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Using Lean Six Sigma for Sustainability in Inbound Logistics: An Application in The Automotive Industry

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Abstract

Lean Six Sigma (LSS) is a method that aims to reduce waste and costs by decreasing defects in business processes, to increase efficiency and quality, to produce value-added goods/services, and to maintain this process. In this study, the LSS application is discussed as an implementation conducted by a company that is a supplier in the automotive industry, together with its customer in the main industry in order to improve the sustainable production process and quality. The results are evaluated in terms of effects on the customer regarding inbound logistics. Define, Measure, Analyze, Improve, Control (DMAIC) technique was used with 500-piece sample. Before the improvement, 41.7 defects occurred; whereas 8.7 after the improvement. As a result, shipping times of the customers operating in the main industry have been streamlined, stock costs have decreased, and sustainability has been achieved by reducing the waste of resources and energy for the environment.

Keywords: Inbound Logistics, Lean Six Sigma, Sustainability

Introduction

Inbound logistics is all physical and information flow activities from the ordering of materials, goods and services used in production to their entry into the factory (Takita and Leite, 2016). Proper management of inbound logistics ensures the supply of everything needed for sustainable production (Jejani et al., 2019). Companies that need to be ahead of their competitors in order to gain competitive advantage in the market (Verma and Seth, 2019) work with suppliers to improve the quality of the supplied material and improve the production process as part of the inbound logistics process (Dombrowski and Karl, 2016). The most important reason for this cooperation is that competition is now between supply chains rather than between businesses (Bhattacharya et al., 1995; Kehoe and Boughton, 2001) and therefore there is a need to increase the competitiveness of supply chain components.

One of the methods used to improve material quality and production processes is the Lean Six Sigma (LSS) method, which is a combination of Six Sigma methodology and lean philosophies. Six Sigma methodology is a roadmap for problem solving in the business process, consisting of Define, Measure, Analyze, Improve, and Control (DMAIC) stages (Krishnan and Prasath, 2013; Smętkowska and Mrugalska, 2018; Girmanová et al., 2017). It has a flexible structure that can be applied to all production and service processes (Fraser and Fraser 2011). It is also a common cross-organizational metric that takes into account customer demands, allowing for quality improvement (Tennant 2002). Lean philosophy promotes reduction of waste and non-value-added production, business standardization and sustainability of workflow (ASQ, 2021). Six Sigma focuses on eliminating defects and process variability, while lean thinking focuses on waste and speed in all processes (George, 2002). By applying these two structures simultaneously, process speed, product/service quality and customer satisfaction can be increased while costs can be reduced (Christopher and Rutherford, 2004). In addition, the goals of Lean Six Sigma, i.e. reducing defects, accelerating production, better management of inventory, reducing the number and costs of transportation, are also in line with the environmental sustainability goals of the companies. Thus, cooperation is ensured in the environmentally friendly production of ready-made parts and final products to be produced with a green supply chain perspective (Huo et al., 2019). The wastes aimed to be prevented by the lean philosophy and their environmental effects are shown in Table 1. Elimination of defects and reduction of waste provide environmental benefits (USEPA, 2020).

In the literature, there are various studies on the use of Lean Six Sigma method in logistics business processes. As a result of the study conducted by Mijajlevski (2013) on the distribution planning of a manufacturer of domestic water heating equipment, route planning errors and average route time were reduced. In the study conducted by Zhang et al. (2016) on companies implementing Lean Six Sigma to improve logistics operations, varying degrees of cost savings and productivity improvement were achieved in all implementing companies. In the study conducted by Gutierrez-Gutierrez et al. (2016), a Lean Six Sigma method was used to continuously improve the payment and shipping process of a consumer electronics company, and it was seen that this increased the quality of logistics service. According to a study by Linares et al. (2019), the loading process in a paper mill was evaluated with the Lean Six Sigma method, and there was an increase in performance and a decrease in cycle time in the business process. While all abovementioned studies take into account customer demands for improvement, it is seen that companies apply the Lean Six Sigma method to their own business processes. Unlike the ones in the literature, in this study, Lean Six Sigma method was applied with the joint participation of the customer and supplier to increase the power of the supply chain components. In this context, the aim of the study is to use the Lean Six Sigma method to improve the production process and quality of the supplier that provides equipment to a manufacturer in the automotive main industry and the results are evaluated in terms of cost and environmental sustainability within the scope of inbound logistics for the manufacturing company in the main industry.

Table 1. Waste aimed to be prevented with a lean philosophy and its environmental effects

Lean Waste Type	Environmental Impacts
Overproduction Manufacturing items for which there are no orders	• More raw materials consumed in making the unneeded products • Extra products may spoil or become obsolete requiring disposal
Inventory Excess raw material, work in process, or finished goods	• Raw materials and energy consumed in making defective products • Defective components require recycling or disposal • More space required for rework and repair, increasing energy use for heating, cooling, and lighting
Transportation Excess transport of work in process **Motion** Human movements that are unnecessary or straining	• More energy use for transport • Emissions from transport • More space required for work in process movement, increasing lighting, heating, and cooling demand and energy use • More packaging required to protect components during movement • Damage and spills during transport • Transportation of hazardous materials requires special packaging to prevent risk during accidents
Over processing Process steps that are not required to produce the product	• More parts and raw materials consumed per unit of production • Unnecessary processing increases wastes, energy use, and emissions
Waiting Delays associated with stock outs, equipment downtime, capacity bottlenecks	• Potential material spoilage or component damage causing waste • Wasted energy from heating, cooling, and lighting during production downtime

Materials and Method

The aim of the study is improving the production process and quality of the parts assembled by arc welding and supplied by a manufacturer operating in the automotive main industry. As the parts that are shipped with faulty production cannot be used in the main industry, they cause prolongation of the shipment and supply process and adversely affect inventory planning within the scope of inbound logistics. In fact, if these parts are mounted on the vehicle by accident, they may cause the entire vehicle to be repaired or scrapped in the main industry due to their location and functions. All these factors increase the supply costs of the main industry producer; also, the extra materials and energy consumed negatively affect the environment. For this reason, the Lean Six Sigma method was applied by the employees of the two companies together to ensure improvement and sustainability in the production process of the supplier in the sub-industry and to evaluate the effects of this situation on the inbound logistics processes of the customer in the main industry.

