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 (℃)	180	185

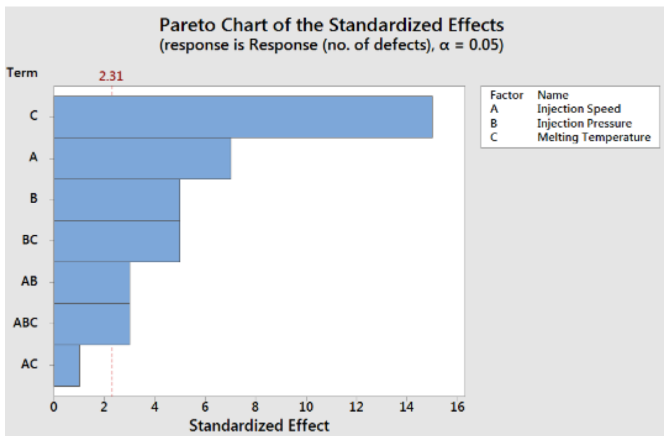

Figure 8. Pareto chart for the standardized effects

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℃ 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

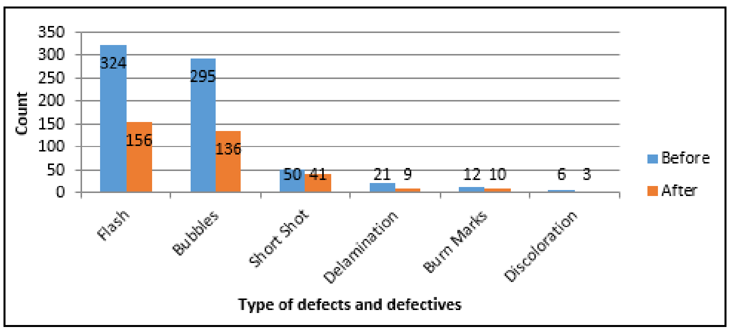

Figure 9. Bar chart comparing before and after improvements

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.

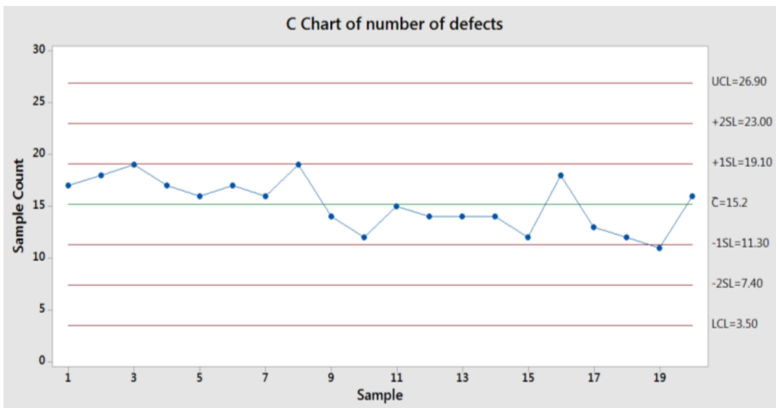

Figure 10. Control chart

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 1.4σ to 2.3σ 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.

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References

Anderson, M. J., and Whitcomb, P. J., *RSM Simplified: Optimizing Process Using Response Surface Methods for Design of Experiments*, 1st 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*, 5th Edition, John Wiley & Sons, Inc., New York, 2013.

George, M. L., Rowlands, D., Price, M., and Maxey, J., *The lean Six Sigma pocket toolbook*, 1st 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*, 7th Edition, John Wiley & Sons, Inc., Hoboken, 2013.

Montgomery, D. C., *Design and Analysis of Experiment*, 6th Edition, John Wiley & Sons, Inc., USA, 2005.

Montgomery, D. C., and Runger, G. C., *Applied Statistics and Probability for Engineers*, 6th Edition, John Wiley & Sons, Inc., USA, 2014.

Myers, R. H., and Montgomery, D. C., *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, 2nd 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

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