

# **Quality Improvement in Plastic Injection Molding Industry: Applying Lean Six Sigma to SME in Kuwait**

**Alaa Alshammari, Sahar Redha, Shahad Hussain, Tuleen Nazzal, Zahraa Kamal, and  
Walid Smew**

Industrial Engineering Department  
American University of the Middle East (AUM)  
Eqaila, Kuwait  
[Walid.Smew@aum.edu.kw](mailto:Walid.Smew@aum.edu.kw)

## **Abstract**

In this paper, Lean and Six Sigma were applied to a Small and Medium-Sized Enterprise (SME), Company XYZ for plastic manufacturing in Kuwait, to reduce the variation in their injection molding process. Variation exists within any process and when this variation goes beyond certain limits, non-conforming parts are produced and the company will face increased percentage of waste, operational cost, and reduced customer's satisfaction. Many of the XYZ Company plastic fittings were rejected as they were defective or having defects such as internal surface marks, flash, and bubbles. Floor Traps 6x4x2 fittings accounted for the highest rejection rate in XYZ Company. Six Sigma DMAIC combined with the 5S were applied to tackle this problem. DMAIC is a general engineering design approach that can be applied for many production or service problems that need practical solutions. It is an acronym stands for Define, Measure, Analyze, Improve, and Control. Results show that by implementing Six Sigma combined with the 5S program, Company XYZ achieved an improvement in its Sigma Level and Defects rate (DPMO) which lead to significant cost savings and increased its competitiveness.

## **Keywords**

Lean Six Sigma, DMAIC, SME, Injection Molding, Variation, Cause and Effect Matrix, SPC, DOE, Desirability Function Approach

## **1 Introduction**

Manufacturing is the action of making things. It is the process of transforming materials into items with greater value. Most materials used in manufacturing are classified into four categories: metals, ceramics, polymers and composites. Polymers are divided into two categories: plastics and rubbers. Thermoplastics and thermosets are two types of plastics. Unlike thermosets, thermoplastics can be subjected to heating and cooling cycles repeatedly without degrading. This property allows thermoplastics to be used in plastic injection molding, which is the primary focus of this study (Valles, Sanchez, Noriega, & Nunez, 2009).

“Injection molding is a process in which a polymer is heated to a highly plastic state and forced to flow under high pressure into a mold cavity, where it solidifies. The molded part, which is called a molding, is then removed from the cavity,” (Groover, 2013, p. 238). Within any process there exists variation. When this variation goes beyond certain limits, defected parts, and waste may be produced. Lean and Six Sigma are principles that aim to reduce variation and eliminate waste as much as possible (Montgomery, 2013).

Lean is a way of thinking that aims to reduce waste, improve throughput, promote work standardization, and organize the workplace to be more effective and efficient (Lee & Wei, 2010). While Six Sigma is a principle, an idea of improving a process by reducing process variation related to the quality characteristics of the product; it describes how a process deviates from the target.

The main idea of Six Sigma is to fit six standard deviations between the mean (target) and the specification limit (Blount et al., 2000). Anything out of the specification limits is considered as defective and is measured by parts per million (PPM) or defects per million opportunities (DPMO).

Lean and Six Sigma are not mutually exclusive as they can be applied side by side. The implementation of lean combined with the Six Sigma principle aim to prevent defects rather than detecting them. Lean Six Sigma is an effective way of improving a process by reducing variation and waste as much as possible (Montgomery, 2013).

## 2 LITERATURE REVIEW

Different case studies were studied, linked, and compared. Before applying the DMAIC methodology, we had to understand how Lean Six Sigma can be applied in plastic injection molding.

Two similar case studies, one by (Lo, Tsai, & Hsieh, 2009) and another by (Bharti, Khan, & Singh, 2011), both aimed to improve the quality of their injected molded products. The product produced in (Lo, Tsai, & Hsieh, 2009) study was plastic lenses while (Bharti et al., 2011) focused on nylon-6 bush. Inappropriate settings of the injection molding process parameters resulted in defects, some of which were: stress marks, warpage, over-shrinkage, sink marks, and stress cracking problems. In both case studies the process conditions were changed only. Tools like Pareto chart, process capability charts, fish bone diagram, Taguchi and many more were used in both case studies. Implementation of DMAIC was successful in both case studies as the process capability index of (Lo et al., 2009) increased from 0.57 to 1.75, and the sigma levels of the process of (Bharti et al., 2011) increase from 2.38 to 5.18.

