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Preliminary investigation into the influence of green lean six sigma enablers on wastewater treatment operations

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Abstract

Manufacturing industries have increasingly recognized the value of Lean Six Sigma (LSS) not only for improving productivity but also for enhancing sustainability. The combination of green concept with LSS has also gained popularity by reducing waste, cost, and emissions. Prompting the exploration of enablers supporting its adoption in environmental services. This study aims to investigate the relationship between Green LSS (GLSS) enablers and operational benefits (OBs) in wastewater treatment plants (WWTPs) in Malaysia. The study examines five independent variables (IVs): strategic-based enablers (S), environmental-based enablers (Env), culture-based enablers (C), resource-based enablers (R), and linkage-based enablers (L), in relation to the dependent variable (DV) of OB. Data was collected from 65 certified competent personnel working in WWTPs and analysed using validity, reliability, factor analysis, and multiple linear regression. The results indicate that the IVs significantly predict OB when the *p*-value is below the 5% threshold. This suggests that the factors examined have a significant impact on WWTP operational benefits. Furthermore, the R^2 value of 0.390 indicates that the model explains 39% of the variance in OB. Specifically, the variables S and C significantly support the hypotheses, while Env, R, and L do not significantly influence OB. These findings provide valuable insights for the wastewater service sector in improving their understanding and implementation of GLSS to enhance operational performance in a developing country, Malaysia.

Keyword: Green lean six sigma, Enablers, Sustainability, Wastewater treatment, Multiple linear regression

1. Introduction

The interconnection between wastewater treatment plants (WWTP) and sustainable development is important for ecosystem health and human well-being. The United Nations, recognizing this nexus, has incorporated the Sustainable Development Goal (SDG) of "ensuring access to clean water and sanitation for all" (Arroyo and Molinos-Senante, 2018). With industrial processes yielding substantial waste, notably wastewater, global attention has intensified related to resource constraints. Consequently, improper treatment and discharge exacerbate water body contamination. Governments respond with stringent regulations, challenging new manufacturing plants to align wastewater treatment with environmental mandates (Boruah, 2015).

Lean Six Sigma (LSS) amalgamates Six Sigma and Lean methodologies, originating from Motorola Corporation and the Toyota Production System, respectively (Jamil et al., 2020). LSS aims to optimize organizational processes by minimizing waste and inefficiencies. Despite distinct origins, Lean and Six Sigma converge on continuous improvement, customer satisfaction, and employee engagement. While LSS improves organizational performance, it may overlook societal and ecological concerns. GLSS, combining green, lean, and Six Sigma principles, improves resource efficiency

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and reduces pollution and carbon footprint (Sreedharan et al., 2018; Farrukh et al., 2020). This study evaluates the enablers of GLSS assessing their potential to enhance operational efficiency and environmental compliance in Malaysia's wastewater treatment service industry.

2. Research motivations

Previous research has extensively examined LSS potential in improving various business aspects. Costa et al. (2021) devised a tool to gauge LSS proficiency, applied in the food industry to pinpoint effective LSS practices. Timans et al. (2012) revised a Six Sigma framework for Dutch small and medium-sized manufacturers. Minh et al. (2019) showcased LSS success in mechanical manufacturing, boosting productivity and quality while optimizing costs. Although these studies offer valuable insights, they inadequately address continuous improvement and environmental concerns.

The United States Environmental Protection Agency (USEPA) emphasizes the integration of LSS with environmental concerns to yield operational and environmental advantages, fostering eco-friendly processes (Ruiz-Benitez et al., 2019). Sagnak and Kazancoglu (2016) highlight how aligning LSS with environmental factors minimizes negative impacts in manufacturing and services, promoting cleaner production and a healthier environment. Despite these advancements, managerial hesitance persists due to readiness gaps, resource constraints, and fear of failure (Thanki and Thakkar, 2018). Enablers are key for efficient operations, particularly in complex systems such as WWTPs (Robescu et al., 2016), urging the adoption of impactful enablers for successful GLSS implementation. This underscores the urgent need for strategies that harmonize sustainable development, continuous improvement, and environmental stewardship in WWTP operations.

Management's active involvement is crucial for resource allocation, a key aspect in implementing new strategies (Yadav and Desai, 2017). Offering rewards boosts staff morale, enhancing commitment to GLSS practices (Singh et al., 2021). Effective project leadership is vital for motivating employees to adopt GLSS principles (Laureani and Antony, 2017). These enablers align with the strategic-based (S) enablers. In addition, carbon reduction efforts support the transition to eco-friendly practices (Wang et al., 2019). Using biodegradable materials for packaging aids in reducing air pollutants (Farrukh et al., 2020). Green product design addresses environmental concerns (Sreedharan et al., 2018). Implementing green transportation systems further mitigates greenhouse gas emissions (Gaikwad and Sunnapwar, 2020). Emphasizing these measures aids operational units in addressing environmental issues, falling under the environmental (Env) enablers for GLSS implementation.

