APPLICATION OF LEAN SIX SIGMA FOR ENHANCING PERFORMANCE IN THE POULTRY WASTEWATER TREATMENT

A. Ishak[1], E. Mohamad[1,2], H. Arep[1], U. Linarti[3] and A. Larasti[4]

[1]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]Faculty of Mechanical and Manufacturing Engineering Technology,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[3]Fakultas Teknik Industri,
Universitas Ahmad Dahlan, 55191 Yogjakarta, Indonesia.

[4]Fakultas Teknologi,
State University of Malang, 65145 Jawa Timur, Indonesia.

Corresponding Author's Email: [1]effendi@utem.edu.my

Article History: Received 6 December 2021; Revised 4 May 2022; Accepted 12 June 2022

ABSTRACT: This paper emphasizes sustainable wastewater treatment (WWT) performance using the Lean and Six Sigma framework. Considering the present global environmental challenges, it is critical to implement wastewater management, especially for treating industrial effluents. This study implements the Six Sigma, DMAIC (*Define, Measure, Analyse, Improve and Control*) approach to construct a novel method for optimizing energy use and reducing chemical consumption by deploying an appropriate WWT unit process assessment procedure that effectively treats effluents before being discharged to the environment. A Malaysian SME poultry plant was selected for data gathering from July 2020 to May 2021. Data evaluation was performed as per the practices suggested in the Lean and Six Sigma framework tools. The study produced noteworthy results where process streamlining and simple changes facilitated a 15.3% reduction in monthly chemical requirement. Moreover, process capacity enhancement concerning DO and pH pertaining to biological and chemical treatment process. Finally, the study outcome suggested a statistically significant ($p<0.05$) reduction in AN, COD, and BOD_5 mean values were near 66%, 58%, and 47% respectively. Therefore, effluent quality was significantly improved using this approach.

KEYWORDS: *Lean Six Sigma, DMAIC, Wastewater Treatment, Continuous Improvement*

1.0 INTRODUCTION

Adequate water quality is critical for health, social wellbeing, vital resources facilitating economic growth, and environmental balance. It is estimated that the world population will rise to nine billion by 2050 [1]. The natural environment is degrading rapidly; hence, it is becoming challenging and critical to preserving water quality. Better wastewater management and pollution control are fundamental solutions [2]. Water resources must be handled wisely; aspects like freshwater consumption, wastewater management, and environmental discharge must be performed appropriately. There has been a reduction in global water quality because of improper WWT and industrial discharge. About 80% of the wastewater produced in the world is discharged into the environment without proper treatment. It is estimated that about 1.8 billion individuals drink water contaminated with faecal matter, thereby making them vulnerable to dysentery, cholera, polio, and typhoid [3]. For this reason, the United Nations adopted "*Access to clean water and sanitation for all*" as a goal of sustainable development at the global level. SDG-6 recommends enhanced global water quality and sanitation by 2030.

Recently, the availability of good quality and quantity of water makes people become more sensitive to this challenge, and industries face increasing pressure for better wastewater management practices concerning the use, treatment, discharge, reuse, and recovery. Wastewater from industry require treatment techniques comprise sophisticated processes facilitated using several units designed to eliminate specific contaminants. Wastewater discharge comprises pigments, dyes, heavy metal, non-biodegradable particles, and toxic and carcinogenic substances [4]. Effective treatment practices should focus on cost-effective and potent techniques implemented under legislative guidelines.

Commonly, WWTP operators face several operational challenges like rehabilitation financing, energy expenditure, expansion and upgrade requirements [5]. Additionally, gaseous emissions and sludge are WWT by-products that must be processed correctly. Moreover, industries are facing pressure for enhancing sustainability by adopting green and environmentally-friendly operations [6]; towards sustainable processes to protect the society. Toyota is credited with developing the Lean ecosystem that gained traction during the 20th century. This approach requires minimizing consumption, enhancing customer values, and reducing waste [7]. Six Sigma is a systematic framework aimed at addressing challenges, thereby offering better customer value through process and product development and process enhancement [8]. Lean techniques are extensively employed by service and product industries. Statisticians typically use such methods to evaluate process variations using scientific and statistical indicators [9].

