Research Article

Improvement of Plastic Manufacturing Processes by Six Sigma and DMAIC Methods

Alhatem Satta Seham Ismail and Azizan As'arry
Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, Selangor, Malaysia

Salit Mohd Sapuan* and Jamal Tarique
Advanced Engineering Materials and Composites Research Centre (AEMC), Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, Selangor, Malaysia

* Corresponding author. E-mail: sapuan@upm.edu.my DOI: 10.14416/j.asep.2023.04.003
Received: 17 December 2022; Revised: 12 February 2023; Accepted: 27 March 2023; Published online: 7 April 2023

Abstract
Improvements are required in any industry to maximize productivity by reducing faults in any method and removing overall waste produced within the manufacturing facility. This study examines the problems faced by some leading companies in the plastic manufacturing industry, such as Motorola, General Electric, and Zamil Plastic and how to solve them. In this study, the key difficulty in this plastic manufacturing industry was black dots, which can be seen in injection molding operations. When compared to other faults, the injection molding technique result shows that black dot defects are the main reason for rejects in May, making up almost 41% of all rejects. Because, Defectives Per Million Opportunities (DPMO) of products in Plastic Remote Controls (PRC) result in numerous wastes, statistical quality control (SQC) methods, such as the Pareto chart, cause-effect diagram, and control chart were utilized to examine the data. Also, this study shows that the time necessary for tool changeover was extremely long, resulting in a significant wait for manufacturing because multiple dies and molds were required for production (types of plastic fuel tanks). The novelty of this research is that it clarifies when the company uses six sigma and the DMAIC method to rapidly discover the problem in the products and find a suitable solution to save time, effort, and cost. Run charts and the layout of mold storage are used to solve the problem and ensure that the process is truly improved by reducing the time it takes to change over for tools and dies.

Keywords: DMAIC, TQM, Six Sigma, Black dot, DPMO

1 Introduction

Many companies use Six Sigma, and case studies from Motorola, General Electric, Honeywell, AlliedSignal, Raytheon, and Delphi Automotive are available in the literature [1],[2]. Six Sigma is a tool that assists to improve productivity by detecting as well as eliminating waste during the improvement phase, thereby increasing output [3].

The fundamental causes of waste, which leads to increased inventory and large investments, as well as a high level of customer happiness, are identified and eradicated using six sigma methods, allowing the company to meet its objective of 3.4 defects per million opportunities (DPMO) [4]. Another main reason for using the six-sigma study is to effectively reduce product cycle time as well as increase the production rate of industries. The most significant element in any plastic manufacturing sector is tools, molds, and dies. Different tools and molds are used in this industry. In the late 1980s, DMAIC was introduced by Motorola. Since then, DMAIC has become the essential component of Six Sigma that aim to improve processes. DMAIC has five phases; define measure, analyze, improve and control [5],[6]. Currently, some enterprises in plastic manufacturing have problems with the products which are the main causes of a high rate of rejection of the products, particularly (Remote controls) in our research (part one). The “Black dot” defects are the key reason for these rejections. based on the look of the product [7]. To investigate the problem, engineers conducted a literature review on TQM (Total Quality Management), Six Sigma, and PDCA (Plan, Do, Check, Act) philosophies, as well as additional sources for this analysis and research approach [5]. We’re also focusing on another issue in this study. The fundamental difficulty with the plastic manufacturing sector is that it takes a long time to change over molds and tools. and dies, causing a delay in the blow molding process for producing plastic fuel tanks [8]. As a result, the primary goal of this section of the research is to apply six sigma, DMAIC methods to the plastic manufacturing industry, which will aid in identifying the true cause of changeover time delays and then finding a solution for this issue during the improvement phase, which will aid in improving overall plastic fuel tank manufacturing in this industry [9], [10]. The company’s products are a type of remote controls, type of toiletry and type of plastic fuel tanks.

Some leading works regarding plastic manufacturing have been done by some of the top plastic manufacturing companies in the world such as Chevron Phillips Chemical Company, Zamil Plastic Industries Co., Dow Chemical Company, etc. Plastic products are ubiquitous in modern life. But although they’re found everywhere, not everyone knows just how they came to be. In fact, in the world of manufacturing, there are eight different plastic forming methods such as plastic injection molding, rotational (Roto) molding, extrusion blow molding, injection blow molding, reaction injection molding (RIM), vacuum casting, thermoforming as well as compression molding. Each is used for a special reason, although they can sometimes be used in combination to make more complex finished parts.

This paper identifies the root cause of the defects (Black dot) rejects in plastic manufacturing products by using Six Sigma, the DMAIC method and its tools after that provides a better solution to eliminate the defects, wastes, rework and improve the quality also, increase the productivity, profitability and save the cost. This paper also identifies the real reason for the delay time in changeover molds, tools as well as dies, causing a delay in the blow molding process in the plastic manufacturing products sector of fuel tanks by using Six Sigma, DMAIC method and its tools, after finding the solution for this problem to eliminate the delay times (reduce product cycle time), which is useful to increase the productivity.

2 Methodology and Material Selection

2.1 *Methodology*

This paper addresses the chosen firm and the study topic. In addition, it describes the research technique that was employed in this study, as well as the selection of the six sigma DMAIC method and tools to identify and solve the problems, which the company requires to improve the products and eliminate the defects.