Another bush study that is similar to (Bharti et al., 2011) was done by (Mansur, Mu'alim, & Sunaryo, 2016). This study was more detailed and thorough with their findings and solutions. The aim of this study was to apply Lean Six Sigma to minimize the defects produced and reduce the waste. The wastes were classified into four types. The types of defects were classified into eight. The data measured and collected was also classified into attribute data and variable data. Based on attribute data of the bush product the sigma level was 4.6 and the DPMO is 988.42. The variable data on each dimension has its own DPMO and sigma level. Similar tools to (Lo et al., 2009) were used.

A study conducted in Malaysia by (Kairulazam, Hussain, Zain, & Lutpi, 2014) was done due to the high rejection rate of high gloss plastics produced by the process injection molding. The rejection was due to technical adjustment, sink mark, flow mark, and others. Tools such as fishbone diagram, Pareto chart, FMEA, and function development matrix were used to identify possible factors. Gage R&R and T-Test were used to test for significant difference. They managed to improve the process from  $1.74\sigma$  to  $3.00\sigma$ .

## 3 Methodology

The DMAIC methodology was used in this study to improve the injection molding process. DMAIC is an acronym that stands for Define-Measure-Analyze-Improve-Control. "These phases lead a team logically from defining a problem through implementing solutions linked to underlying causes, and establishing best practices to make sure the solutions stay in place" (George, Rowlands, Price, & Maxey, 2005, p. 1).

### 3.1 Define Phase

The first phase of DMAIC is define, where the problem is stated along with the inputs and outputs of the system. The projects goal, objective and customer requirements are also stated in this phase.

Fig. 1 shows that the process of injection molding contributes to around 75% of the company's sales. Thus, improving the quality of an injected molding product will highly affect the company's profits.

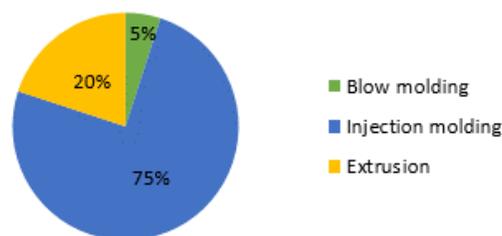


Figure 1. Percentage of company XYZ sales

In Company XYZ, the product with the highest percentage of rejection was Floor Trap 6x4x2; thus, the boundary of our project was to focus on this product.

A project charter was constructed to illustrate the project’s objective, scope, team members and the due dates to accomplish each phase of DMAIC. The project charter was used to provide the management of Company XYZ with the direction in which our project was going. In addition, it served as an agreement between the Lean Six Sigma team, and the management of the company. The goal and scope of this study was to reduce the defect rate of Floor Trap 6x4x2 fittings up to 50%.

Furthermore, a SIPOC diagram was constructed to identify relevant elements of the project, in which it gives general information and an overview of the project. SIPOC is an acronym that stands for suppliers, inputs, process, outputs, and customers. The SIPOC diagram is shown in Fig. 2.

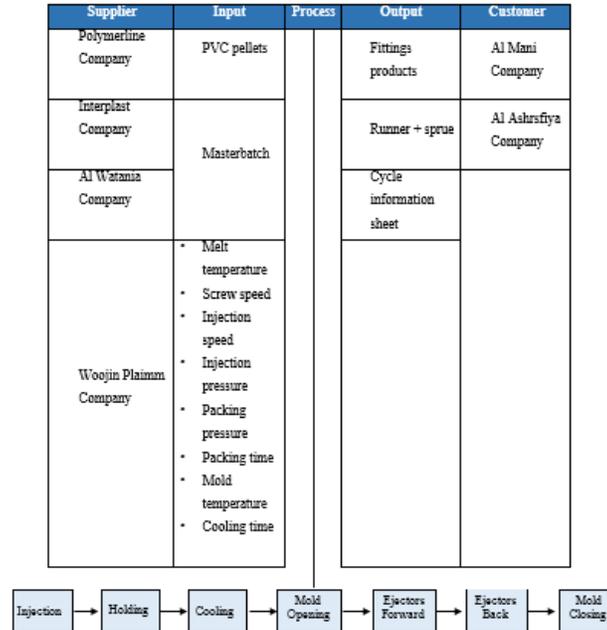


Figure 2. SIPOC diagram

In the define phase of DMAIC, SIPOC helped us to agree on the project’s boundary, and identified the stakeholders. Stakeholders are those who are related to the project; anyone that benefits from the project, or gets affected by it is considered a stakeholder.

