APPLICATION OF SIX SIGMA TOOLS IN THE PRODUCTION OF WELDED CHASSIS FRAMES

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One of the most important activities in the management of companies is the continuous improvement of products quality concerning their sustainability and better market position. The submitted paper aims to optimise the production process in the production of weldments. The study revealed a significant number of dimensional and threaded defects on the welded chassis of the loader. One possibility of continuously increasing the required performance of a company is to eliminate the number of non-conforming products using the tools of the Six Sigma methodology. This policy must be introduced by a company into the business processes management if a company wants to successfully meet the customers´ needs and improve the processes while cutting the costs of production. The resulting analysis focused on the selected type of defects to reduce their occurrence using the Six Sigma tools, specifically the DMAIC improvement cycle. The presented approach and the results obtained highlight the importance of applying quality tools in practice and their undeniable contribution in improving performance and quality, reducing the number of defects occurring and reducing the cost of poor quality in production, both now and in the future.

KEYWORDS

Six Sigma, Improvement Cycle, Lean Manufacturing, Weld, Defects

1 INTRODUCTION

In recent years, there has been increasing pressure from customers and competitors to improve quality requirements and reduce costs both in the production and services sectors. This has prompted many industries to adopt either Six Sigma as an improvement in their process and problem solving, or Lean Manufacturing to increase the speed of response to customer needs and overall costs reduction as a part of their management strategy to increase market share and maximize profit. Most large companies have achieved significant results in their organizations by implementing Lean or Six Sigma methodologies. The main objective of any organisation in the world is to use these strategies to help them achieve quality, required operational productivity and improve their performance.

Six Sigma is a data-driven approach using specific tools and methodologies that lead to fact-based decision-making. This is a continuous improvement to reduce process variability and eliminate waste.

The aim of the paper is to minimize one problem selected from several most common defects on a given product and also to maximize performance gain.

1.1 *Six Sigma application areas*

Today, there is broader adoption of Six Sigma in many organizations, focusing on minimizing variations, measuring defects and improving the quality of products, processes and services. In the mid-1980s, Motorola company designed Six Sigma as an approach to improve their production, productivity, quality and reducing operating costs. Its designation Sigma is taken from the Greek alphabet and, from the quality control point of view, Sigma (σ) is traditionally used to measure changes in the process or its output. [Krejci 2019], [Rahman 2018]

Six Sigma was originally used in production processes. Nowadays, this methodology can also be encountered in the fields of:

- Marketing,
- Management,
- Purchase,
- Logistics,
- Insurance,
- Psychology,
- Information technology, etc.

Virtually, it is used in all areas where the current situation or process needs to be improved. The Six Sigma approach begins with a business strategy and ends with a top-down implementation that has a significant impact on a company´s profit. Several literary sources and articles provide basic concepts and benefits of the Six Sigma methodology, such as its integration with Lean which can be seen in the picture below (Fig. 1). [Albliwi 2015], [Gijo 2011]

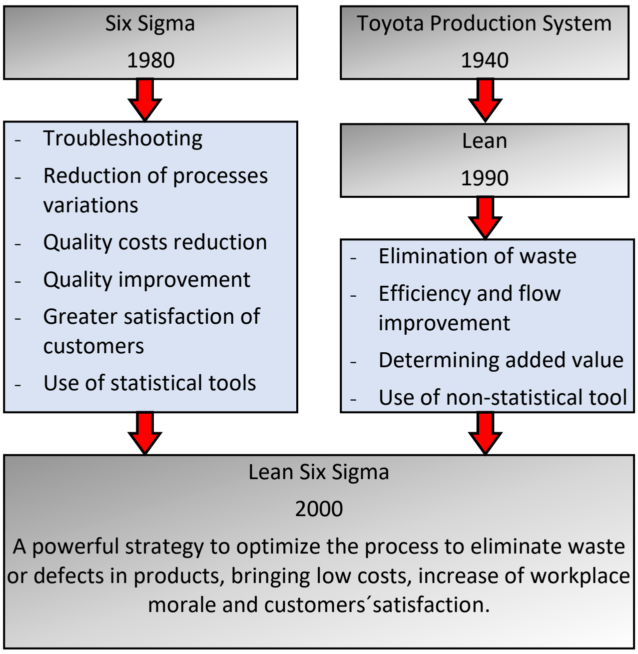

Figure 1. Integration of Six Sigma & Lean Manufacturing [Albliwi 2015]