2.2 *Material selection*

2.2.1 Selection of company

The firm (the United Company for Plastic Industry, Iraq) conducted this study, which is essentially a case study. This case study was conducted within the organization. This case study concentrated on the problem at the 18- and 30-tone injection molding assembly lines of the plastic part manufacturing department of the company (Black dot 2020). Remote controls and tiny plastic components are the department's major products, which are made for both internal and external clients. There is also more information on the production of plastic fuel tanks in another sector of the company, which has a problem by delaying in the cycle time of changeover molds and tools.

2.2.2 Six Sigma DMAIC method and tools selection

Six-sigma project methodology (DMAIC) was utilized to modify the approach for this case study.

2.3 *Part one (Black dot) problem*

2.3.1 Stage of define

The goal of the define stage is to clearly define the problem, requirements, and the goals of the project. At this stage, rejection data will be collected and analyzed in order to create a Pareto diagram that will aid in identifying the major rejection issue.

2.3.2 Measure stage

Whether the project is looking at a new or old process, a technique and what type of response (Y) to use to measure the process's performance must be established. If the process is already in place, assess the measuring system's accuracy and variability, as well as the process' present performance. Input factors (X) that create a variance in process performance was identified, which is the most essential step.

2.3.3 Analyze stage

It is not enough to identify the problem, gather, and show the appropriate data in any high-quality job. The data must also be examined to identify the sources of variance. There are usually several reasons for variation, but one root cause is usually more substantial compared to the others; this root cause must later be discovered and eliminated. Matrix of Cause and Effect was created to evaluate the significance of each input in generating a variance in output.

2.3.4 Improve stage

The underlying cause discovered during the measurement step must now be removed, and the process must be optimized as well. With the root cause, several options to remedy the problem will be presented, and one that best addresses the root cause picked. A planned experiment is generally done to optimize the process, with the input variables chosen to get the best result.

2.3.5 Control stage

Control is the final stage of the DMAIC process. The control mechanism will be proposed at this point, but the proof will be required once the changes have been implemented to show that the process is in control and is more competent than before the modifications. It is critical to preserve and maintain the new better-quality level if the process is more competent than before. This is mostly accomplished by statistical process control, particularly control charts [11].

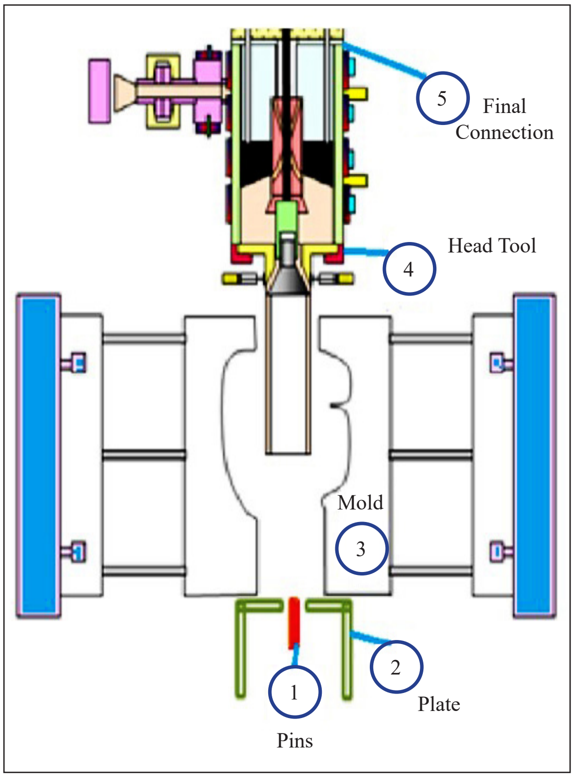

Figure 1: Changeover items.

2.3.6 Part 2 (The delay time in changeover mold, head tools)

We already have used the DMAIC method and its tools to define the problem and suggest the appropriate solution to save the products. The changeover process begins with the head tool, which is accomplished by two persons, followed by the mold, which is done by those same two persons after a head tool is changed, as well as finally, once the mold is changed, one person adjustments the pin and plate (Figure 1). Following the completion of the changeover from head tool to plate, all hydraulic connections are made, and it is finally connected to final connection. When manufacturing of one type of tank stops, the process of changeover begins, and all these parts are changed for production of the next assembly. Data were collected (Table 1) for each different process, and individual time was recorded to provide a clear picture of which process takes how long for the changeover.

Table 1: Time of changeover tool

Sr No Change Over	Different Activities Time (Minutes)				
	Head Tool	Mold	Pinch Plate	Spreader Pin	Final Connection
1	45	33	15	8	7
2	40	31	14	8	7
3	39	38	8	6	7
4	38	33	7	8	8
5	56	32	7	7	6
6	44	35	7	8	9
7	43	37	10	4	8
8	52	47	14	6	6
9	40	33	10	6	7
10	55	30	12	5	8
11	42	36	11	7	7

3 Results and Discussion

3.1 *Injection molding process*

Before being injected into the cover mold, the raw material is usually in the form of pellets or granules, which are melted by heat and shearing forces. Resin pellets are fed to the screw by a feed hopper, which is a huge open-bottomed container. A screw is driven by a motor, which feeds pellets into its grooves [12]. Injection molding process layout is shown in Figure 2. Inside the barrel, plastic is melted at a high temperature utilizing heater bands and mechanical shear between the barrel and the revolving screw. To produce a shot, the spinning screw goes backward while the plastic advances forward. When there is enough melt for one shot, the screw stops revolving and advances, pumping the melt under pressure into a cooler mold chamber via the gate.