Studies conducted earlier integrated the Lean and Six Sigma techniques in green philosophy to create a complementary framework for facilitating reduced waste, better resource use, and higher customer satisfaction by offering high-quality products and reliable processes [10]. The US EPA recommended using a comprehensive approach by using "Lean and Six Sigma" for upskilling individuals to determine and remove environmental waste by employing Lean and Six Sigma principles to facilitate lesser environmental effects and better regulatory adherence [11].

Despite the fact that Six Sigma has been adopted by many service, manufacturing and financial sectors, its application in wastewater sector is still in its infancy, DMAIC was presented by [12] for reducing phenol levels in Indian oil refinery. Researchers [5] presented how Lean and Six Sigma assessment could be used for enhancing Romanian municipal wastewater treatment plant (WWTP) effectiveness by lowering sludge production at a lesser cost. To bridge the gap, the present study aims to assess the efficacy of Lean and Six Sigma for optimizing WWT characteristics in a poultry plant.

2.0 MATERIALS AND METHODS

Market competition requires industries to use sustainable techniques for sustainable production and appropriate consumption; however, such techniques are typically cost-intensive [13]. There are numerous approaches like Lean and Six Sigma for manufacturing better products [14]. Nevertheless, Lean and Six Sigma are not sufficient for sustainability-related concerns [15]. Researchers [16] assert the integration of Lean and Six Sigma for addressing environmental concerns for manufacturing high quality, environmentally friendly products at a reduced cost in the manufacturing field. Besides [5] and [12] to control discharge level, previous studies by [17] showed the successful of Six Sigma implementation led to costs reduction in water and wastewater company. According to [18] sustainable Lean and Six

Sigma is an emerging strategy that can aid manufacturing organizations in mitigating environmental impacts such as air emission, resource depletion, energy consumption and wastewater pollution. Study by [19] applied the IMR control charts, Ishikawa diagram and process capabilities assessment to control the Indonesian pharmaceutical WWT discharge quality. This research is motivated by the need to assess the efficacy of Lean and Six Sigma by emphasizing pollution control equipment such as WWTP. WWTP is a fundamental aspect that helps enhance environmental metrics for organizations, thereby protecting the environment and society that would face adverse impact if the processes run ineffectively.

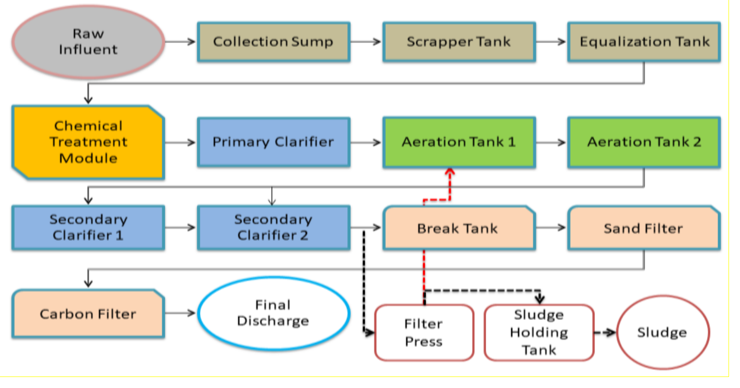

Figure 1: Poultry WWTP components and unit processes.

To enhance the Six Sigma adoption in WWT sector, the present study assesses a poultry plant in Melaka, Malaysia. The business started in 1999 and committed to providing fresh and quality poultry products for local consumption. The plant has a processing capacity of $200m^3$/day of Extended Aeration Activated Sludge (EAAS) supported by Physical-Chemical unit used for the 15,000 birds processed daily. Much waste is produced from stunning, bleeding, halal slaughtering, feather removal, scalding, chilling, and evisceration areas. The effluents processed by the WWT are drained into Sungai Melaka tributaries in compliance with the rigorous Standard A, Industrial Effluent Regulations, 2009. WWT unit process constituents are depicted in Figure 1. The EAAS line removes chemical, biological, and physical nutrients; these lines are independent and performs in continuous flow. The Scrapper Tank (ST) and Collection Sump (CS) are the two fine screening units for preliminary treatment, removing residue like grit, feathers, and grease. All material is transferred to the Equalization Tank (ET) for futhure processing. The ET regulates wastewater characteristics like temperature, pH, pollution level, and flow rate.