This wide area of use can be confirmed according to available expert articles, where their authors applied the Six Sigma methodology in different areas. For example, [John and Kadadevaramath 2020] applied this methodology in the information technology industry, to improve the time-consuming nature of the applications support process. [John 2020] Another contribution (Guo et al. 2019) dealt with the optimisation of the air conditioner assembly line using the VSM-DMAIC model to improve economic benefits and reduce waste of production lines. [Guo 2019] The Six Sigma methodology was also used to reduce weld defects in valve components (Bharathi et al. 2017), resulting in a reduction in weld defects and significant financial savings for the company. [Bharathi 2017] The use of Six Sigma in the automotive industry is discussed in the papers of authors (Antony et al. 2012), who have implemented this methodology in a highly accurate and critical process of production of automotive parts. The result here was a significant financial impact on the company's profitability. [Antony 2012]

The systematic research of expert articles from 2000 to 2013 concerning the Lean Six Sigma was carried out by the authors of the paper (Albliwi et al. 2015), who studied the most common Lean Six Sigma (LSS) topics in the manufacturing sector and identify potential gaps that may prevent users from benefiting from their LSS strategy. This paper also identifies gaps in contemporary literature and develops an outline for future research into LSS topics. [Albliwi 2015]

2 LEAN SIX SIGMA APPLICATION

Lean and Six Sigma are two widely recognised strategies for improving business processes, currently available to organisations to achieve significant results in terms of cost reduction, times focused on process performance and quality improvement. More recently, both of these strategies have been used and are integrated into a more efficient and effective hybrid system, addressing many weaknesses and retaining most of the strengths of each strategy. In this case, we can talk about Lean Six Sigma, which resulted from the natural development of quality improvement processes in production companies. It combines the time-oriented strategy of the Lean Manufacturing methodology, helping to increase processes efficiency in terms of speed and costs, utilizing quality analytic tools from Six Sigma. It is based on the DMAIC methodology, which forms a core part of Six Sigma and serves in Lean Six Sigma primarily for projects to improve the already existing processes. [Kumar 2006], [Banuelas 2005]

2.1 DMAIC Cycle

The DMAIC Improvement Cycle is a data-driven quality strategy that is used to reduce defect or improve processes. It is an integral part of the Six Sigma initiative but can be generally implemented as a separate quality improvement process or as a part of other process-enhancing initiatives such as lean.

The DMAIC procedure applies to our project helping to find better tools and techniques used in the controlled line to reduce the number of defects. The method is defined by five phases (Tab. 1), designed for the successful implementation of a change or management of a project. [Marsikova 2018], [Rahman 2018]

Define	Measure	Analyse	Improve	Control
Start of a project	Defining	Providing graphical analysis	Finding and choosing the right solution	Process KPI settings
Project selection	Process mapping	Correlation	Design of solutions and risk review	Scheduling a process check
Building a project team	Planning data collection	Regression analysis	Implementing a change	Verification of improvement
Project plan	Verification of measuring systems	Root cause generation	Accepting a change	Project handover and termination
Specify the scope of a project	Collecting process data	Reduction of the root causes		
Collection of customer feedback	Calculation of eligibility			
Settings CTQ and project objectives	Identification of a quick win			
Identification of project risks and benefits				
Writing Project Charter				

Table 1. DMAIC improvement cycle phase [Rahman 2018]

3 CASE STUDY – IDENTIFICATION OF DEFECTS AND CORRECTIVE MEASURES IN THE PRODUCTION OF WELDED FRAMES

In the case study, the company dealt with the optimization of the production process using Six Sigma tools, specifically using the DMAIC methodology. To successfully implement this improvement cycle, it was necessary to correctly apply all five phases that this cycle contains. The aim was to minimise negative phenomena in the production of weldments, in particular, to reduce the number of defects occurring, as well as to reduce the cost of poor quality in production.