High-molecular polymers undergo very complicated heating, cooling, and mechanical shearing in the injection molding process. Due to different thermal-cold histories and mechanical shearing histories of polymer regions, during the injection molding process, the melt undergoes a strong shearing action in the barrel, and the injection pressure and injection rate are two process parameters that determine the shear strength of the melt. Increasing the temperature of the plastic melt will speed up the movement of the internal molecular chains and thereby achieve better relaxation. An increase in injection pressure will also increase the injection rate, which leads to an increase in the melt flow rate and an increased shear effect. Injection molding temperatures for common plastic are tabulated in Table 2.

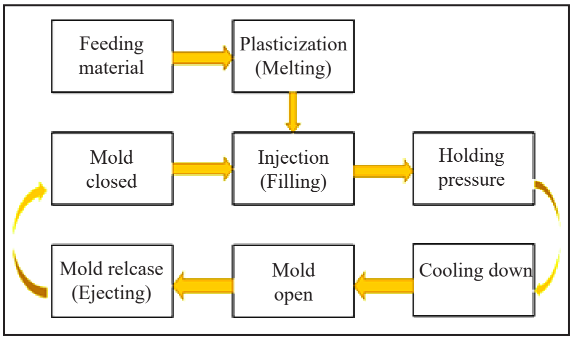

Figure 2: Injection molding processes layout.

Table 2: Injection molding temperature for common plastic as below

Plastic Material	Injection Molding Temperature (°C)	Mold Temperature (°C)
ABS	210–275	50–90
PP	250–270	50–75
POM	200–210	>90
LDPE	160–260	50–70
HDPE	260–300	30–70

As the screw gets closer to the mold, the depth of screw flights decreases, squeezing the hot material. The pellets are pushed forward in the screw as it turns. In the cavity, the plastic melt cools and hardens, adopting the shape of the mold cover. The molten material is pushed through a hole in the die, which determines the shape of the finished product form (Cover Remote Control) [13], [14]. The tubes that the plastic travels through on their way to the chamber will likewise solidify. This frame is made up of a frame that is attached to the sprue, which runs parallel to the direction of draw from the molten resin reservoir, and runners, which run perpendicular to the draw direction and deliver molten resin to the injection gate(s) or point(s), cut, or twist off the sprue and runner system and recycle it, and the sprue and runner systems are sometimes granulated near the molding machine. Some molds are built in such a way that the part is removed automatically, depending on the mold's activity.

The injection molding process makes use of the most available plant space. Automation is a primary criterion in plastic injection molding productions and layouts, even though automation takes up more floor space than manual labor. The layout is usually changed after a time, such as five years, due to technological advances that might occur or any change in products or materials. When organizing the layout of a plastic injection molding plant, the most important factors to be taken into consideration are:

1) Maximum use of floor space
2) Improvement of the flow of material
3) Advancement in labor ability and automation
4) Readiness for expansion

3.2 *DMAIC – Define the process (Black Dots)*

All circumstances must be established before the process can be studied. SIPOC (Suppliers, Inputs, Processes, Outputs, and Customers) is a term used to characterize such situations. The events leading up to the molding of the cover are detailed here in chronological sequence.

- DuPont nylon plastic is a material provider
- ABS material is an input
- Receive ABS and feed it into the hopper
- ABS dry
- Supply ABS to the molding machine
- Cover for a mold
- Deliver protection to the staging areas
- Results - Cover Plastic for Remotes control
- Customers–assembly stations/external customers

The main issue in this specific field of plastic manufacture was (Black Dots), which may be visible in injection molding operations because of product flaws. Plastic remote controls (the cover) have a high defect per million operations (DPMO) rate, which produces a lot of trash. Examples of statistical quality control (SQC) methods that were applied to the data analysis include the Pareto chart and cause-and-effect diagram. It was determined what the problems' underlying causes were. Adopting the Six Sigma method is intended to achieve DMAIC tools, which are tools to identify problems and find suitable solutions to improve products. The main difficulty in implementing the proposed method appears to be when employers and supervisors lack adequate training and experience insufficient workplace stress.

3.2.1 Determine the source of the present reject problem

The rejection data for a 30-tone injection molding assembly line for April 2020 are shown in Table 3. When compared to previous months' rejection statistics, this data shows the highest rejection ratio. The Pareto diagram for specific part rejections based on the code name is shown in Figure 3. Component BMQ case A has the highest monthly rejection rate of 4567 units, accounting for 30.61% of the overall rejection rate, according to the results. The component of the study with the highest rejection rate was chosen as the research element of research.