### 3.2 Measure Phase

The second phase is measure. In this phase a baseline is set to understand the current performance of the process. The baseline will be useful later on in the improve phase when we want to compare the improvements made (Jirasukprasert, Garza-Reyes, Soriano-Meier, & Rocha-Lona, 2012).

First, we needed to understand the procedure that the Floor Trap fitting goes through. A deployment flowchart, also known as swim lane flowchart, was constructed to show the steps of the process and the interactions between people or departments. This is shown in Fig. 3.

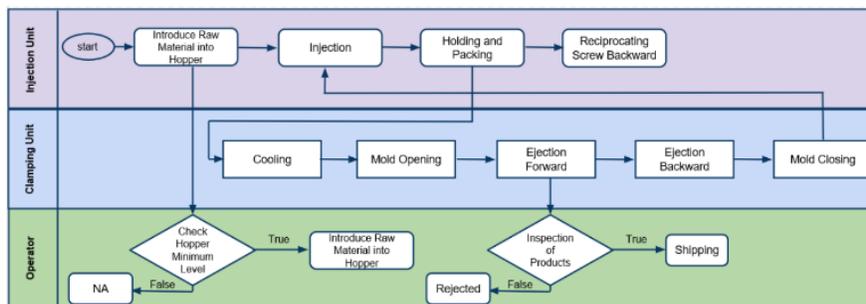


Figure 3. Swim lane flowchart

In the lane of the operator, the operator inspects the products and decides whether to accept or reject it. Measuring attribute data in terms that rely on human judgment may cause problematic measurement system issues (Linderman, Schroeder, Zaheer, & Choo, 2003). Since the judgment of the operator is nominal, we have used the Kappa Statistic. Kappa is a type of attribute Measurement System Analysis (MSA) which measures the degree of agreement of the assessments that are made by different appraisers when assessing the same samples. We have used Minitab software to generate an output for the Kappa Statistics which consists of four categories. Fig. 4 displays two of the categories. As it can be seen in Fig. 4, the percentages of agreement are all 90% or above which states consistency and almost perfect agreement.

We have concluded from the attribute agreement analysis, the operators' judgment is acceptable; therefore it states that the source of variation is from the process itself.

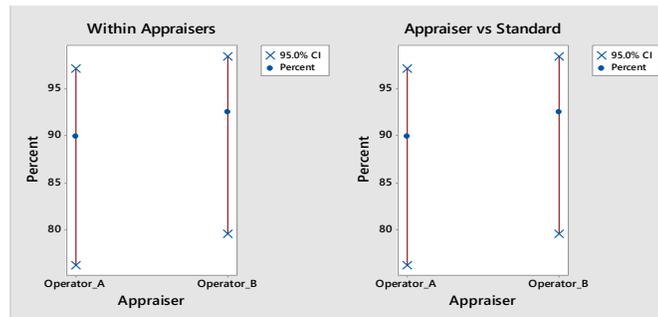


Figure 4. Attribute agreement analysis

A random sample of 400 products was gathered to specify the types of defects and defectives that were caused by the process. The Pareto chart in Fig. 5 shows that internal surface marks, flash, and bubbles were the vital few and the rest were considered as the trivial many.

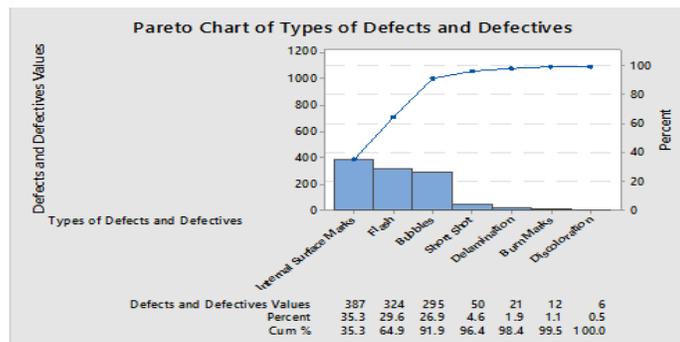


Figure 5. Pareto chart of the types of defects and defectives

The defect rate was interpreted into two levels. The two levels were DPMO and sigma level. Table 1 shows the current and expected DPMO, sigma level, and loss in terms of money.