The military repair company in which this study was carried out is a state enterprise established by the Ministry of Defence, dealing with military and civilian production. Production is divided into three areas in the company, where two areas involve the production of military equipment and the third production area is intended for the civil sector, focusing on the production of upper and lower parts of the chassis intended for construction and road machinery. The production itself is further divided according to technological operations into material cutting and edging, workpiece and welding shop, paint shop and assembly, and repair shop of military equipment. [Bucko 2019], [Hofrova 2018]

The case study of this paper deals with the civilian part of the production, namely the production of the chassis frame for a German-branded wheel loader (Fig. 2). A significant number of different types of non-conformities were found on this product, which led to a requirement to reduce a certain type of defect. To analyse all the material defects, including their frequency, the team held a brainstorming meeting. The table below (Table 2) lists the significant types of these defects that occurred and may occur in the production of weldment within one year. [Krejci 2019], [Hofrova 2018]

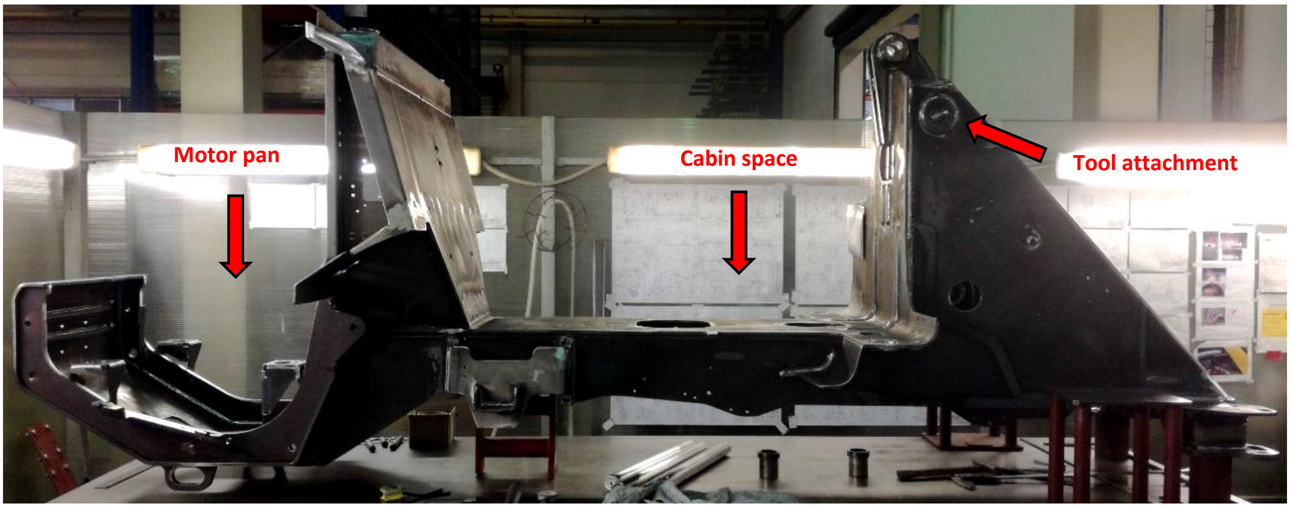

Figure 2. Wheel loader chassis weld [Hofrova 2018]

Type of defect	Number of defects per year [pcs]	Number of pieces to check [pcs]	Number of pieces returned [pcs]	% of returned pieces [%]
Non-compliant welds (A)	819	1085	610	56
Rear-axle perpendicularity (B)	33			
Symmetry (C)	6			
Non-pass-through thread (D)	390			
Non-compliant dimension (E)	260			
Missing part (F)	0			
Non-chamfered edges, weld spray (G)	81			
Obstruction of the control pin (H)	51			
Protruding bushings (I)	1			
SUM (∑)	1641			

Table 2. Types of defects on the chassis per year [Hofrova 2018]

The table shows (Tab. 2) that the largest proportion of defects resulting from the production of weldments consists of non-compliant welds, non-passable threads and also non-compliant dimensions. In the next part of the study, the identification of bottlenecks is further carried out using the individual phases of the DMAIC cycle.