Table 3: Based on the component generated, an in-line rejection is made

Model	In-line Reject Unit	In-line (k unit)	Percentage	Acc.
BMQ-Case A	4567	4.57	30.61	30.61
BMQ-Case B	2067	2.07	13.86	44.47
BNX-Spacer	1789	1.79	11.99	56.46
BPJ-Case B	741	0.74	4.97	61.43
BPJ-Case C	675	0.68	4.53	65.96
BPJ-Case A	477	0.48	3.20	69.16
BPY-Spacer	461	0.46	3.09	72.25
BNM-Case B	403	0.40	2.70	74.95
BNT-Case B	372	0.37	2.49	77.44
Bezel	353	0.35	2.37	79.81
BLX-Case C	353	0.35	2.37	82.18
BPZ-Case A	350	0.35	2.35	84.53
BBM-Case B	349	0.35	2.34	86.86
BNM-Case C	184	0.18	1.23	88.10
BLP-Case C	167	0.17	1.12	89.22
BNM-Case A	144	0.14	0.97	90.19
BBM-Case A	102	0.10	0.68	90.87
BNC-Case B	100	0.10	0.67	91.54
BPZ-Case D	77	0.08	0.52	92.05
STEM	51	0.05	0.34	92.40
BPZ-Case C	34	0.03	0.22	92.62
BPZ-Case B	16	0.02	0.11	92.73
Others	1085	1.08	7.27	100.00

3.2.2 Measure phase

To track down the issue with this element, data were collected for 6 months, from May to October 2020, for output line rejections in the 30-tone injection molding assembly line focused on the production of part BMQ

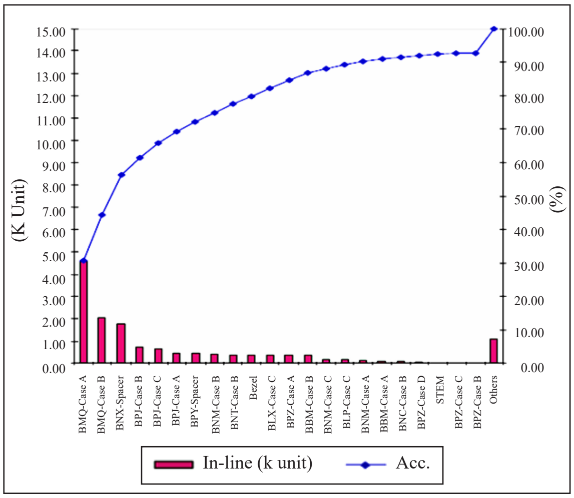

Figure 3: Pareto diagram (In-line rejection).

case A. The reject data for each machine was obtained since four units are making identical parts [15], [16]. Each month's defect per million opportunities (DPMO) was calculated using these statistics. Total output, reject amount, DPMO, and sigma level (Figure 4) also are shown in (Table 4). From May through October 2020, once a month. For instance, Equation (1) shows total rejection (R) per unit (total units made) (P) R/P = DPU (defect per unit). Equation (2) shows Sigma Level (Z) =0.8406+√ {29.37-2.221ln (DPMO)} as shown below:

For the six months of May to October 2020, the database's Sigma level was used.

● How to calculate Sigma Levels in Basic Steps Determine the CTQ

● Define the potential for defects Collect information on flaws Calculate the DPMO

● To calculate the Sigma level, use the standard formula. Basic steps to compute the Sigma level were calculated using the following formula.

● P is a total number of pieces produced. R (total rejection) CTQ total = O

DPU (defect per unit) = R/P

DPU/CTQ = DPO

DPO × 10^6 = DPMO

Sigma level (Z) = 0.8406+√ {29.37-2.221ln (DPMO)}

Sigma level calculated for May 2020.

P = 299520 total units made

R = 4619 total rejection

CTQ total, O = 5

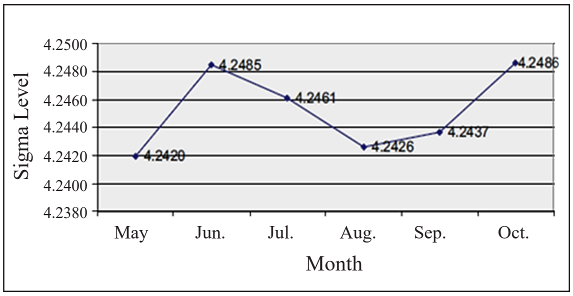

Figure 4: Sigma level from May to October 2020 for Black dot.

R/P = 0.0154213408 = DPU DPO, DPU/CTQ = 0.0030843 DPMO, DPO × 10^6 = 3084.3 (1)

Sigma level 6 = 0.8406+√ {29.37 – 2.22ln (3084.3)} = 4.2420 (2)

The sigma level for the process was computed using the data in Table 4 and displayed in Figure 4. From May through October, the sigma level ranged from 4.2420 to 4.2686, as shown in Figure 4. The whole method has a sigma level of 4.2452, as shown. The lowest sigma level was in May, while the highest sigma level was in October. Because May has the lowest sigma level, it will be the focus of studies and research. This information was used to figure out what was causing the most rejections on the subject.

The defect type data for May 2020 is shown in (Table 5). As previously stated, four machines create the identical part: In BMQ Case A, based on machines, data regarding faults was gathered. This is to determine, which machine is responsible for the greatest rejection rate. The faults listed in Table 5 are the most common types of problems with plastic components. This is made using the injection molding technique and shows that black dot defects are the leading cause of rejection during May, accounting for almost 41% of all rejections when compared to other faults. When compared to machines, the black dot still has the most faults. Others, as well as the machines, contribute the blackest dot fault in comparison to other machines. Machine E03 will be used to track down the problem since it shows the fundamental cause of black dot failures. Because it has the highest rejection rate, analytical results are used as a reference for other research.