Table 1. Current and expected values

Estimations for Floor Traps 6x4x2 Fittings	Current	Expected
Sigma Level	1.4	$\geq 2$
DPMO	516,500	$\leq 256,250$
Rejected Quantity/Day	81	40
Rejected Percentage (%)	18%	9%
Rejected Loss in KWD/Year	6343.35	3171,67

### 3.3 Analyze Phase

The third phase is analyze. The aim of this phase is to identify problems in the injection molding process that would contribute to the production of defects; the data gathered from the Measure phase was used to pinpoint the cause of these defects. In addition to identifying the root causes of the problem, the aim of the analyze phase is to provide insight into how to eliminate these causes.

A Cause and Effect diagram, also known as Fishbone diagram or Ishikawa diagram is a graphical tool that is used to sort the potential causes of any problem, in order to identify its root causes. It is illustrated in Fig. 6.

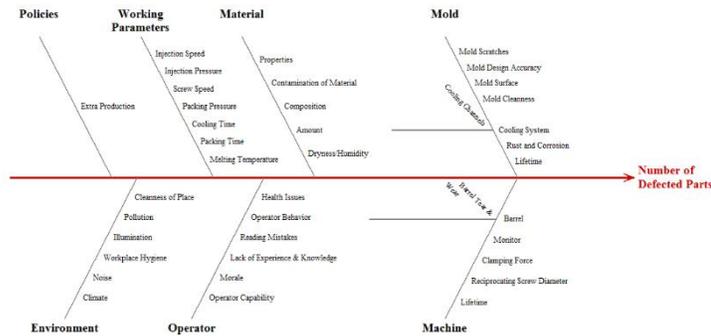


Figure 6. Fishbone diagram

The most critical causes in the Fishbone diagram were selected, and were further analyzed; they turned out to be: working parameters, monitor of the machine, contamination of the material, amount of the material, dryness of the material, surface of the mold, cleanness of the mold, environment of the workplace, and operator’s behavior and health.

### 3.4 Improve Phase

The fourth phase is improve. After identifying root causes in the analyze phase, we move onto the improve phase. In the improve phase, we generate possible solutions, select the best solutions, test the solutions and then evaluate the improvement in terms of sigma level. From the analyze phase, potential root causes were identified.

One of the root causes was the working parameters. The working parameters can be adjusted through design of experiments (DOE). Before applying DOE, we needed to minimize the amount of working parameters, and find out which are critical enough to be used as the factors in DOE (Anderson & Whitcomb, 2005).

Cause and effect matrix was used to identify the few key input variables that must be addressed to improve the variables of the process output. Fig. 7 displays the relationship between the inputs and the outputs. We concluded from the cause and effect matrix that three out of the nine inputs, and one output will be tested using DOE. The three inputs were: injection speed, injection pressure, and melting temperature, while the output was the number of defects.

Process Step	Input Variables (Xs) ↓	Importance to Customer (1-10)				Weighted Score (X)	%	Order	Status (critical or eliminated)
		Weight	Cycle time	Thickness	Number of defects				
Injection molding process	Injection speed	9	9	9	9	216	23.7%	1	critical
	Injection pressure	9	3	9	9	198	21.7%	3	critical
	Screw speed	3	9	3	3	90	9.9%	4	eliminated
	Packing pressure	3	1	1	3	56	6.1%	6	eliminated
	Packing time	3	3	1	1	42	4.6%	7	eliminated
	Cooling time	3	3	1	3	62	6.8%	5	eliminated
	Melting temperature	9	9	9	9	216	23.7%	2	critical
	Clamping force	0	1	0	0	3	0.3%	9	eliminated
	Contamination of material	0	0	0	3	30	3.3%	8	eliminated
Weighted Score (Y)		39	38	33	40	913			

Figure 7. Cause and effect matrix

After selecting our inputs and the corresponding output, we conducted Factorial Design of experiments (DOE). According to (Montgomery, 2005) “is a systematic method to study and determine the relationship between factors

affecting a process, and the output of that process”. A  $2^3$  full factorial experiment was conducted. The levels of each factor are shown in Table 2.