In the Define phase, which is the first step of the DMAIC process, the whole process is evaluated and a roadmap is drawn up on where and how to find the problem (The Council for Six Sigma Certification, 2018:169). In this process, with the support of the senior management of both companies, the employees worked together and defined the project process; thereafter a project statement was created, and improvement teams were established.

The purpose of Measure phase, which is the next process, is to collect as much information as possible using qualitative and/or quantitative methods in order to understand the status of the current process and how it works (Desai, 2010). At this stage, various methods were utilized to obtain information to be used in the analysis of manufacturing defects. In this framework, data about processes were collected using control charts, pareto charts, “Suppliers, Inputs, Process, Outputs, Customers” (SIPOC) diagrams.

After the Measure phase, sufficient information is obtained about the situation and conditions of the problem. Then, in the Analyze phase, an answer is sought for why the problem occurred. The main purpose here is to identify potential root causes and then confirm them with data since the Improvement process cannot be started without finding the root causes of the problem (Desai, 2010). Function equation of the problem in all

Lean Six Sigma projects formulated as y= f(x). In the formula, y is the output resulting from the request or requirement. x represents the inputs, factors or parts that make up the outputs and there can be more than one x. The responsibility of the Lean Six Sigma team here is to analyze each x in the y= f(x) function, to identify the root causes of the problem and to investigate its effect on the y output. After adequate analysis, various theories are developed to determine the basis of the problem. These theories are tested so that root causes can be verified (Kumar, 2006). In this framework, in the analysis phase of the study, fishbone diagram, cause-effect matrix and action plans were created in the light of the data obtained. The results of the analyzes were observed during the production process and their effects on welding faults were investigated.

In the Improve phase of Six Sigma, it is aimed to improve the root causes affecting the performance of the product and to reach the desired level (Park, 2003). In this phase, teams often turn to solutions that seem the fastest and simplest; however, solving problems can be more complex and difficult than they seem. Therefore, it is necessary to be sure that the decision taken in the improvement phase will eliminate the problem (Thomsett, 2005). The final phase is Control and it is evaluated whether the targeted quality level has been achieved by measuring the effects of the improvements and corrections.

Results

In the study, first of all, the problem to which Lean Six Sigma method will be applied is defined. Accordingly, the focus is on manufacturing defects in a bracket and custom-made pipe sub-parts assembled with gas metal arc welding. In order to guarantee the quality of the parts, production is required according to the standards determined by the main industrial vehicle manufacturer. These are dimensional, visual and source quality standards. By reducing the defect rates by meeting the determined standards, it is expected that the inventory will be better managed, the costs will be reduced and environmentally friendly production will be made by reducing the amount of waste in the supply chain.

The defect types related to the selected part group are shown in Figure 1 compared to other defect types, it is seen that the defects related to gas metal arc welding problems come first in the part. For this reason, it has been decided to make a Lean Six Sigma project for welding defects by the main industry producer company and supplier industry, which are the project stakeholders. By creating a project statement, business processes were defined, improvement teams were established with the participation of experts from both companies, and a project plan was created.