Table 4: Total output and Sigma level

Month	Output	Machine (Reject Quantity)				Total Reject per Month	DMPO	SIGMA
		E01	E03	E07	E10			
May	299520	120	1870	1819	810	4619	3084.3	4.2420
June	299520	130	1828	1789	783	4530	3024.8	4.2485
July	299520	117	1893	1756	796	4562	3046.2	4.2461
August	299520	105	1875	1815	815	4610	3078.3	4.2426
September	299520	120	1890	1821	765	4596	3068.9	4.2437
October	299520	132	1810	1797	789	4528	3023.5	4.2486
Total	1797120	724	11166	10797	4758	27445		

Table 5: Data on rejects based on defect category for May 2020

BMO-CASE A	Machine No				Sub Total	Percentage	Acc.
Defect	E01	E03	E07	E010			
Black dot	77	694	545	536	1852	40.10	40.10
Scratches	4	608	490	188	1290	27.93	68.02
Oily/Dirty	0	320	330	43	693	15.00	83.03
Short Mold	0	0	235	0	235	5.09	88.11
Part drop	28	86	100	17	231	5.00	93.12
White Mark	4	128	20	5	157	3.40	96.51
Dented	4	17	84	15	120	2.60	99.11
Silver mark	2	17	10	0	29	0.63	99.74
Burr	0	0	0	6	6	0.13	99.87
Sink Mark	0	0	5	0	5	0.11	99.98
Weld line	1	0	0	0	1	0.02	100.00
Hook NG	0	0	0	0	0	0.00	100.00
Others	0	0	0	0	0	0.00	100.00
				Total	**4619**		

3.2.3 Analyse phase

When new models are launched, the number of faults increases dramatically. It is possible that the operators did not get enough training or did not get any specific instructions to understand how to make the part correctly. Besides that, the machines may have contributed to the high failure rate. The machines are working. It may be run by inexperienced or untrained technicians. During the machining process, this will result in mistakes in issue-solving. A high number of rejections might sometimes be the result of a stressful environment. It is human nature for people to feel stressed in the workplace, which leads to unhappiness with their working conditions and, at the same time, a high rate of fault. Aside from that, the technique or standard operating principles might also result in a significant number of faults. Methods or SOP for a certain process may differ from the real SOP for the process, resulting in incorrect machine settings or operating parameters. According to the analysis of the rejects based on models, the model BMQ –case A had the greatest proportion of faults. The probable sources of high faults are depicted in (Figure 5).

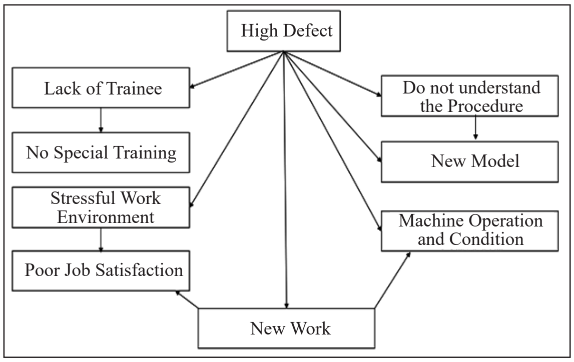

Figure 5: Reasons for a high number of faults.

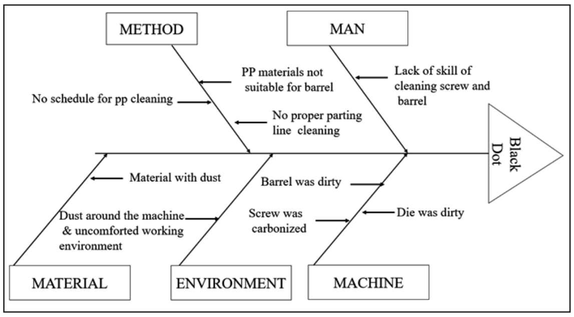

Figure 6: Cause and effect diagram for black dot.

Root causes analysis for Black dot defect: Machine, environment, man (operator), technique, and material are the five primary variables that produce incorrect component defects (Figure 6).

3.2.4 Improve phase

The black dot fault was discovered after collecting and analyzing data, and it caused a serious Injection molding line with 30 tones has a quality concern. A cause-and-effect diagram (Figure 6) was also created to illustrate the root causes of major issues, so we suggest a suitable solution for the rejections of the products to improve the processes. Also, cleaning the screws and barrels was suggested as a remedy for other problems with the products.

3.2.5 The delay time in the industry of producing plastic fuel tanks

The primary difficulty with this portion (sector) of the plastic manufacturing industry is that the changeover of molds, tools, and dies takes a long time, which delays the manufacture of fuel tanks as a result, the primary goal of this part of the study is to adopt six sigma DMAIC techniques in the plastic manufacturing industry to identify the root cause of changeover time delays and, ultimately, to find a solution to the problem [14].