3.1 Phase 1 – Define

Within the first phase of the cycle, a suitable project was identified to address the appropriate type of defect. Based on the brainstorming process, data was collected to create a project selection matrix (Tab. 3). This matrix contains an evaluation of the individual defects listed in the previous table (Tab. 2). The evaluation was based on criteria, to which their weight significance has been assigned (high – 9, medium – 3, low – 1). [Krejci 2019], [Hofrova 2018]

The table shows (Tab. 3) that the defect related to non-pass-through threads came out as the most suitable for the solution due to the number of occurrences. Another reason was also the fact that this defect was the cause of a large proportion of complaints from the customer. [Bharathi 2017]

Criteria	Weight	Type of defect								
		A	B	C	D	E	F	G	H	I
Time manageability (10 weeks)	9	3	1	1	9	1	1	1	1	1
Data availability	1	9	3	1	9	9	1	3	3	1
Team availability (resources)	9	1	1	1	3	1	1	1	1	1
System impact	3	1	1	1	3	3	1	1	1	1
Description of defects	1	1	1	1	9	1	1	1	1	1
Sponsorship	9	3	3	3	3	3	3	3	3	3
Demands of investments	3	3	3	3	3	3	3	3	3	3
Internal complaints	9	9	1	1	9	3	1	9	3	1
Customer complaints	9	3	1	1	9	1	1	1	1	1
Project support by production	3	1	1	1	3	1	1	1	1	1
SUM (∑)	-	196	82	80	342	112	80	154	100	80

Table 3. Matrix for project selection [Hofrova 2018]

Thus the production representatives were willing to support our project. Defects related to non-pass-through threads have been selected as the issue for our project to be solved. [Hofrova 2018]

The project was precisely planned, and it was determined what it would take to bring it in a given time. For this, the Gantt chart was used to graphically illustrate the planned sequences of all activities over time. The project team in charge of this project consisted of five members who met at regular intervals. The team included a project manager, principal investigator, controller, project owner and technologist. Identification of possible project risks included the emergence of another priority during the project solution, failure to find an acceptable technical solution to the problem or failure to allocate financial means for preventive measures.

The collection of information from the customer included data from complaints and e-mail communications. The customer partially recorded the missing threaded holes or missing threads in these holes. The reason why these defects were not detected in time within the production company before being dispatched to the customer was the fact that some of these parts were produced by a subcontractor. The cooperation was responsible for the work carried out and the company no longer caught these defects due to the non-existing inspection of the supplied products. An example of this customer claim is shown in the relevant figure (Fig. 3). [Krejci 2019], [Hofrova 2018]

Figure 3. Wheel loader chassis weld [Hofrova 2018]

Four critical characteristics have been defined for the quality (CTQ – Critical To Quality):

- CTQ 1: Minimizing the costs of poor quality from CZK 20, 000 to CZK 1,000.
- CTQ 2: Removal of defects in non-pass-through threaded holes.
- CTQ 3: Increase in First Pass Yield (FPY), the percentage of products that go through the process for the first time without disagreements from 40% to 95%.
- CTQ 4: Increase the percentage of products delivered at the required time from 60% to 80%. [Hofrova 2018]

3.2 Phase 2 – Measure

All threads have been numbered using a 3D model of the product. These numbers have been added to the table by the thread sizes and their location on the chassis. One piece of product contains a total of 300 threads. Data collection took place for five weeks at the quality inspection workplace. When the thread was detected as non-pass-through, its date of production, type and serial number was recorded to identify this defected part. [Hofrova 2018]

The eligibility calculation was provided using the number of defects per unit (DPU), with one unit being represented by one completed product. As a result, on average, some 1,094 defects were found on each product under inspection. Early detection of a defect in the project included cooperation notices concerning the missing threaded holes to the third party and training of a new employee on-the-job. [Krejci 2019]

3.3 Phase 3 – Analyse

From the available data, it was found that 85 pieces of chassis were checked during the reference time, of which 48 contained at least one defected non-pass-through thread. A total of 93 non-pass-through threads were detected. A Paret's analysis of the reasons for impassibility has been created (Fig. 4), where the most common reason for the impassability was a weld spray that contained balls in the thread. These threads defected by the weld spray (Fig. 5) were marked on the 3D model, finding out that these threads form certain "zones" (Fig. 6). [Bharathi 2017], [Bucko 2019]