Several Chemical Treatment Module (CTM) aided by coagulant, Poly Aluminium Chloride (PAC) flocculant, polymer and caustic soda are used for pH adjustment, Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) and heavy metals removal. The Primary Clarifier (1C) isolate the supernatant at the surface and sludge was collected from the tank bottom. Biological treatment comprises an aerobic conditions for eliminating inorganic loads such as COD, BOD, and organic Ammoniacal Nitrogen (AN) by Aeration Tanks (AT) 1 and 2. Double train of Secondary Clarifier (2C) units handle the bio-sludge, and facilitate activated sludge recovery. The tertiary phase comprises Carbon Filters and Sand Filters (CF and SF) to eliminate remaining inorganic load and micropollutants in the form of Suspended Solids (SS); subsequently, the treated wastewater is discharged to the environment. In addition, the Sludge Holding Tanks (SHT) regulates the sludge management in the WWTP. The bio-sludge circulation is augmented by pumping systems to waste activated sludge (WAS) or returned activated sludge (RAS) into the plant. To develop the study, Figure 2 depicts a comprehensive outline for DMAIC application in poultry WWTP process capability enhancement.

2.1 Define Phase of Improvement

The *Define* phase requires identifying the process targeted for improvement, customer requirements, and mapping vital internal aspects to evaluate research objectives. Assessing problems during this phase comprised semi-structured interviews of plant operators and manager, process step evaluation, and document assessment and process monitoring. Additionally, discharge characteristics were also documented, recorded, and assessed. The Quality Function Deployment (QFD) technique was recommended for determining the major challenge to improve WWTP performance was established during group discussion. Table 1 specifies the QFD technical parameters from the assessment, which suggest better chemical dosing and sludge management. Similarly, QFD in [5] manage to select bioaugmentation process as optimum WWT alternatives to satisfying customer's expectations.

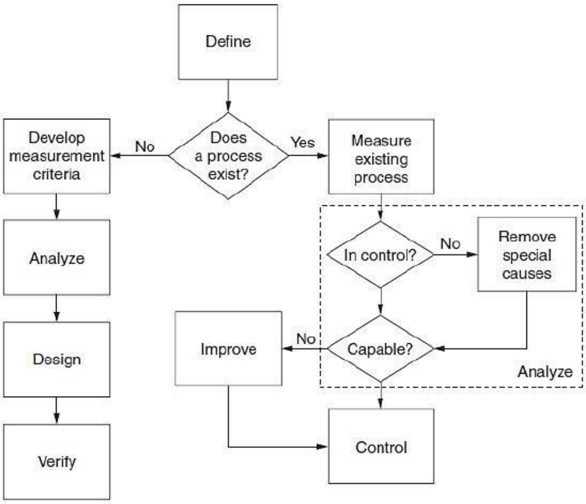

Figure 2: DMAIC and DMADV approach adopted from [12].

Table 1: QFD for improving poultry WWTP performance.

Technical Requirement / Customer Requirement	Flowrate in design criteria	Physical load separation	Chemical dosing effectiveness	Effective sludge management	Clarifier effectiveness	Improve tertiary polishing	Reduce workplace hazard	Energy efficiency program	Importance level
Effluent discharge meet the legal requirements	9	7	9	8	7	5	5	7	5
Reducing amount of sludge	7	6	9	9	7	4	4	5	5
Reducing odors	3	6	3	7	4	-	2	-	4
Reducing electricity consumptions	-	4	6	7	6	2	-	6	4
Reducing noises	-	3	4	7	4	3	3	-	3
Minimize workplace incidents	2	4	5	7	3	-	7	-	3
Reducing GHG	3	3	4	7	3	3	4	7	4
	110	138	169	211	143	74	99	112	

2.2 Measure the Performance

According to the DMAIC approach, the *Measure* part requires that the process state be defined as it is currently implemented. Aeration and chemical processes were inconsistent, causing non-compliant outcomes from July to December 2020. The significant discharge parameters are complied with specification limits (O&G< 10mg/L, temperature <40°C, and pH= 6.0-9.0). However, some of the COD, AN, SS, and BOD_5 values exceeded Standard A specifications are listed in Table 2.

Table 2: Effluent quality characteristic (July – Dec 2020)

Variable (mg/L)	**N**	**Mean**	**Std. Dev**	**Min**	**Max**	**Limit**
BOD_5	24	25.50	7.04	11.20	39.90	20
COD	24	109.34	15.75	86.80	141.00	80
SS	24	53.83	18.52	26.00	99.00	100
AN	24	17.47	4.17	10.22	22.41	20

After specifying non-compliant aspects and significant AT and CTM process parameters were determined, WWTP performance monitoring (PM) is required for assessing the probable reason. Influent and effluent metrics, pH, Dissolved Oxygen (DO), and flow rate data were recorded from all unit processes. The data concerning temperature, pH, activated sludge processes, and unit process management. Moreover, plant design, operating procedures, and equipment specifications for all processes and chemical inputs were collected.