3.2.6 Measure phase

This phase provides a true measurement of the current system as well as a system analysis based on data fluctuations. Validation is discovered in this step of the process by gathering data from any source and then validating it (Table 6). In the measurement phase, it is quite straightforward to determine if the collected data is genuine or not. The process of changeover begins with the head tool, which is done by two individuals, and then moves on to the mold, which is done by the same two individuals. After the head, the tool is replaced, and the mold is replaced, one person replaces the pin and plate after the head tool is replaced and the mold is replaced. After the changeover from head tool to plate is complete, all hydraulic connections are completed, and it is finally linked to the final connection. When the manufacture of one type of tank comes to a halt, the changeover process begins, and all these parts are swapped out for the creation of the next assembly. The data was gathered for 6 weeks, as well as the changeover time was counted using a basic timer. Each time of step was recorded separately so that a clear image of which process takes how long to switch could be produced. As soon as the previous action is completed, the timer for the next activity begins.

3.3 *DMAIC process*

3.3.1 Pareto chart

The Pareto chart, often known as the 80–20 rule, states that 20% of the problems in the entire system are responsible for 80% of the problems. This graphic makes it evident which factors are most likely to result in defects out of all the potential causes of defects. Since it will be simple to pinpoint and concentrate on the single factor that will enhance changeover and increase the maximum capacity of tank manufacturing, the Pareto chart is used in this project to determine which factor would cause the greatest delay in changeover [17]. From (Figure 7) it can be seen which factors produce the most flaws and which factors create the most defects in the entire process.

The graph shows that the head tool changeover procedure has the highest rate of defects (51.3%). The longer this tool switch takes, the longer the whole procedure takes. The next significant component detected in the graph that may create a defect is the molding process, which has a percentage of 24.3% in the graph, indicating that the blow molding process has taken longer owing to the longer time required for mold changeover. The figure clearly illustrates that the pin, plate, as well as final connection processes do not create significant delays in the process since they cause fewer errors throughout the changeover [18].

Table 6: Time of change over tools

Sr. No. change over	Different Activities Time				
	Head Tool	Mold	Pinch Plate	Spreader Pin	Final Connection
1	45	33	15	8	7
2	40	31	14	8	7
3	39	38	8	6	7
4	38	33	7	8	8
5	56	32	7	7	6
6	44	35	7	8	9
7	43	37	10	4	8
8	52	47	14	6	6
9	40	33	10	6	7
10	55	30	12	5	8
11	42	36	11	7	7
12	44	31	10	8	7
13	50	33	8	7	8
14	48	40	10	8	7
15	58	29	9	6	7
16	44	32	11	4	7
17	42	32	10	9	7
18	39	31	9	8	9
19	34	34	10	6	7
20	49	33	10	7	6
21	43	29	9	9	6
22	44	32	7	5	7
23	39	30	7	10	7
24	44	31	9	9	9
25	50	38	9	5	6
26	44	29	9	6	5
27	42	33	7	6	7
28	54	38	14	7	5
29	36	32	10	6	5
30	48	22	11	5	9
31	33	30	12	6	7
32	37	27	13	5	7
33	52	31	13	4	8
34	33	34	10	7	7
35	39	36	11	5	6
36	40	33	12	8	6
37	42	27	11	7	7
38	59	32	11	6	9
39	38	41	10	9	6
40	40	32	12	7	6
41	44	33	12	6	7
42	43	36	10	5	8
43	50	37	10	4	7
44	39	32	9	5	7
45	55	32	9	6	8
46	37	27	7	9	9
47	44	30	7	9	9
48	43	33	9	8	8
49	49	36	9	7	7
50	30	29	10	9	7

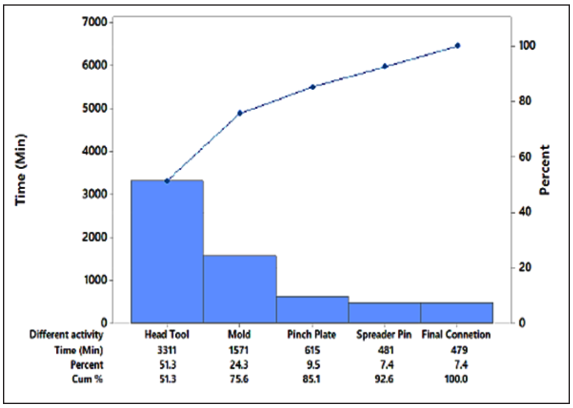

Figure 7: Pareto chart.

3.3.2 Analyse phase

After the task is finished, the information obtained will be utilized as a starting point for analyzing against metrics to assess the program's effectiveness. In this phase, all the data obtained is thoroughly reviewed using techniques like the run chart, process capacity analysis, ANOVA (Analyses of Variances), and others to discover what can be learned where the problem is located and aid in the identification of the most important areas for repair. To determine the area for improvement, all data is plotted on a run chart to see where the issue is occurring and how we may enhance the process. Run charts are generated for each activity to find areas for development (Figure 8) and a common source of variance is discovered, with elements that are more out of the ordinary being considered for improvement [19].

