-compliance not being detected during final inspection.	2	Worn-out light bulb.	Maintenance activities - checking the lighting at the workstation once a month.	6	Final inspection operator at process station X. Visual method.	6	72	Increase workplace lighting inspections to twice a month.	Maintenance staff	30.06.2020	2	6	3	36
	Inspection not in accordance with the final inspection instructions and the Table Samples.	Non-compliant part qualified as compliant or reversed.	5	Inadequate staff knowledge of the final inspection standard.	Supervision of the final control operator's work by the shift leader.	5	Final inspection operator at the X operation station. Visual method. Table of Boundary Samples.	7	175	Training of employees in the execution of final inspection and Boundary Samples and internal audits by the quality technician once a week.	Quality technician	31,05.2020	3	5	5	75

3.5. Six Sigma Project – Control Phase

After the introduction of improvement activities, a process control was carried out according to the Control Plan (Table 7).

Table 7. Control plan for process X



Process control plan X

Process name	Process X	Prepared by:	Quality technician	Page:	1 of 1
Customer	XXX	Checked:	Quality leader	Document number:	1
Location	YYY	Approved:	Quality manager	Date of revision:	31.05.2020
Supplier	Company XYZ				

Process	Process step	CTQ		Specification	Specification limits	Measurement method	Sample size	Frequency	Person responsible	Recording of the result	Decision rule / Corrective action	Audit plan
		Process	Product		USL LSL							
X	Preparation of the stiffener		x	Length	Length range within tolerances: 900 +/- 10 mm	Linear gauge up to 1000 mm at process station X	1	100%	Process operator X responsible for the preparation of stiffeners	Process Characteristics Register X - R.01	If non-compliance occurs, follow procedure P.01 Dealing with non-compliance	Audit each day by a leader on each shift and a quality technician once a week
	Notch of the gasket at the location of the stiffener		x	Notch width	Width range within a tolerance of 10 +/- 2 mm	Linear gauge up to 20 mm at process station X	1	Raz na godzinę	Process operator X responsible for the preparation of stiffeners			
	Positioning of the stiffener in the gasket		x	Correct position	Position of the stiffener from the notch: 10 mm +/- 5 mm	Linear gauge up to 20 mm at process station X	1	100%	Process operator X responsible for placing element X in the seal			
	Drying the incision site		x	Moisture content of the incision site	No wet spots	Visual	1	100%	Process operator X responsible for drying the incision site			
	Bonding the incision site		x	Aesthetics	No glue stains	Visual	1	100%	Process operator X responsible for bonding			
	Final control		x	Product compliance	The characteristic limits are specified in the final control instruction KK.01	Visual	1	100%	Person performing the final control			

Control of action for 4 weeks. The results were recorded in the Final Control Sheet. After week 4, the results were collected and the percentage of recoil of non-compliant parts was calculated. Again, withthe help of the Pareto-Lorenz diagram, the dominant defect that has the greatest impact on the % of recoil during the final control is shown (chart 3).

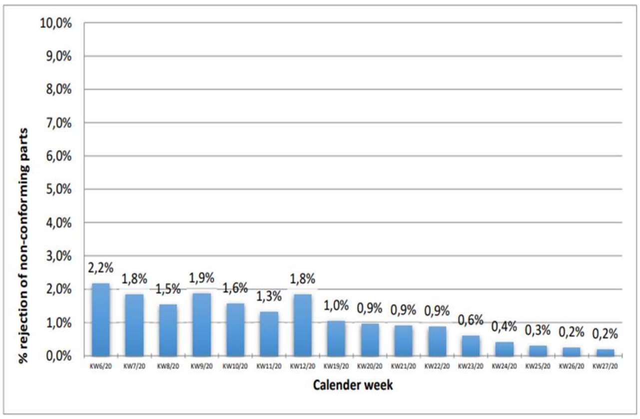


Chart 3. Results of the final inspection in weeks 6–27 of 2021

The results from the final control from the 6th week of 2021 were summarized (Table 8) and the Pareto-Lorenz diagram (chart 4) was made on their basis. It shows that this time the dominant defect is the incorrect gluing of the incision.