Minitab was used to analysis the data of our experiment (Montgomery, 2014). As it can be seen in Fig. 8, all terms were significant excluding the two-way interaction between the injection speed and the melting temperature.

Table 2. Levels of each factor

Factor	Levels	
	Low	High
Injection speed (%)	3	8
Injection pressure (Bar)	165	170
Melting temperature (°C)	180	185

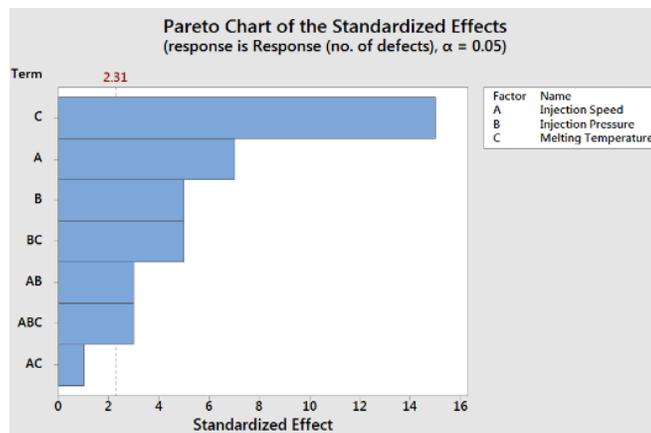


Figure 8. Pareto chart for the standardized effects

The fitted regression model was optimized using the Desirability Function Approach (Myers & Montgomery, 2002), implemented in Minitab, in order to find the optimum solution of the selected input parameters (Derringer & Suich, 1980). The values were found to be 6.125%, 170 Bar, and 180°C for the injection speed, injection pressure, and the melting temperature, respectively. With the corresponding values, the minimum number of defects produced is two.

Failure Modes Effects Analysis (FMEA) was applied to tackle the root causes that have been revealed in the Fishbone Diagram that could not be solved through DOE. After identifying the possible failures, their effects on the product were determined and actions to reduce the failures were then assigned. In addition, these actions are prioritized through the use of FMEA. The actions that were taken are displayed in Table 3.

After improving the process and executing the action plans, we needed to measure the improvement that has been made so it can be compared to the baseline. We noted and counted the types of defects that were seen. We did not take the internal surface marks into consideration as it is caused from a scratch on the mold. The count of the types of defects and defectives that were seen, are presented in a before and after bar chart shown in Fig. 9.

We interpreted our counts into sigma level and DPMO. As it can be seen in Table 4, the sigma level improved from 1.4 to 2.37 and the DPMO decreased from 516,500 to 190,000. This would reflect on the amount of products rejected every day, and costs related to recycling and rejection would decrease (Hung & Sung, 2011).

Table 3. Action plan

RPN	Failure mode	Action Plan
560	Dryness of material	✓ Use a drying machine
294	Contamination of material	✓ Reduce the recycled material and distribute it evenly among the batches of PVC
270	Occupational health issues	✓ Provide a first aid kit ✓ Provide frequent breaks
160	Behavior of operator	✓ Assign rewarding and recognition programs ✓ Assign penalties
140	Cleanness of mold	✓ Make a schedule to clean the mold
84	Insufficient amount of material inserted	✓ Make a schedule to check the amount of material in the hopper

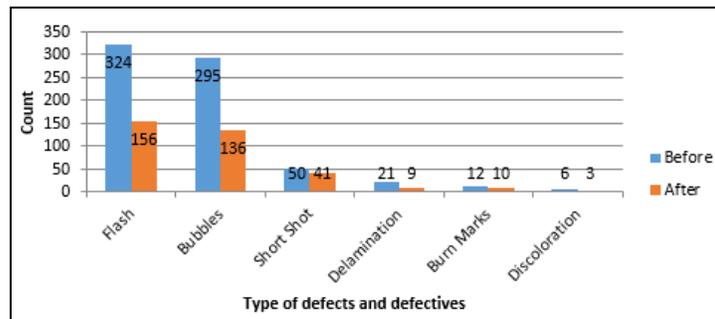


Figure 9. Bar chart comparing before and after improvements

Table 4. Before and after values

Floor Trap Product	Before	After
Sigma Level	1.4	2.3
DPMO	516,500	190,000
Rejected quantity/ day	81	30
Rejected percentage (%)	18	7
Rejected loss in KWD/year	6343	2333