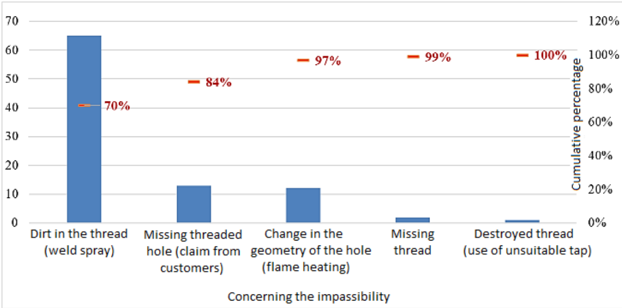

Figure 4. Paret's analysis concerning the impassibility [Hofrova 2018]

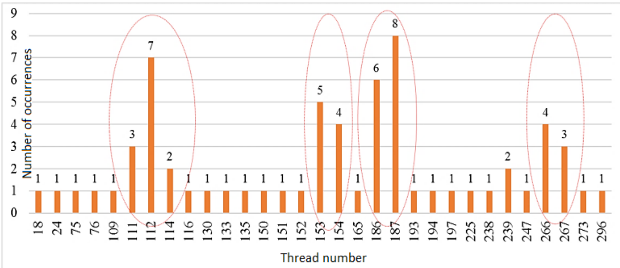

Figure 5. Number of impassable holes due to impurities [Hofrova 2018]

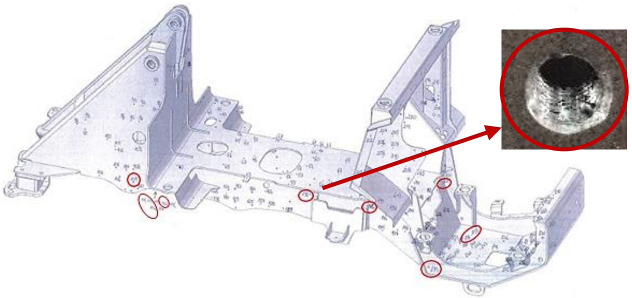

Figure 6. Weld spray zones [Hofrova 2018]

As a part of the analysis, for weld spray defects 5x Why? was carried out (Tab. 4). The second most common reason for a complaint was a completely missing threaded hole, which was detected by collecting information and letters of complaints from the relevant customer. The third most common defect was a change in the geometry of the hole, which was caused by the heating of the flame. There were also defects of the type of destroyed or completely missing thread when its destruction occurred by stretching the fine thread with a tap designed for a classic thread. [Krejci 2019], [Hofrova 2018]

The next step was to create Ishikawa using brainstorming, which was intended to detect any effects on the process related to changing the geometry on the given thread. This was due to a change in the geometry of the very same threaded hole.

Why?	Because
1. Why an incorrect welding method was used?	The worker did not use the correct welding method (instead of WIG he used CO2).
2. Why the worker did not use the correct welding method?	He/she did not have a technological procedure.
3. Why the worker did not have a technological procedure?	The worker did not attend a training course, where he/she would learn the procedure.
4. Why the worker did not attend a training course?	He was new and working on the night shift; training was planned for the afternoon shift workers.
5. Why the employee was allocated to the night shift without passing a training?	He was experienced, so he was given the confidence to take up the night shift immediately.

Table 4. Weld spray – 5 Whys method [Hofrova 2018]

As a result of applying the 5 Whys method (Tab. 4), it was found out why the problem occurred. The corrective actions have been identified and are included below.

3.4 Phase 4 – Improve

To improve thread impassibility due to weld spray, it was recommended to cover the threads in the marked zones. The threads can be covered with screws or plugs designed for the coverage. Remedial measures to eliminate the weld spray damages, resulting from the 5 Whys method (Tab. 4) were identified as [Bucko 2019]

1. Necessary entry training for new employees.
2. Visualization in the workplace.
3. Shadow chart – weld size engraving.
4. Supervision for the job.
5. Production check journal introduction.