The run chart for the head tool (Figure 8) shows, where the data gathered (Table 6) over time for the changeover is input to examine how the data pattern is, and if it falls inside or outside of the limitations. The head tool's top and lower specification limits are 28 and 50 min, respectively. The run chart reveals that the data is beyond the limit at some point, indicating that the head tool may malfunction. The transition time taken is between 55 and 60 min, which is beyond the intended range. The following run chart, which is of importance here, clearly demonstrates that the data is out of the limit at several points, the required limit being 18–38 min. However, at times, the mold switch takes 47 min and at other times, it takes 40 min (Figure 9). The run chart demonstrates that all data is within the necessary limit

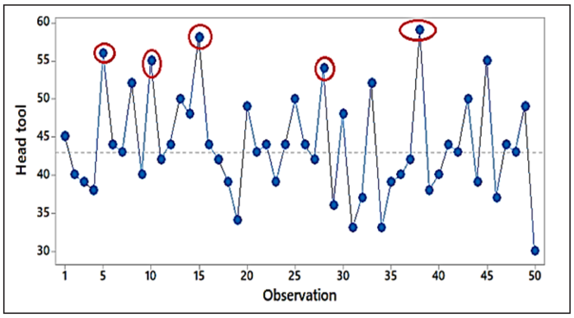

Figure 8: Run chart head tool.

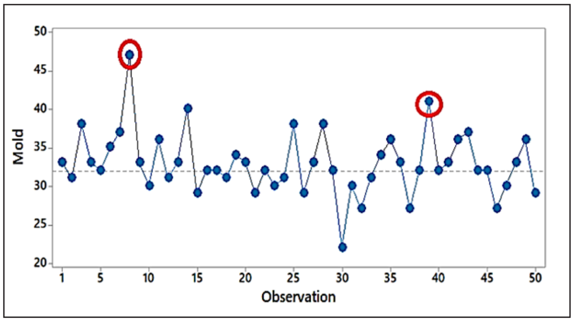

Figure 9: Run chart for mold.

in the event of various changeover processes for the pin, plate, and final connection [14].

3.3.3 Cause and effect diagram

This diagram is utilized to determine what factors may have contributed to the emergence of this problem. In this diagram, we can see many causes of an issue, including those caused by man, machines, and the environment, among others. The variables that might create issues in this project are stated in the causes, and the consequence is a delay in changeover time that is longer than the needed time (Figure 10) [20]. In addition, the lengthy tool changeover times caused manufacturing to significantly lag since many head tools, dies, and molds were needed to produce each item (types of plastic fuel tanks). Adopting Six Sigma is intended to achieve DMAIC, which is to identify aspects that will speed up tool and die modifications as well as those that will address the issue during the analysis phase. By lowering the amount of time needed to switch out tools and dies, run charts and the arrangement of mold storage are employed to tackle the issue and guarantee

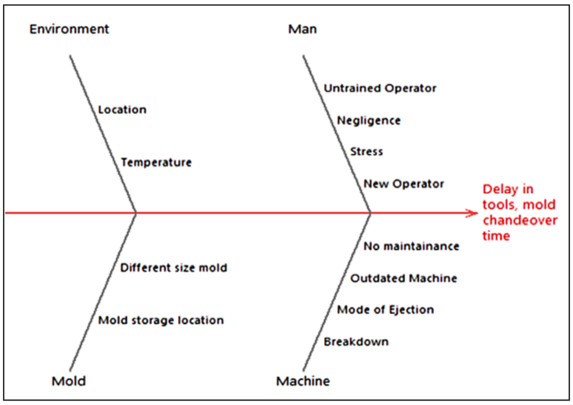

Figure 10: Cause and effect diagram.

that the process is improved. The main difficulty in implementing the proposed method appears to be when employers and supervisors lack adequate training and experience insufficient workplace stress.

3.3.4 Improve phase

The improve phase collaborates with analyze phase, in which the problem causes identified in analyze phase are addressed and corrected in the Improve phase. This method entails brainstorming possible ideas, testing the chosen option, and assessing the outcome of the implemented solution [20]. This project's head tool and mold are considered for improvement after reviewing the work plan with the changeover team for improvement in the head tool. It was discovered that creating a tool chart for all tools located at the workstation would reduce the extra time necessary to complete the changeover procedure.

4 Conclusions

The application of the Six-Sigma DMAIC technique (Define, Measure, Analyze, Improve, and Control) in plastic manufacturing processes was one of the study's goals (its main contribution), and it was accomplished at the United Company for the Plastic Industry, Iraq). On the 30-tone injection molding production section, an improvement proposal was made, and the Six-Sigma technique was used to examine the quality problem in this department as well as the fundamental cause of the black dot problem, which had been identified effectively. A material, as a key medium in the injection molding process, also contributes to several significant flaws. For example, when foreign particles get into a material, it changes the way the part works and causes it to fail and get major flaws. It proved extremely straightforward to identify the underlying problem in this plastic manufacturing business by applying the six-sigma DMAIC tools, which helped to enhance total tool, mold, and die changeover efficiency by 50%.

Initially, the entire process of changeover from tool, mold, pin, plate and final connector took an average of 95 min, but after applying the six sigma tools, this time-consuming procedure was eliminated from the transition process. Now, the average time for changing the head tool, mold, plate, pin, and final connector is 70 min, which is a significant improvement. Maintenance and the lack of expertise of the operator are also crucial since, without them, the performance of the machine would suffer, and the intended output would not be achieved. Another source of the problem was the working environment. It follows corporate policy, which stipulates that the assembly department is divided into two shifts, each with a 12 h working time. This might lead the operator to lose focus, get weary, and get bored while doing the task. The firms must commit to putting the recommended corrective action into effect. The insights gained from this research can be used to enhance other projects. The firm is expected to follow through on the proposal presented in this research. Future studies should look at ways to improve the skills of operators, focus on tools, and use automation to cut down on mistakes and costs.