According to the Fishbone diagram in Fig. 6, the workplace hygiene had an impact on the number of defects produced in the injection molding process. Currently, the principles of 5S are being applied in Company XYZ. 5S is a lean tool used for organizing a workplace in an efficient, sanitary and safe manner (Khedkar, Thakre, Mahantare, & Gondne, 2012). It is named after a different Japanese word beginning with the letter “S” which are: Seiri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Standardize), and Shitsuke (Sustain) (Kobarne, Gaikwad, Dhaygude, & Bhalerao, 2015).

### 3.5 Control Phase

The fifth and final phase is control. The purpose of the control phase is “to complete project work and hand off improved process to process owner, with procedures for maintaining the gains” (George et al., 2005, p. 17). An attribute control chart shown in Fig. 10 was constructed (Mishra, Mishra, & Sachendra, 2015). *No assignable causes nor patterns were present in the control chart, and since all points fall randomly within the control limits, we have concluded that the injection molding process is under control and exhibits common cause variation.*

Following the execution of phase-one of the control charts, phase-two should be done by Company XYZ to monitor the performance of their process. An Out-of-Control-Action Plan (OCAP) was formed as a corrective action plan. It consists of checkpoints and terminators. Checkpoints are the potential assignable causes while terminators are the actions that should be taken to eliminate these causes.

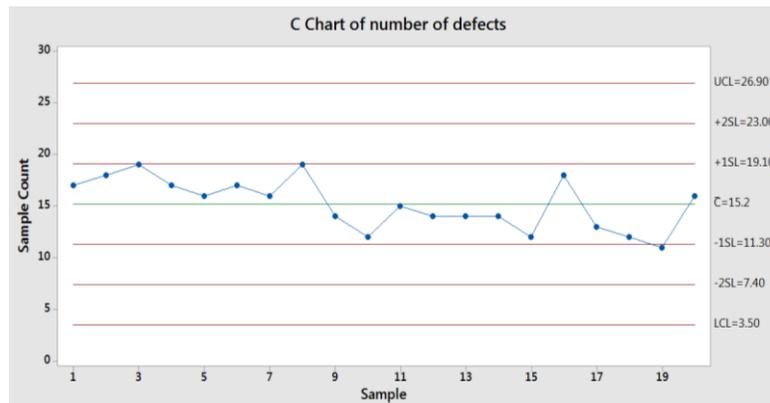


Figure 10. Control chart

After completing the five phases of DMAIC, a sign off ensured that the project was accomplished on time, while meeting the outcomes of the project’s scope and quality (Wankhade, Gride, & Bandabuche, 2014).

## 4 CONCLUSION

In this project, the concepts of Lean Six Sigma were successfully applied to Company XYZ to improve its injection molding process (Dwivedi, Anas, & Siraj, 2014). DMAIC was used to tackle the problem of the rejecting poor quality products. We found that the consequences of producing poor quality products affected the reputation of the company; money, time and effort are lost when rejected products are scraped, reworked or recycled.

We started off by selecting the product with the highest rejection percentage which turned out to be Floor Trap 6x4x2. We then classified the types of defects and defectives produced in this type of product. The current performance of the injection molding process was evaluated in terms of sigma level, and DPMO. This acted as a baseline for our study. In order to find the root causes of the problem, a Fishbone diagram was constructed. Brainstorming sessions were useful in selecting the most appropriate causes that had an influence on the number of defects produced.

Following that, DOE was used to find the optimum parameters of the injection speed, injection pressure, and melting temperature that would produce the minimum number of defects. Other causes such as the operator’s behavior, mold surface and so on, were considered in the FMEA. Actions that would reduce the number of defects were implemented, and recommended to Company XYZ.

After improving the system, the sigma level increased from  $1.4\sigma$  to  $2.3\sigma$  and DPMO decreased from 516,500 to 190,000. This improvement accounts for more than 50% of process improvement. A control chart was used to check for stability of the process, and an Out-of-Control-Action plan was provided to the company for maintaining process improvements. The improvement that we have made will increase profits made by the organization and improve the overall performance of the injection molding process.