Besides, teamwork and communication are important for GLSS implementation (McDermott et al., 2022). Strong teamwork builds confidence in adopting new approaches (Tampubolon and Purba, 2021). Organizations should foster a conducive culture and efficient communication (Pardamean Gultom and Wibisono, 2019) to successfully implement sustainable program, utilizes the culture-based (C) enablers to evaluate GLSS implementation. Further, awareness programs and training, along with understanding the methodology, are resource-based (R) enablers (Hariyani and Mishra, 2023). Effective training enhances staff skills and fosters a culture of understanding and motivation (Sony and Naik, 2020), driving comprehensive GLSS implementation for process sustainability.

Integrating GLSS into buyer-supplier relationships and core business processes is important for implementation (Bhattacharya et al., 2019). This linkage fosters sustainability through the 3R's concept, aligning industry profitability with eco-friendly practices (Psomas, 2016). This study considers these linkage-based (L) enablers as positive indicators for assessing successful GLSS implementation in WWTP operations. Moreover, previous research indicates the operational benefits (OBs) of LSS across diverse industries. For example, Raval et al. (2021) assessed Indian manufacturing efficiency with DEMATEL, yielding strategies for enhancement. Gultom and Wibisono (2019) proposed an LSS framework for supply chains, while Habidin and Yusof (2013) measured Malaysian automotive performance with LSS. Titmarsh et al. (2020) aligned LSS with sustainable manufacturing. Yet, GLSS application in WWTPs still underexplored (Boruah, 2015; Robescu et al., 2016). This study aims to evaluate GLSS enabler's efficacy in optimizing OB, addressing this gap and identifying GLSS implementation in Malaysian WWTPs.

3. Research methodology

Considering to limited studies on LSS or GLSS in WWTP operations, this research combined literature reviews and expert consultations to establish measurement instruments. Building upon Singh et al. (2021) work's on Indian SMEs, this study assessed GLSS enablers as independent variables (IVs). However, operational benefits (OBs) as the dependent variable (DV) was not explicitly included in their study. To address this, Gastelum-Acosta et al. (2022) study's was integrated. The instrument underwent validation by six experts, including academician, industrialist, WWTP consultants, and government official. The pilot study was conducted with thirty certified professionals who are knowledgeable about WWTP operations. The expert panellists' background are summarized in Table 1. Certified WWTP professionals with ≥3 years' experience were surveyed. A theoretical framework is formulated in Fig. 1, illustrates the model to examine the IVs impact on OBs, focusing on GLSS enablers' influence in WWTP operations. Based on this, the following hypotheses are formulated:

H1. There is a significantly positive impact of strategic-based enablers on WWTP operational benefits.
H2. There is a significantly positive impact of environmental-based enablers on WWTP operational benefits.
H3. There is a significantly positive impact of culture-based enablers on WWTP operational benefits.
H4. There is a significantly positive impact of resource-based enablers on WWTP operational benefits.
H5. There is a significantly positive impact of linkage-based enablers on WWTP operational benefits.

In this study, data were collected empirically through questionnaires using modified Likert scales of 1 (Strongly Disagree) to 5 (Strongly Agree). 65 respondents were randomly selected from the National Registry of Certified Environmental Professionals (NRCEP) using non-probability sampling frame. The questionnaire, sent with a cover letter explaining the study objectives, elicited diverse responses reflecting individual opinions. Participants completed the Google Form questionnaires within 10-15 minutes. For example, respondents rated "Top management commitment is crucial for successful GLSS implementation in WWTP operation" to measure strategic-based enabler. Participants had three weeks to complete the questionnaire. The research methodology process is detailed and illustrated in Fig. 2. Meanwhile, Appendix A contains the full survey questionnaire used for data collection.

The questionnaire gathered data from diverse WWTP sectors: manufacturing, agricultural, and domestic wastewater services. Hypothesis testing results will be analysed using IBM SPSS Package version 27.0. The t-test compared means of two sets of observations for a single sample, assessing average differences. Results present t-test and p-value, with significance indicated if both are <0.05, denoting a meaningful relationship between variables.