Acknowledgements

The authors would like to extend my thanks and appreciation to Universiti Putra Malaysia for their support.

Author Contributions

A.S.S.I.: investigation, methodology, writing an original draft, research design, data curation, data analysis, funding acquisition; S.M.S.: conceptualization, project administration, funding acquisition, research design, reviewing and editing; J.T.: writing-reviewing and editing; A.A: writing-reviewing and editing. The authors have all read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] C. Harris, R. Harris, and E. Wilson, *Steps to Implementing a Lean Material Handling System*. Massachusetts: Lean Directions, 2004.

[2] T. Bendell, "A review and comparison of six sigma and the lean organisations," *The TQM Magazine*, vol. 18, no. 3, pp. 255–262, 2006.

[3] A. S. Chahal and V. Singh, "Review to six sigma: A metric and a methodology," *International Journal of Recent Engineering Research and Development*, vol. 8, no. 10, pp. 58–60, 2013.

[4] J. R. Evans and W. M. Lindsay, *An Introduction to Six Sigma and Process Improvement*. Massachusetts: Cengage Learning, 2014.

[5] M. J. Harry and R. Schroeder, *Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*. Sydney, Australia: Currency, 2000.

[6] A. Chiarini, "Improvement of OEE performance using a Lean Six Sigma approach: An Italian manufacturing case study," *International Journal of Productivity and Quality Management*, vol. 16, no. 4, pp. 416–433, 2015.

[7] M. S. Raisinghani, H. Ette, R. Pierce, G. Cannon, and P. Daripaly, "Six Sigma: Concepts, tools, and applications," *Industrial Management & Data Systems*, vol. 105, no. 4, pp. 491–505, 2005.

[8] A. K. Sahoo, M. K. Tiwari, and A. R. Mileham, "Six Sigma based approach to optimize radial forging operation variables," *Journal of Materials Processing Technology*, vol. 202, no. 1–3, pp. 125–136, 2008.

[9] C. Bott, E. Keim, S. Kim, and L. Palser, "Service quality six sigma case studies," in *ASQ World Conference on Quality and Improvement Proceedings*, 2000, Art. no. 225.

[10] A. Chiarini, "Risk management and cost reduction of cancer drugs using Lean Six Sigma tools," *Leadership in Health Services*, vol. 25, no. 4, pp. 318–330, 2012.

[11] K. Raweesawat and S. Sukparungsee, "Explicit formulas of ARL on double moving average control chart for monitoring process mean of

zipinar (1) model with an excessive number of zeros," *Applied Science and Engineering Progress*, vol. 15, no. 3, Art. no. 4588, 2022, doi: 10.14416/j.asep.2021.03.002.

[12] V. Dwivedi, M. Anas, and M. Siraj, "Six sigma; as applied in quality improvement for injection moulding process," *International Review of Applied Engineering Research*, vol. 4, no. 4, pp. 317–324, 2014.

[13] P. D. Kale, P. D. Darade, and A. R. Sahu, "A literature review on injection moulding process based on runner system and process variables," in *IOP Conference Series: Materials Science and Engineering*, vol. 1017, no. 1, 2021, Art. no. 012031.

[14] D. Desai and B. N. Prajapati, "Competitive advantage through Six Sigma at plastic injection molded parts manufacturing unit: A case study," *International Journal of Lean Six Sigma*, vol. 8, no. 4, pp. 411–435, 2017.

[15] S. Sugiarto and I. Krisnadi, "Management monitoring quantity reject, output dan cycle time produksi di mesin tapping berbasis komunikasi modbus rtu dengan labview," Ph.D. dissertaion, Department of Electrical Engineering, Universitas Mercu Buana, Indonesia, 2018.

[16] R. Mahendran, V. Amarnath, P. Rajkumar, L. Nirmal raj, S. Karthikeyan, and L. Rajeskumar, "Productivity improvement in a manufacturing industry by using man–machine chart analysis," in *Technology Innovation in Mechanical Engineering*. Singapore: Springer, 2022, pp. 603–613.

[17] G. Eckes, *The Six Sigma Revolution: How General Electric and others Turned Process into Profits*. New Jersey: John Wiley & Sons, 2002.

[18] P. C. Gholap and T. N. Desai, "Reduction of rework the Six Sigma way: case study of an Indian small scale industry," *International Journal of Six Sigma Competitive Advantage*, vol. 7, no. 1, pp. 92–116, 2012.

[19] J. De Mast and J. Lokkerbol, "An analysis of the Six Sigma DMAIC method from the perspective of problem solving," *International Journal of Production Economics*, vol. 139, no. 2, pp. 604–614, 2012.

[20] V. Lall and A. Gupta, "A tool based framework for applying Six Sigma methodology to services and transactional data," *International Journal of Productivity and Quality Management*, vol. 5, no. 4, pp. 440–451, 2010.