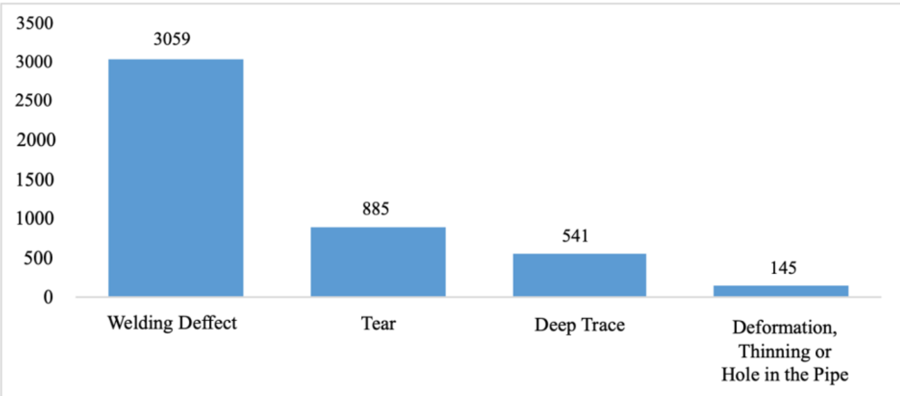

Fig. 1. Part defect types and numbers

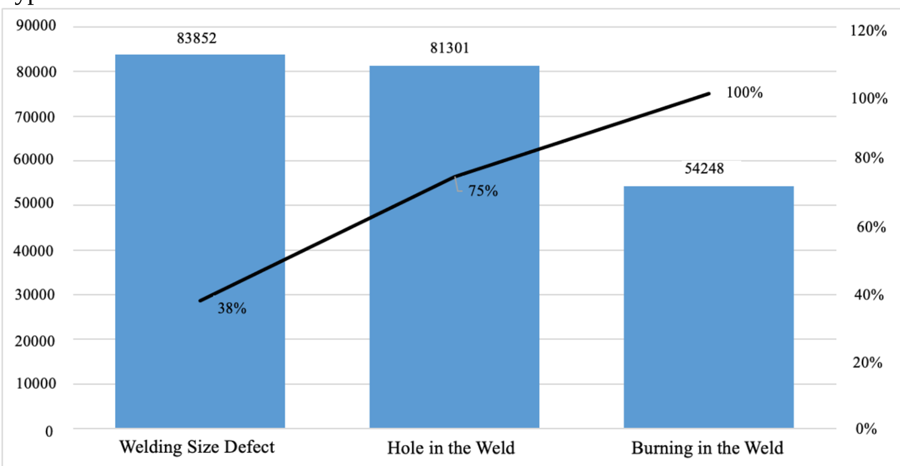

Fig. 2. Welding defect types DPMO pareto chart

During the measurement phase, the data of the past six months on welding defects were examined. According to these data, three defect types were encountered. These defects were detected as incorrect weld length, hole in the weld and burning in the weld, as shown in Figure 2. Incorrect weld length is the defect that occurs as a result of the weld length of the part being outside the tolerance specified in the supply contract of the main industry manufacturer, namely 28mm-33 mm. Hole defects in welding are small pin holes formed on the weld; whereas burning in welding is the defect that occurs as a result of perforation of the part during welding.

In order to detect the defects in the current situation, the defect rate and the number of defects were determined by making measurements on 500 pieces of production made in twenty shifts. While p control charts were used to determine the defect rate, np control charts were used to determine the number of defects (Yıldırım et al., 2018). According to the P control chart in Figure 3, the average defect rate was determined as 0.0833. According to the NP control chart in Figure 4, the number of defects in 500 measurements was determined as 41.7.

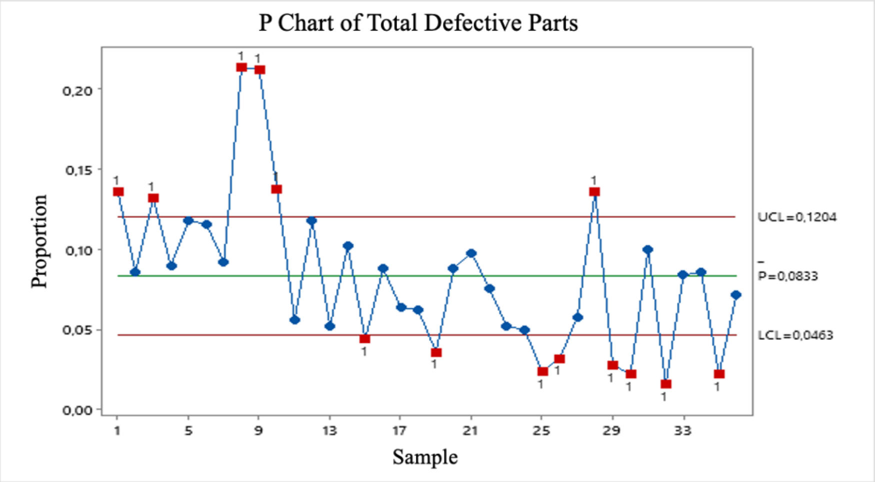

Fig.3. Part P control chart

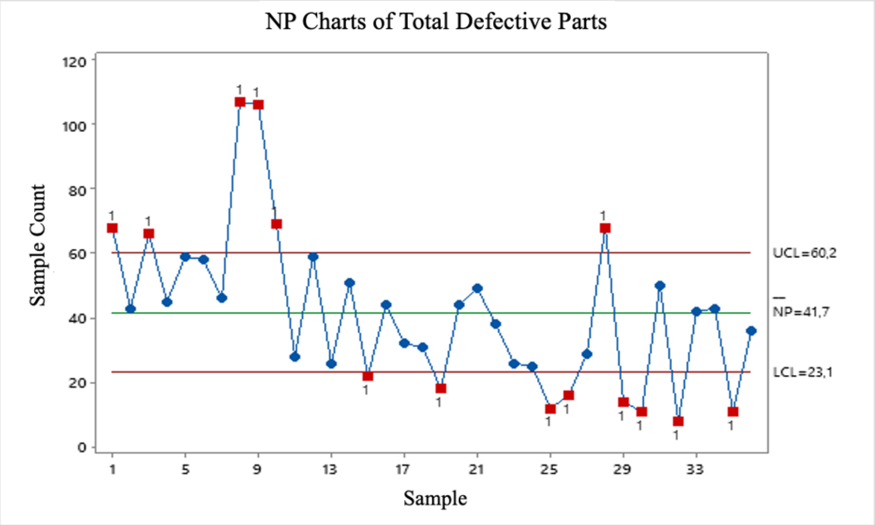

Fig. 4. Part NP control chart

Part production process consists of press operation, supply of sub-parts, welding operation and final control/shipment operation, respectively. The SIPOC diagram in Table 2 shows in which operation the problem started and the inputs in this operation. The inputs in the operation where the defect occurred are reference to understand the root cause of the problem. The selected part group consists of two sub-parts, a bracket and a pipe. The bracket part is manufactured by the company, while the pipe lower part is supplied from another supplier. The basic production process of the bracket part starts with the press operation. In the supply of lower parts, the required quantities of pipe and bracket parts are calculated and transported to the stock areas for welding production and stocked. The parts supplied in the welding operation are joined by gas metal arc welding. In the final control and shipment process, the parts are shipped in shipping boxes after undergoing visual and dimensional control Then, as seen in the Quality Characteristics (CTQ) tree in Figure 5, it was determined that, “0” defect for the number of defects, “0” defect for the scrap count, “0” defect for the number of reworks, “0” defect for the final control is required and defect-free measures should be applied to make the production process defect-free.