2.3 Analyse the Performance

Cause and Effect Diagrams are prepared during the *Analyse* phase, as depicted in Figure 3. The Ishikawa diagrams helped to assess probable combinations causing the CTM and AT non-compliance. Enhancement efforts were arrived upon considering the criticality using PM process data from both stages considering personel, material, measurement, equipment, method and environment criteria.

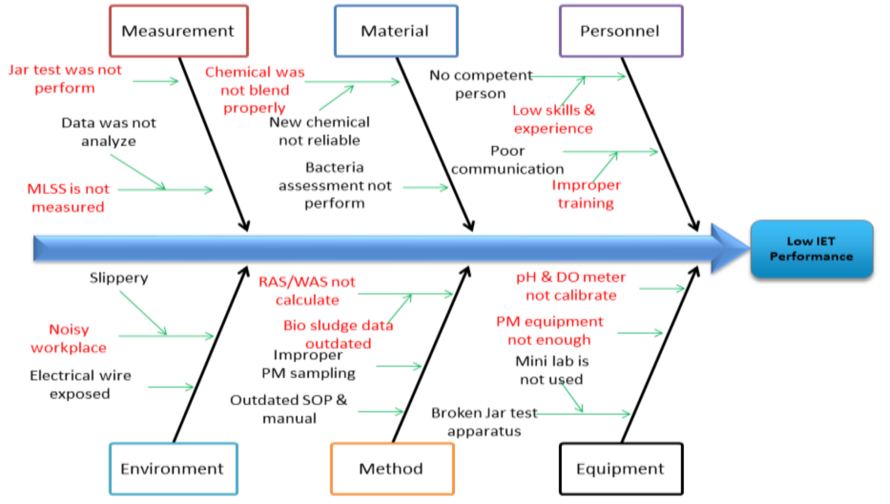

Figure 3: Ishikawa diagram

Measure and *Analyse* assessments lead to the following determinants for poor plant performance:

a. Shortage of DO and pH measuring probes; lack of calibration for requirement PM processes cause AT and CTM metric variations;
b. Adequate pH level and chemical dose determination using jar test were not completed regularly, thereby leading to potentially incorrect dosing configuration, and;
c. Poor maintenance of constant activated sludge recirculation systems led to poor AT performance.

3.0 RESULTS AND DISCUSSION

Improve and *Control* are the last two phases of the DMAIC approach. They facilitate cost-effective process enhancements and efficiency optimization.

3.1 Improve the performance

The *improve* phase is challenging because the analysis and decisions are required using the inputs from the previous stages. The present study specifies a series of prioritized steps considering risks, effects, and results of the suggested processes. Hence, the optimal solution is to reassess the PM process by pH measurement at CTM, assessing DO and pH values in the ATs, PAC dosing by performing jar test regularly, and manage the WAS/RAS steps for regulating constant sludge inventory in the WWTP is critical.