According to the recommendation, a worker will know the correct size of the weld and the welding method. As part of the improvement, further training was organized for existing employees on the issue of choosing the appropriate type of tap for fine threads. They were further trained in terms of knowledge of thread holes, threads and weld size for the most frequently deformed thread. After these changes were introduced into the production, it was recorded that the problem with the faulty threaded holes on the weldment chassis is solved. The table with data collected before and after implementation of changes (Tab. 5) is shown below. As can be seen, the formation of non-pass-through threaded holes has been eliminated. [Hofrova 2018]

3.5 Phase 5 – Control

Based on the corrective measures taken, the formation of non-passable threaded holes was eliminated. The defined values of the key CTQ indicators contained in Project Charter were also met.

Results of four critical characteristics for quality **(CTQ – Critical To Quality):**

- CTQ 1: Reduction of the cost of poor quality from CZK 20,000 to CZK 0.
- CTQ 2: Elimination of defects of non-pass-through threaded holes to zero (Table 5).
- CTQ 3: Increase of FPY (eliminating the product due to the non-passing-through thread) from 40 % to 100 % (Fig. 7).
- CTQ 4: The percentage of products delivered to the customer increased from 60% to 85% at the required time.

Threaded parts were subjected to worker inspection, with the occurrence of non-pass-through holes being zero after the implementation of the improved processes. In terms of the zero incidences of this defect, it has been suggested that every third piece of thread will be inspected only.

Case study was handed over to the owner at a team meeting, where improvements were presented together with the results. The project was accepted by the owner and subsequently successfully terminated. It is important to provide a retrospective evaluation of the entire project team and their activities during the process of advancing the project itself. This retrospective evaluation subsequently helps to learn from potential errors occurring in the course of the closing project, which can be beneficial for any future project. [Hofrova 2018]

Production data collection	Monitored period	Number of pieces to check [pcs]	Number of pieces returned [pcs]	% returned pieces [%]	Type of defect
					Non-pass-through thread
Before implementing the changes	3.11. – 3.11.	5	2	40	4
	6.11. – 10.11.	27	17	63	11
	13.11. – 18.11.	28	18	64	12
	20.11. – 24.11.	31	17	55	14
	27.11. – 1.12.	27	20	74	25
	2.12. – 8.12.	39	30	77	21
	11.12. – 12.12.	9	5	56	2
After implementing the changes	3.1. – 5.1.	11	2	18	0
	8.1. – 12.1.	33	10	30	0
	15.1. – 19.1.	41	19	46	0
	22.1. – 26.1.	38	17	45	0
	29.1. – 2.2.	32	9	28	0

Table 5. Data comparison for implementing the changes [Hofrova 2018]

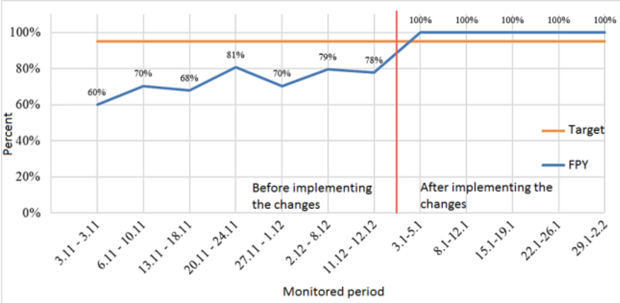

Figure 7. FPY for the monitored period [Hofrova 2018]

4 CONCLUSION

The problem solved by the paper was the obstruction of the threads. The issue of unsatisfactory welds on the product began to be necessary in the company to solve.

The results showed that a significant problem in the production was a defect in thread impassability when the main cause was weld spray, poor hole geometry or completely missing threaded hole. After the introduction of corrective measures, the impassability of the threads on the product was eliminated to zero. The values of the key CTQ indicators were met in such a way that the increase in the percentage of products that go through the process for the first time, without disagreement, increased to 100% and the percentage of products delivered to the customer at the required time was increased to 85%. The objective of reducing cost of poor quality to CZK 0 was met.

Defined steps and their verification allow you to implement these quality tools in production to eliminate potential problems before they occur. The engineering company covered by the study confirmed the timeliness and success of the project based on the implementation of the Six Sigma methodology into the production process. Based on the results found, this methodology can be successfully applied to other defects which affect the quality, requirements and satisfaction of customers.

The paper aimed to improve the production process using Six Sigma tools. Using DMAIC, the whole process was researched and improved. In the future, research can focus on eliminating other defects and create a database of rules to prevent them.

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