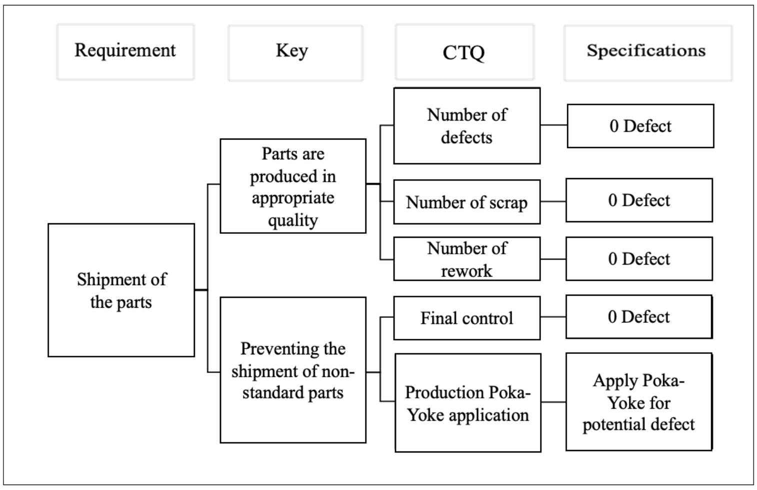

Fig. 5. CTQ Tree

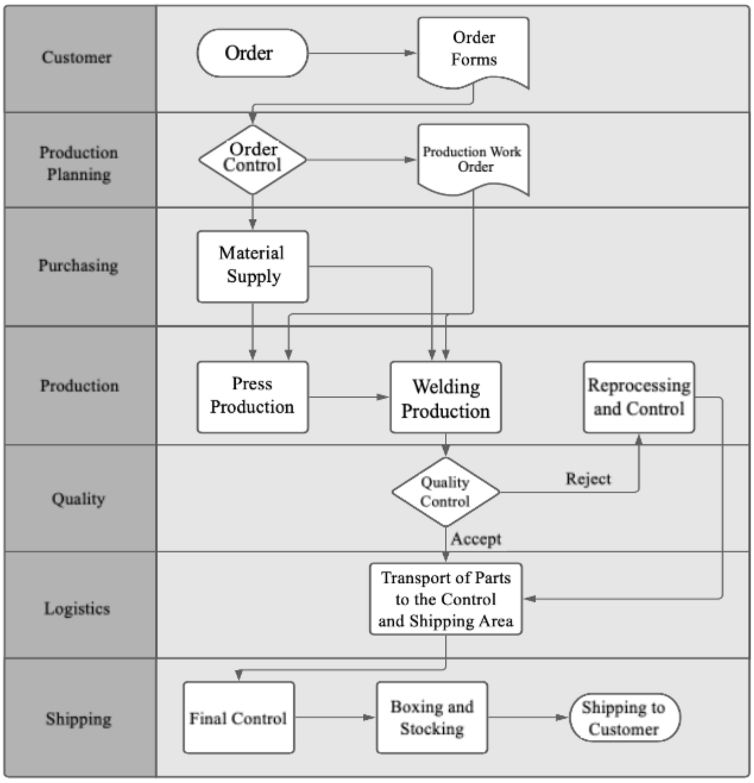

Fig. 6. Process information

Table 2. SIPOC Diagram

Supplier	Inputs	Process	Outputs	Customers
1.Sheet Supplier 2.Press Company 3.Driver Company 4.Molding Room	1.Sheet 2.Press 3.Driver 4.Mold	Press	Bracket	Logistics Department
1.Raw Material Supplier 2.Press Production	1.Pipe 2.Bracket	Bottom Part Supply	Transported and Stocked Part	Weld Production
1.Wire Supplier 2.Robot Producer 3.Jig Producer 4.Gas Supplier 5.Support Supply 6.PLC Producer 7.Logistics	1.Welding Wire 2.Robot 3.Jig 4.Gas 5.Nozzle 6.PLC Program 7.Bottom Part	Welding	Welded Part	Shipping
1.Customer 2.Control Fixture Producer 3.Forklift 4.Customer 5.Welding Production	1.Box 2.Control Fixture 3.Forklift 4.Manifest / Kanban 5.Welded Part	Final Control / Shipping	Boxed Item/ Ready to Shipping	Final Customer

Then, process mapping was done. The process information that the part follows from the moment it is ordered to the moment it is shipped is shown in Figure 6. Process mapping is an effective tool for visualizing operations that add value to the main industry producer, which is the customer of the supplier, and that affect the output. After the quality control operation, it is planned to accommodate the detected defects through reprocessing and to transport them with the defect-free parts to the final control area with the help of forklifts. Quality operators decide whether a manufactured product is defected or not. The accuracy of the decisions made is of great importance for the results to guide the Lean Six Sigma team correctly. Measurement systems analysis was used to analyze the accuracy of the quality operators' defect detections. For this purpose, Gage R&R analysis was performed. This analysis is widely used to evaluate measurement systems (Satıcı et al., 2020). Analysis of weld length is shown in Table 3. Accordingly, firstly, 15 sample pieces were selected for two quality operators. The measurement of the sample pieces was first made by an expert and the nominal value was found. It was then performed by Operator 1 and Operator 2 in two repetitions.