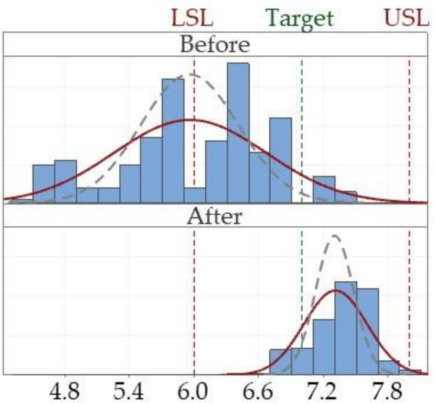

Figure 4: CTM pH capability metric comparison

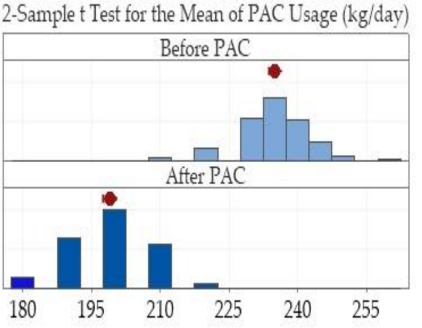

Figure 5: PAC use comparison

The limitation of [19] in discharge COD value assessment using process capability was extended in this study's application to the CTM unit process to identify the pH performance and PAC consumption. By performing monthly scheduled Jar tests and dosing regulation caused the improvement of CTM significantly; control the pH value in range of 6.0 to 8.0 by appropriate chemical dosing setting. Figure 4 shows near 98% out-of-level pH values had statistically significant improved ($p<0.001$); mean pH value increased from 5.95 to 7.30; Cpk measured in CTM improved to 1.31 from -0.03. The mean value of chemical consumption (PAC) decreased significantly by 15.3% ($p<0.05$). March-May 2021 usage were 199.1 kg per month as compared to 235.1 kg per month during October-December 2020. This study support the finding of performing regular Jar test will improve the effluent quality [20]. Figure 5 depicts the daily PAC consumption levels. Moreover, an additional DO measuring probe was procured and set up at ATs 1 and 2.

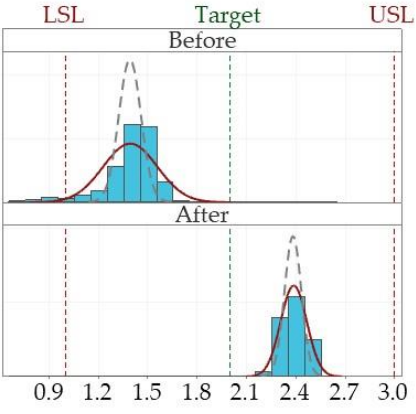

Figure 6 AT1 DO value

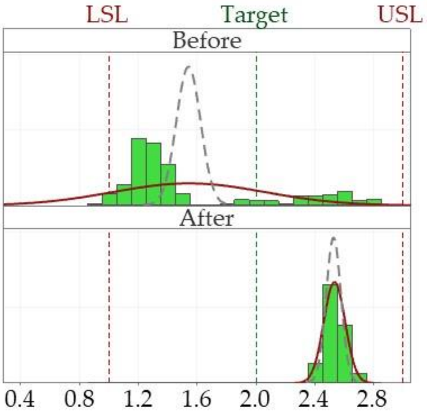

Figure 7 AT2 DO values

Subsequently, the biological process improvement were conducted at the ATs 1 and 2 had improved the daily mean DO values; transitions from 1.38 to 2.38mg/L, and 1.53 to 2.56mg/L, as depicted in Figures 6 and 7, respectively. DO levels should ideally be in the 1 to 3mg/L range to prevent microbial biomass death. The biomass culture process is cost and time intensive. Moreover, operating the aeration blower at >3 mg/L is expensive and energy inefficient. Previously, the phenol variation was manage to figure out by using graphical chart by [12], in this study Figures 8 and 9 of IMR charts also indicating daily pH mean values that increased from 5.91 to 7.25 for AT1, corresponding to a Cpk transition to 2.44 from -1.06. Similarly, AT2 pH transitioned from 5.83 to 6.95, corresponding to Cpk improvement to 2.12 from -2.16. Consequently, the biological process is improved with minimum variation of DO value and to the fullest extent with zero potential pH range (6.5-8.5) breach.