## 5 FUTURE WORK

After successfully improving the process of injection molding for the Floor Trap product, further Six Sigma projects can be applied in the same sector to induce further improvements. For future work, the same project can be replicated to the other fittings that are produced such as applying Lean Six Sigma to the Coupling UPVC 63 mm fitting. Moreover, the same project can be applied to the same product (Floor Trap 6x4x2) but concentrating on variable Critical-to-Quality (CTQ) characteristics, instead of attribute CTQ.

### Acknowledgment

We would like to acknowledge AUM and the Industrial Engineering department for facilitating this project and for their support throughout the time to make this work come true. Many thanks to Dr. Suat Kasap for all the assistance and feedbacks to participate in IEOM-Bandung (2018). Also, we would like to thank XYZ Company for their genuine cooperation and allowing us to practice our engineering knowledge and skills to finalize this project with full support and open arms.

### References

- Anderson, M. J., and Whitcomb, P. J., *RSM Simplified: Optimizing Process Using Response Surface Methods for Design of Experiments*, 1<sup>st</sup> Edition, Productivity Press, New York, 2005.
- Bharti, P. K., Khan, M. I., and Singh, H., Six Sigma Approach for Quality Management in Plastic Injection Moulding Process: A Case Study and Review, *International Journal of Applied Engineering Research*, vol. 6, no. 3, pp. 303-314, 2011.
- Blount, B. C., Milgram, K. E., Silva, M. J. Malek, N. A., Reidy, J. A., Needham, L. L., and Brock, J. W., Quantitative Detection of Eight Phthalate Metabolites in Human Urine Using HPLC-APCI-MS/MS, *Analytical Chemistry*, vol. 72, no. 17, pp. 4127-4134, 2000.
- Derringer, G., and Suich, R., Simultaneous optimization of several response variables, *Journal of quality technology*, vol. 12, no. 4, pp. 214-219, 1980.
- Dwivedi, V., Anas, M., and Siraj, M., Six Sigma: As Applied in Quality Improvement for Injection Molding Process, *International Review of Applied Engineering Research*, vol. 4, no. 4, pp. 317-324, 2014.
- Groover, M., *Principles of Modern Manufacturing*, 5<sup>th</sup> Edition, John Wiley & Sons, Inc., New York, 2013.
- George, M. L., Rowlands, D., Price, M., and Maxey, J., *The lean Six Sigma pocket toolbox*, 1<sup>st</sup> Edition, The McGraw.Hill Companies, USA, 2005.
- Hung, H. C., and Sung, M. H., Applying Six Sigma to Manufacturing Processes in the food Industry to Reduce Quality Cost, *Scientific Research and Essays*, vol. 6, no. 3, pp. 580-591, 2011.
- Kairulazam, C. K. A. C. K., Hussain, M. I., Zain, Z. M., and Lutpi, N. A., Reduction of Rejection Rate for High Gloss Plastics Product Using Six Sigma Method, *Applied Mechanics and Materials*, vol. 606, pp. 141-145, 2014.
- Khedkar, S. B., Thakre, R. D., Mahantare, Y. V., and Gondne, R., Study of Implementing 5S Techniques in Plastic Molding, *International Journal of Modern Engineering Research*, vol. 2, no. 5, pp. 3653-3656, 2012.
- Kobarne, A. R., Gaikwad, V. K., Dhaygude, S. S., and Bhalerao, N. H., Implementing of 5S Technique in a Manufacturing Organization: A Case Study, *International Journal of Research in Enigeering and Technology*, vol. 4, no. 1, pp. 136-148, 2015.
- Jirasukprasert, P., Garza-Reyes, J. A., Soriano-Meier, H., and Rocha-Lona, L., A Case Study of Defects Reduction in a Rubber Gloves Manufacturing Process by Applying Six Sigma Principles and DMAIC Problem Solving Methodology, *International Conference on Industrial Engineering and Operations Management*, pp. 472-481, Istanbul, Turkey, 3-6 July, 2012.
- Lo, W. C., Tsai, K. M., and Hsieh, C. Y., Six Sigma Approach to Improve Surface Precision of Optical Lenses in the Injection-Molding Process, *The International Journal of Advanced Manufacturing Technology*, vol. 41, no. 9, pp. 885-896, 2009.