Table 3. Weld length measurement

Measuring Order	Nominal(mm)	Operator 1		Operator 2	
		Repetition 1	Repetition 2	Repetition 1	Repetition 2
1	29,30	30,11	30,14	30,13	30,09
2	30,40	29,98	30,10	30,24	30,25
3	29,00	29,31	29,41	29,18	29,14
4	29,60	29,42	29,43	29,20	29,26
5	30,00	29,65	29,53	29,67	29,69
6	29,80	29,62	29,74	29,68	29,59
7	29,45	29,67	29,65	29,70	29,54
8	29,20	29,87	30,01	30,12	29,88
9	29,60	29,47	29,48	29,58	29,50
10	29,70	29,70	29,79	29,61	29,69
11	29,87	29,80	29,81	29,86	29,79
12	30,04	30,15	30,01	30,10	29,96
13	30,10	30,05	30,05	30,05	30,16
14	29,65	29,72	29,68	29,69	29,62
15	29,98	29,88	29,95	30,02	30,04

Table 4. Weld length gage R&R results

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0,0082565	9,93
Repeatability	0,0046817	5,63
Reproducibility	0,0035749	4,30
Operator	0,0000000	0,00
Operator*Measurement Rank	0,0035749	4,30
Part-To-Part	0,0748492	90,07
Total Variation	0,0831057	100,00

The measurement results were analyzed by Minitab19 and the results in Table 4 were obtained. According to the results, the Total Gage R&R value was found to be 9.93%. This value is expected to be <10% for the adequacy of measurement systems. Although the result is close to the limit, it was accepted that the measurement system was sufficient since it remained within the limit.

As seen in Table 5, the measurement of sample parts related to the appearance of holes in the weld was first made by an expert and the nominal value was found. It was then measured by Operator 1 and Operator 2 in two repetitions. The measurement results were analyzed by Minitab19 and the results shown in Figure 7 were obtained. Accordingly, Operator 1 and Operator 2 measurements are 100% consistent within themselves. In addition, it is seen that the measurements of Operator 1 and Operator 2 are 100% consistent with the measurements made by the expert. As seen in Table 6, the measurement of sample parts related to the occurrence of burning in the weld was conducted by an expert and the nominal value was found. It was then measured by Operator 1 and Operator 2 with two repetitions. The measurement results were analyzed by Minitab19 and the results in Figure 8 were obtained. Accordingly, repeated measurements by Operator 1 and Operator 2 are 100% consistent within themselves. In addition, it is seen that the measurements of Operator 1 and Operator 2 are 100% consistent with the measurements conducted by the expert.

Table 5. Hole gage R&R measurement at weld

Measuring Order	Nominal(mm)	Operator 1		Operator 2	
		Repetition 1	Repetition 2	Repetition 1	Repetition 2
1	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
2	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
3	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
4	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
5	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
6	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
7	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
8	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
9	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
10	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
11	PRESENT	PRESENT	PRESENT	PRESENT	PRESENT
12	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
13	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
14	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
15	PRESENT	PRESENT	PRESENT	PRESENT	PRESENT

Table 6. Combustion gage R&R measurement at source

Measuring Order	Nominal(mm)	Operator 1		Operator 2	
		Repetition 1	Repetition 2	Repetition 1	Repetition 2
1	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
2	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
3	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
4	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
5	PRESENT	PRESENT	PRESENT	PRESENT	PRESENT
6	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
7	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
8	PRESENT	PRESENT	PRESENT	PRESENT	PRESENT
9	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
10	PRESENT	PRESENT	PRESENT	PRESENT	PRESENT
11	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
12	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
13	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
14	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
15	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT