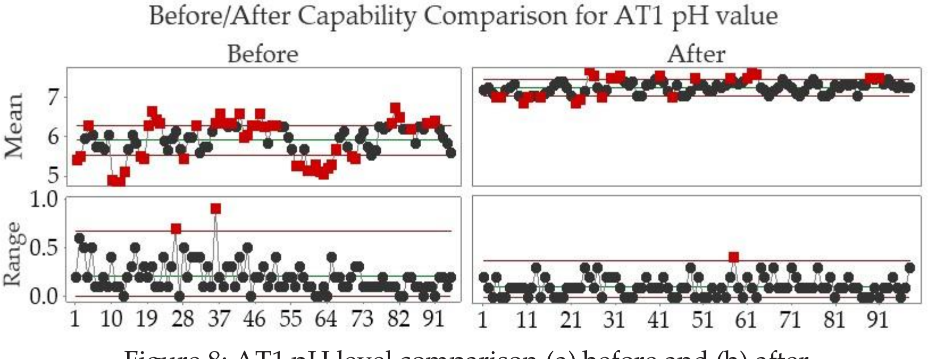

Figure 8: AT1 pH level comparison (a) before and (b) after improvement

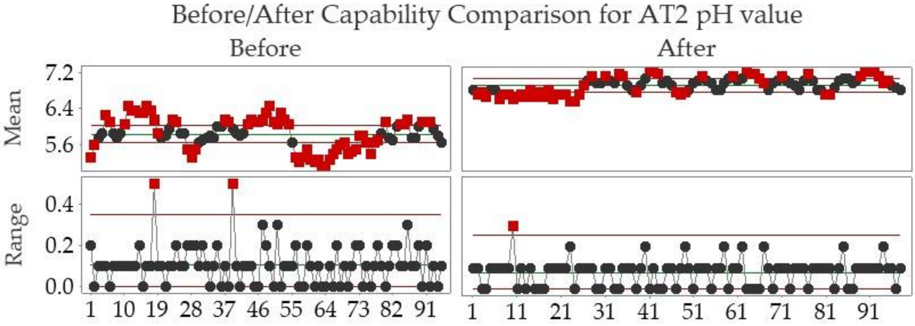

Figure 9: AT2 pH level comparison (a) before and (b) after improvement

3.2 Control for Continuous Improvement

Controlling WWTP performance is required for ensuring the sustainable enhancements implemented previously. Table 3 lists the aggregate improvement in treated effluent mean parameters for AN, COD, and BOD_5 were near 66%, 58%, and 47% respectively.

Table 3: Improvement in final discharge mean values

Variable (mg/L)	N	Mean Before	Mean After	Improvement
BOD_5	12	26.43	13.91	+47.37%
COD	12	119.01	49.42	+58.47%
SS	12	58.67	58.08	+0.01%
AN	12	19.87	6.67	+66.43%

In contrast, SS metrics did not improve significantly because of the requirement for advanced preliminary treatment such as Dissolved Air Floatation (DAF) and a constant activated sludge system which time consuming. According to the technological review in [20], the advanced technologies for poultry wastewater treatment are considered successful in terms of water recycling, reuse and waste reduction. However the cost effective in their operation is more vital to promote long term sustainability. Considering that poor WWTP can cause adverse environmental and human impact, the present study recommends to extend the monitoring the control metrics specified in Table 4 for future continuous improvement.

Table 4: Control phase approaches

Method	Current	Improvement
Maintaining constant MLVSS through SVI	From the design criteria and analysis, the value is low; 2,142 mg/L.	The optimum range for MLVSS is 3,000 to 5,000 mg/L for EAAS. Maintaining by proper RAS and WAS daily routine.
Maintaining constant F/M ratio	From the assessment the F/M ratio is 0.04 kg BOD/day.	The optimum range is 0.05 to 0.15 kg BOD/day. The insufficient F/M ratio must counter with nutrient additional.
Maintaining constant sludge age (θc)	Current θc is 7 days and too young.	Maintaining the RAS and WAS activity will improve MLVSS and θc to optimum 15 to 30 days.

4.0 CONCLUSION

An efficacious WWTP setup comprises advanced technology and systems along with optimal management techniques and trained operators. The present study succefully emphasizes the integration of Lean and Six Sigma in WWTP process improvement. Efficient treatment is enhanced by facilitating lesser unit process variability at a better cost. Since the DMAIC process is never ending cycle, this study suggest the Lean and Six Sigma improvement campaign to be continue in regular base. Nevertheless, sustaining such an enhancement for an extended period required activated sludge performance characteristics like sludge volume index (SVI), F/M ratio, and sludge age for regulating WWTP is require in the future. This study demonstrates the pilot Lean and Six Sigma conducted at a Malaysian SME poultry sector, which can be performed to other site especially in feedstock industry. There were several small process changes for better streamlining. The integration of Lean and Six Sigma for enhancing environmental aspects of performance provide a viable option for decreased chemical use, better chemical dosing in term of coagulation, flocculation, and biological process capabilities pertaining to the WWTP.

ACKNOWLEDGMENTS

The authors are grateful to the Malaysian government and Universiti Teknikal Malaysia Melaka (UTeM) for funding the research via grant FRGS/1/2020/TK0/UTEM/02/42.

REFERENCES

[1] S. Wunderlich and K. A. Gatto, "Consumers' food choices and the role of perceived environmental impact", *International Journal of Sustainable Development and Planning*, vol. 11, no. 6, pp. 989–995, 2016.

[2] United Nations World Water Assessment Programme, "Summary Progress Update 2021: SDG 6 — water and sanitation for all", United Nations, Geneva, Switzerland, 2021.