Table 8. Results of the final inspection for process X in weeks 6–27 of 2021

% of recoil	45 245	**Controled parts**	**Results**
1,03%	465	**NOK parts**	
30,32%	141	**Incorrect gasket connection**	**Defect names**
0,00%	0	**Visible metal part**	
10,54%	49	**Offset on gasket connection**	
38,92%	181	**Incorrect gluing of the incision**	
3,87%	18	**Pollution**	
0,00%	0	**Papules**	
0,00%	0	**Foreign body**	
0,43%	2	**Deformed gasket**	
0,00%	0	**Wrong label**	
0,22%	1	**Visible metal part**	
1,94%	9	**Other**	

Taking into account the results so far, the current capacity of the process was calculated. To determine it with the attribute CTQ, use:

- Sample size: 45245, i.e. 514 containers of 88 pieces in each
- Measures of process capability:
  - ✓ % defects = 1.03%,
  - ✓ Number of critical characteristics per unit = = 11,
  - ✓ DPU = 12,6,
  - ✓ DPMO = 9548,
  - ✓ Process Sigma Level = 3.8,

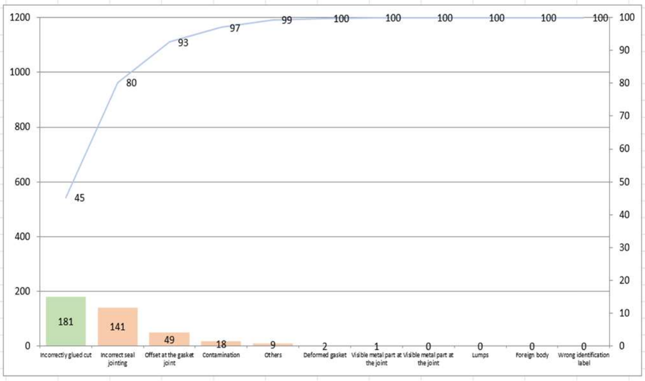


Chart 4. Pareto– Lorenz diagram of defects during process X for results in weeks 6–27 of 2021

4. Conclusions

The purpose of this study on the use of the Six Sigma methodology in process improvement in one of the selected companies was to present the possibilities of improving the manufacturing process in enterprises using the Six Sigma methodology. The implementation of this goal required analytical research to implement a project improving the process of manufacturing a rubber product. The selected problem concerned one of the stages of production, namely it was the stage of strengthening the product structure in the X process.

According to the described Six Sigma methodology and the assumptions of the DMAIC cycle, the project consisted of the following steps:

- DEFINE,
- MEASURMENT,
- ANALYZE,
- IMPROVE,
- CONTROL.

In each of the steps of the DMAIC cycle, many methods and tools characteristic of this methodology were used. The aim of the project was to reduce the percentage of recoil of non-compliant parts during the final inspection, which verifies the stiffening process, called the X process.

Comparing the final result that was obtained from the period of the 39th week of 2020 to the 6th week in 2021 with the result from the period after the implementation of corrective actions, it can be concluded that the project carried out brought the expected results. The percentage of recoil fell from 3.18% to 1.03%. The sum of non-compliant parts from the second half of 2020 is 2269, with as many as 1161 falling into the category of defect, which was incorrect gluing of the incision site and accounted for more than half of all rejected parts, i.e. 51.17%, and the sigma level was 3.4. In weeks 6 to 27 in 2021, a lower percentage recoil of non-compliant parts can be observed during the final inspection. During this period, the sum of rejected non-compliant pieces was 465, where for the defect incorrect glued notch the result was 181, the percentage share of this category of defects to the total gives a result of 38.92%, which means that it shows a downward trend and decreased by 12%, the sigma level for this result is 3.8.

The improvement measures carried out were appropriate and allowed to reduce the weekly recoil of non-compliant parts by 8% to 0.2%. Activities related to updating documents, training andequipping the organization with equipment were carried out efficiently. The purchase of lockable containers with a smaller capacity used to store a sufficiently small volume of glue in them, which was intended to ensure a longer usefulness of the glue, was not a good solution. The containers are too small and thus make it difficult for operators to work, as the need to take glue from the chemical warehouse increases several times. In addition, a common case is the loss of caps and the glue containers themselves due to their small size. Therefore, it was decided to leave the existing containers taking into account the collection of smaller volumes of glue.

The charts of weekly discards tend to decrease, in my opinion, carrying out the inspection for the next 4 weeks would bring even better results than before.

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