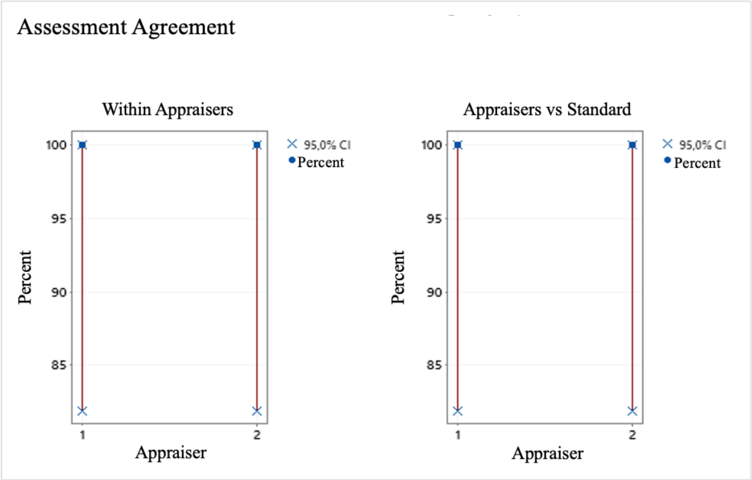

Fig. 7. Hole gage R&R result in weld

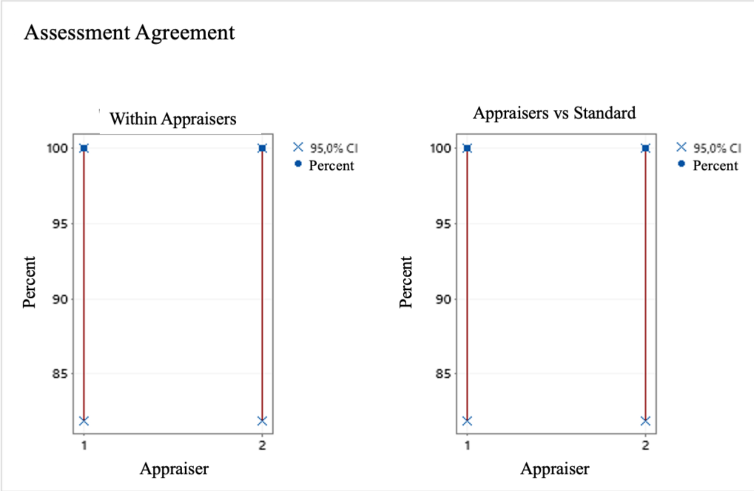

Fig. 8. Weld burn gage R&R measure result

As a result of the measurement systems competence analysis, it was observed that the operator evaluations regarding three different defects were sufficient, and the measurement reliability of the operators was confirmed. In the analysis process, the causes of the problems were determined by making a fishbone diagram about the welding defects. These causes were divided according to defect types in the cause-effect matrix in Table 7 and scored according to their probability of occurrence. The root cause with the highest score is prioritized. Accordingly, some improvements were made on-site, while an improvement plan was created for others.

For the improvements and corrections that could not be made on-site, a six-week improvement plan was made, as seen in Table 8. During the root cause checks, it was decided to design an experiment on part surface cleaning, welding current and gas flow parameters.

Table 7. Welding defects cause and effect table

Root Causes			Defect Types: Defective Welding Lenght	Defect Types: Hole in the Weld	Defect Types: Burning	Probability	Scoring
			10	**8**	**9**		
Man	Defective Setting	Defective nozzle setting	9	9	9	9	2187
	Defective Part Settlement	Insufficient Instruction	9	9	9	3	729
		Untrained Operator	9	9	9	3	729
	Part Measurement Error	Inappropriate Instruction	9	9	9	9	2187
		Inappropriate Operator Competence	3	3	3	1	81
Method	Inappropriate Parameters	Incorrect Gas Flow Parameter	1	9	9	9	1467
		High Current	9	9	9	9	2187
		High Nozzle and Welding Tip Cleaning Frequency	3	9	9	9	1647
Material	Defective Welding Equipments	Defective Welding Nozzle	3	9	9	1	183
		Defective Welding Wire Pipe	3	3	3	1	81
	Inappropriate Bottom Part	Inappropriate Bracket	1	1	3	3	135
		Unclean Bottom Part	1	9	1	9	819
		Inappropriate Pipe	1	1	3	3	135
	Defective Welding Wire	Non-standard Wire Diameter	9	9	9	1	243
		Non-standard Wire Material	9	9	9	1	243
Machine	Inappropriate Machine Design	Inappropriate Wire Length – Part Spacing	9	1	1	9	963
	Inappropriate Wire Feed Angle	Lack of Welding Wire Flow Pipe Instruction	1	3	3	9	549
		Incorrect Gas Flow	1	9	9	3	489
	Defective Welding Torch	No Correct Torch	1	9	9	9	1467
	Inappropriate Machine Qualification	Wide Machine Production Tolerance	9	9	9	1	243
	Inappropriate Jig Qualification	Gap Between Jig and Part	9	3	3	3	423
		Gap Between Clamp and Part	9	3	3	3	423

Table 8: Improvement plan

#	Root Causes	Improvement Points	Plan (Week)							Result
			N	N+1	N+2	N+3	N+4	N+5	N+6	
1	Defective Nozzle Setting	1-Preparation of Nozzle Adjustment Instruction	■							Done
		2-Increasing the Frequency of Nozzle Change	■							Done
2	Insufficient Part Settlement Instruction	1-Revision of Work Instructions	■	■						Done
		2-Training the Operators			■					Done
3	Insufficient Part Measuring Instruction	1-Revision of Work Instructions		■	■					Done
		2-Training the Operators			■					Done
6	Nozzle and Welding Tip Cleaning Frequency is High	1-Increasing the Frequency of Nozzle Change	■							Done
7	Incorrect Welding Wire Pipe	1-Replacement of Welding Wire Conduction Pipe				■				Done
9	Inappropriate Wire Lenght – Part Spacing	1-Checking the Distance Between the Tip of the Welding Wire and the Part	■							Done
10	Insufficient Part Surface Cleaning, Welding Current, Gas Flow Parameters	1-Making Full Factorial Experiment Design	■	■	■	■	■	■		Done
		2-Making Standardization According to New Parameters							■	Done

Table 9. Welding parameters experiment design

	Welding Current (A)	Gas Flow (L/Min)	Part Cleanliness
1	75	10	Clean
2	85	12	Unclean

Table 10. Experiment design measurement result table

Sorting	Ampere (A)	Gas Flow (L/Min.)	Part Situation	Total Production	Number of Defects			DPMO
					Short Weld	Hole	Burning	
1	85	12	Clean	30	1	0	0	33333
2	75	10	Unclean	30	1	0	0	33333
3	85	10	Clean	90	1	0	0	11111
4	85	10	Clean	190	1	0	0	5263
5	75	12	Clean	190	4	0	0	21053
6	85	10	Unclean	30	1	0	0	33333
7	85	12	Unclean	60	1	0	0	16667
8	75	10	Clean	60	1	0	0	16667
9	85	12	Unclean	90	1	0	0	11111
10	75	10	Clean	60	1	0	0	16667
11	75	12	Unclean	190	3	0	0	15789
12	75	12	Unclean	90	0	0	0	11111
13	75	10	Unclean	30	1	0	0	33333
14	85	10	Unclean	90	2	0	0	22222
15	85	12	Clean	30	3	0	0	100000
16	75	12	Clean	90	1	0	0	11111

In the Improve Phase, improvement plans that were determined according to the findings obtained during the analyze phase were implemented. In the previous analysis, it was decided to design a three-factor and two-level experiment, since it was concluded that the parameters related to welding current, gas flow and part surface would have a significant effect on welding defects. As seen in Table 9, the levels were determined such that the welding current was 75A and 85A, the gas flow was 10 L/Min and 12 L/Min, and parts were either cleaned or not cleaned. A total of sixteen trials, with eight different trials and two repetitions, were conducted according to the full factorial experimental design method. Defect types, number of defects and defects per million opportunities (DPMO) results are shown in Table 10.