[3] United Nations World Water Assessment Programme, "The United Nations World Water Development Report 2017: Wastewater, The Untapped Resource", Paris, 2017.

[4] I. Khalek, M.A., El Hosiny, F.I., Selim, K.A. and Osama, "A novel continuous electroflotation cell design for industrial effluent treatment", *Sustainable Water Resource Managemen*t, vol. 5, no. 2, pp. 457–466, 2019.

[5] R. Robescu, L.D., Silivestru, C., Presura, A., Pana, A. and Mihai, "Application of Continuous Improvement Strategy for reducing environmental impact of a wastewater treatment plant", *Water Utility Journal*, vol. 14, pp. 29–40, 2016.

[6] A. Ishak, E. Mohamad, L. Sukarma, A.B.R. Mahmood, M.A. Rahman, S.H. Yahya, M.S. Salleh, and M.A. Sulaiman,, "Cleaner Production Implementation using Extended Value Stream Mapping for Enhancing the Sustainability of Lean Manufacturing," *Journal of Advanced Manufacturing Technology*, vol. 11, no. 1 (1), pp. 47–60, 2017.

[7] D. Womack, J. P., Jones, D. T., & Roos, *Machine That Changed the World.* Simon and Schuster, 1990.

[8] X. Zu, L. D. Fredendall, and T. J. Douglas, "The Evolving Theory of Quality Management: The role of Six Sigma", *Journal of Operation Management*, vol. 26, no. 5, pp. 630–650, 2008.

[9] R. Sreedharan V, G. Sandhya, and R. Raju, "Development of a Green Lean Six Sigma model for public sectors", *International Journal of Lean Six Sigma*, vol. 9, no. 2, pp. 238–255, 2018.

[10] R. Siegel, J. Antony, J. A. Garza-Reyes, A. Cherrafi, and B. Lameijer, "Integrated Green Lean Approach and Sustainability for SMEs: From literature review to a conceptual framework", *Journal of Cleaner Production*, vol. 240, 2019.

[11] United States Environmental Protection Agency, "The Environmental Professional's Guide to Lean & Six Sigma", 2009.

[12] M. Boruah, and T. Nath "Application of Six-Sigma Methodology in Effluent Treatment Plant", *International Journal of Engineering Research and Technology*, vol. 4, no. 9, pp. 589–594, 2015.

[13] K. Hussain, Z. He, N. Ahmad, M. Iqbal, and S. M. Taskheer Mumtaz, "Green, lean, Six Sigma barriers at a glance: A case from the construction sector of Pakistan", *Building and Environment*, vol. 161, pp. 106–225, 2019.

[14] F. Voehl, H. J. Harrington, C. Mignosa, and R. Charron, *The Lean Six Sigma Black Belt Handbook: Tools and Methods for Process Acceleration*, 1st ed. Productivity Press, 2013.

[15] S. Kumar, S. Luthra, K. Govindan, N. Kumar, and A. Haleem, "Barriers in green lean six sigma product development process: An ISM approach", *Production Planning Control*, vol. 27, no. 7–8, pp. 604–620, 2016.

[16] R. Henao, W. Sarache, and I. Gómez, "Lean manufacturing and sustainable performance: Trends and future challenges," *Journal of Cleaner Production*, vol. 208, pp. 99–116, 2019.

[17] A. Ghassemi, and M. Saghaei, "Implementing Six Sigma for cost reduction in the water and waste water company", *Journal of Current Research in Science*, vol. 2, no. 6, pp. 590–598, 2014.

[18] A. Farrukh, S. Mathrani, and A. Sajjad, "A DMAIC approach to investigate the green lean six sigma tools for improving environmental performance," in *2021 IEEE Asia-Pacific Conference on Computer Science and Data Engineering*, 2021, pp. 1–6.

[19] D. Rimantho and Y. W. Nugraha, "Wastewater quality control analysis in the pharmaceutical industry using process capability approach", *ARPN Journal of Engineering and Applied Science*, vol. 15, no. 5, pp. 716–723, 2020.

[20] B. R. Baker, R. Mohamed, A. Al-Gheethi, and H. A. Aziz, "Advanced technologies for poultry slaughterhouse wastewater treatment: A systematic review", *Journal of Dispersion Science and Technology*, vol. 42, no. 6, pp. 880–899, 2021.