- Lee, K. L., and Wei, C. C., Reducing Mold Changing Time By Implementing Lean Six Sigma, *Quality and Reliability Engineering International*, vol. 26, no. 4, pp. 387-395, 2010.
- Linderman, K., Schroeder, R. G., Zaheer, S., and Choo, A. S., Six Sigma: A Goal Theoretic Perspective, *Journal of Operations Management*, vol. 21, no. 2, pp. 193-203, 2003.
- Mansur, A., Mu'alim, and Sunaryo, Plastic Injection Quality Controlling Using the Lean Six Sigma and FMEA Method, *IOP Conference Series: Materials Science and Engineering*, vol. 105, Yogyakarta, Indonesia, 28 January, 2016.
- Mishra, A., Mishra, P., and Sachendra, Six Sigma Methodology in a Plastic Injection Molding Industry: A Case Study, *International Journal of Industrial Engineering and Technology*, vol. 7, no. 1, pp. 15-30, 2015.
- Montgomery, D. C., *Statistical Quality Control: A Modern Introduction*, 7<sup>th</sup> Edition, John Wiley & Sons, Inc., Hoboken, 2013.
- Montgomery, D. C., *Design and Analysis of Experiment*, 6<sup>th</sup> Edition, John Wiley & Sons, Inc., USA, 2005.
- Montgomery, D. C., and Runger, G. C., *Applied Statistics and Probability for Engineers*, 6<sup>th</sup> Edition, John Wiley & Sons, Inc., USA, 2014.
- Myers, R. H., and Montgomery, D. C., *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, 2<sup>nd</sup> Edition, John Wiley & Sons, Inc, New York, 2002.
- Valles, A., Sanchez, J., Noriega, S., and Nunez, B. G., Implementation of Six Sigma in a Manufacturing Process: A Case Study, *International Journal of Industrial Engineering*, vol. 16, no. 3, pp. 171-181, 2009.
- Wankhade, A. R., Gride, S. S., and Bandabuche, P. N., An Application of Six Sigma in Service Sector: A Case Study, *International Journal of Research in Advent Technology*, vol. 2, no. 2, pp. 1-8, 2014.

## **Biographies**

**Walid Smew** is an Assistant Professor in Industrial Engineering at the American University of the Middle East (AUM), Kuwait. He earned B.Sc. and M.Sc. in Industrial and Systems Engineering from Benghazi University, Libya and PhD in Lean Supply Chain Management from the School of Mechanical and Manufacturing Engineering in Dublin City University (DCU), Ireland. Dr. Smew is a Chartered Engineer and member of Libyan Engineers Association, he is also a certified Lean Six Sigma Greenbelt and Product and Process Validation engineer in Ireland. Dr. Smew has published several journal and conference papers and supervised many graduation projects. He has an excellent experience, both theoretically and practically, in machining and metal forming operations and the application of Lean Six Sigma for problem solving and finding optimized solutions through the application of different statistical techniques. Dr. Smew provided technical guidance to assembly processes using work measurement techniques to identify opportunities to improve production performances in terms of time and cost. Dr. Smew has done consulting in the area Supply Chain Management (SCM) and Simulation Modeling along with Dr. John Geraghty from DCU; they developed a comprehensive production and distribution simulation model for Ireland's future oil supply on behalf of Byrne Ó Cléirigh for engineering and management consultancy. Dr. Smew research interest include Quality Control, Lean Six Sigma, SCM, Manufacturing Processes, Simulation and Optimization.

**Alaa Alshammari, Sahar Redha, Shahad Hussain, Tuleen Nazzal, and Zahraa Kamal** are recently graduated students from the American University of the Middle (AUM) in Kuwait, majoring in Industrial Engineering. During their four years of study they gained several engineering and computational skills. They worked with computer software such as MS Office, AutoCAD, Minitab, MATLAB, Arena, Solid works, Jack, and Visual Studio. They participated in many AUM academic activities and in addition to their major graduation project presented in this paper, they worked on several course projects in the area of manufacturing processes and robotics, safety and ergonomics, operation research, quality control, simulation, and lean six sigma.