The results were analyzed by Minitab19 at 95% confidence level. Accordingly, as seen in Figure 9, while the parameters on the left side of the value given by the dashed line did not make a significant contribution to the result, the parameter on the right side of the value contributed significantly to the result. The parameter affecting the result was determined as the combination of gas flow and part surface parameters, which are seen as BC.

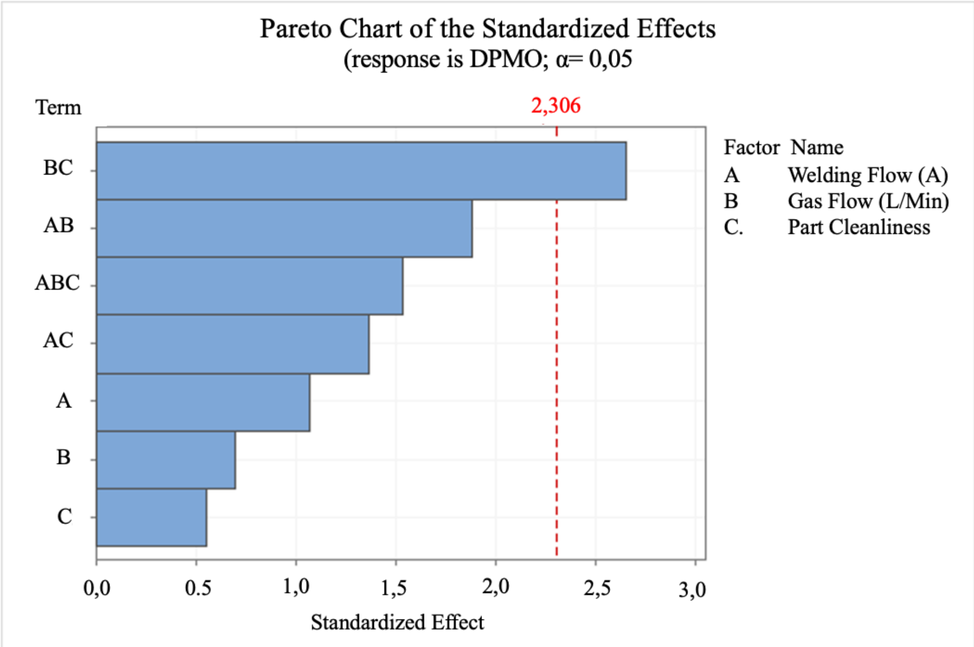

Fig. 9. Experimental design parameters interaction graph.

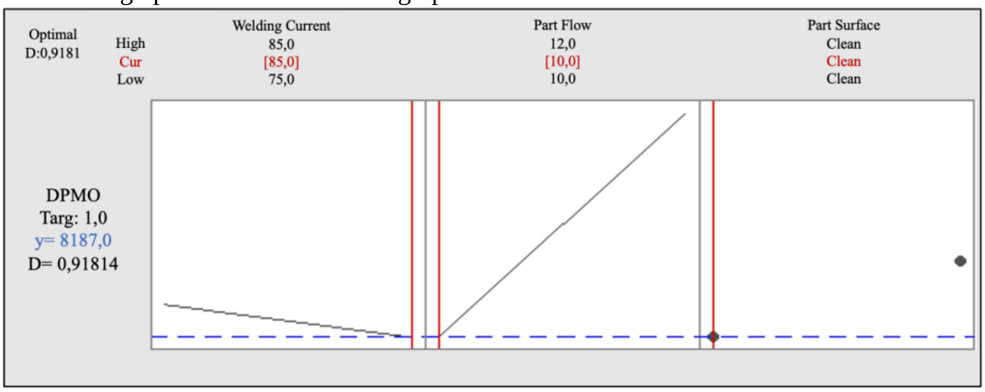

Fig. 10. Optimal parameter graph

Table 11. Experimental design parameters analysis table

Coded Coefficients						
Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		24507	4309	5,69	0,000	1,00
Welding Current (A)	9247	4624	4309	1,07	0,315	1,00
Gas Flow (L/Min)	6031	3015	4309	0,70	0,504	1,00
Part Surface	-4788	-2394	4309	-0,56	0,594	1,00
Welding Current (A)*Gas Flow (L/Min)	16265	8132	4309	1,89	0,096	1,00
Welding Current (A)*Part Surface	-11805	-5903	4309	-1,37	0,208	1,00
Gas Flow (L/Min)*Part Surface	-22917	-11458	4309	-2,66	0,029	1,00
Welding Current (A)*Gas Flow (L/Min)*Part Surface	-13268	-6634	4309	-1,54	0,162	1,00

As seen in Table 11, it was determined that the gas flow and part surface composition had a significant effect on the result since the P-Value value was less than 0.05, while the other parameters did not have significant effect on the result because their P-Value values were greater than 0.05.

The parameter that should be used to produce the least defective part was calculated using Minitab19 software as seen in Figure 10. According to the analysis result, the most appropriate parameter to be used is Current: 85A, Gas flow: 10L/Min, Part surface: The surface has been determined as clean and these findings were standardized. The productions made during the control phase were made by considering the most appropriate parameter determined.

After the improvements were completed and the most suitable welding parameters were determined, samples of 500 pieces produced in 20 shifts were taken during the control phase and the number of defects was monitored. The results obtained are shown in the I Control chart in Figure 11. The situation before the improvement and the situation after the improvement are shown side by side in the graph. While an average of 41.7 defects was encountered in the measurement of 500 pieces before the improvement, an average of 8.7 defects was reached in the measurement of 500 pieces after the improvement.

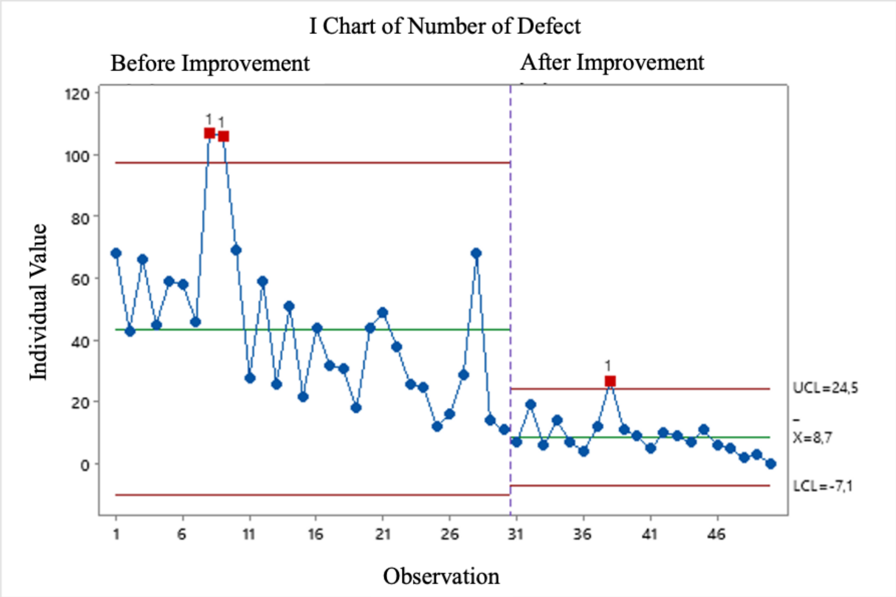

Fig. 11. I control chart before and after improvement

The sigma calculation before and after improvement is as follows;

Before improvement
DPMO: (41,7÷500)*1000000=83400
Process Sigma: 2,88

After improvement
DPMO: (8,7÷500)*1000000=17400
Process Sigma: 3,61

Difference: 3,61-2,88= 0,73 sigma improvement was achieved.

When the improvement is evaluated in terms of inbound logistics, it can be seen that the decrease in the number of scrap and rework in production leads the shipment from the sub-industry supplier to the main industry producer to be made in the planned time and amount. In this context, the total amount of stock and storage costs kept in the inventory of the main industry producer, which previously placed an early order in order not to run out of parts, had more stock on hand and incurred higher storage costs, decreased. As a result of the decrease in the defect rate, resulting from the quality controls performed while the parts are delivered from the supplier to the manufacturer in the main industry, the reverse logistics processes and costs of sending the defective parts to the supplier have decreased. In terms of environmental effects, the reduction in the amount of waste and scrap in production ensures that the waste of resources and energy is reduced in the entire inbound logistics process.

Discussion and Conclusion

While the Lean Six Sigma method reduces costs by reducing the number of defects in achieving improvement goals in business processes, it also reduces waste and environmental pollution by eliminating unnecessary activities. Sustainability is ensured by incorporating this approach into the business process of companies. By using the Lean Six Sigma approach, companies can work with their suppliers to provide the products or services they demand in a competitive supply chain structure.

In the study, the top management of both companies supported the Lean Six Sigma application and provided the necessary motivation. As the first step of the process, making the definition of the problem in an accurate, clear and understandable way constitutes the first step in keeping the process on the desired route and finalizing it. Making the definition of the problem clear and complete facilitates the solution. In this study, it was decided that the supplier's production process should be improved within the scope of inbound logistics in order to create a competitive supply chain structure. For this purpose, defect type, defect rate and number of defects were determined by drawing defect graph at the measure stage. Root causes were determined in the analyze part of the study. The analyzes should reveal the root causes and the factors causing the problem. For this reason, possible root causes were determined and scored by the fishbone and cause-effect matrix. Each of the root causes was observed in the production area, and evaluations were made for the improvement process. Experimental design method was used to estimate the effect of parameters such as welding current, gas flow and part surface specified in the study. After the trials, the most suitable parameter for improvement was selected and this parameter was standardized.

In the study, the improvement of the supplier's production process led to a decrease in the customer's stock level and storage costs in terms of inbound logistics, reduction of reverse logistics processes and costs, and reduction of resource and energy waste. In addition, improvements made as a result of root cause observations are standardized in control plans and

FMEA. Otherwise, if the necessary standardization activities are not implemented, a reversion to the old situation may occur. Reducing waste provides environmental gains, however, it would be more appropriate to conduct a lean six sigma study focusing on this issue in order to determine the environmental impacts or costs.

In future studies, simultaneous Lean Six Sigma applications for different processes of supply logistics can be realized. Thus, the effect of the improvements made on the whole supply chain can be seen more concretely. Likewise, the environmental impacts can be directly evaluated with the improvement works to be carried out by taking into account the environmental management systems.

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