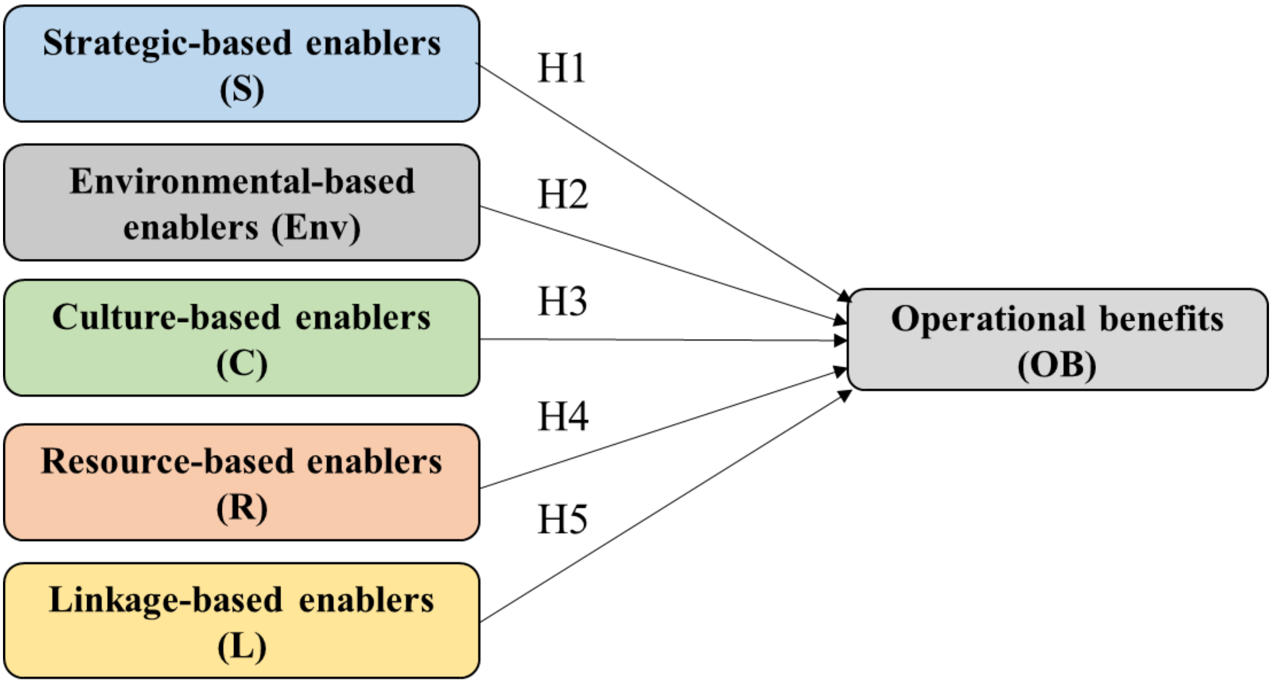

Fig. 1 GLSS enablers and operational benefits relationships.

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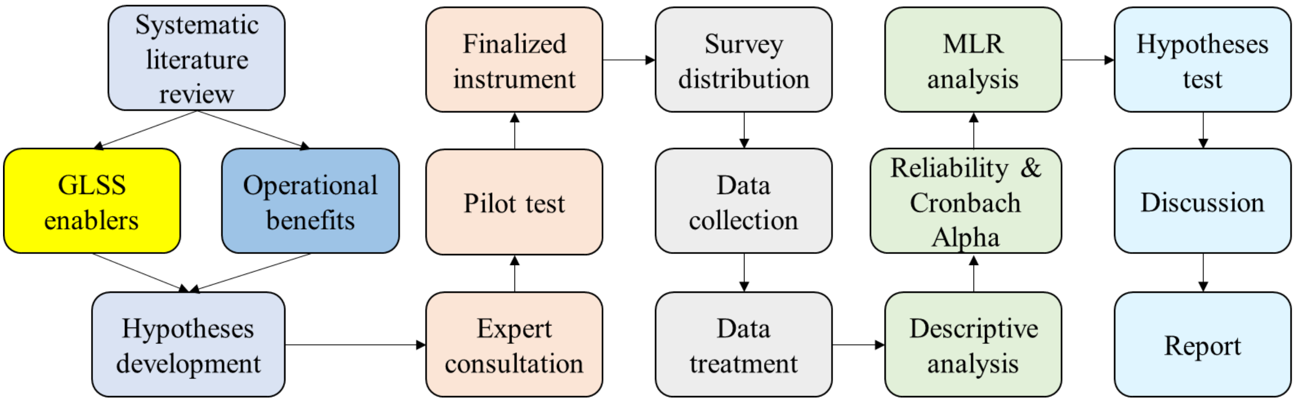

Fig. 2 Research methodology process.

Table 1 Detailed information of experts.

Expert	Sector	Current Position	Professional Experience
Expert 1	Industry	Head of Operation & Maintenance	35 years
Expert 2	Industry	Assistant Manager	15 years
Expert 3	Consultant	Technical Director	28 years
Expert 4	Academic / Consultant	Managing Director	38 years
Expert 5	Academic	Associate Professor	24 years
Expert 6	Government	Senior Assistant Director	18 years

4. Results and discussion

Descriptive statistics and multiple linear regression (MLR) were employed to analyse the data. Likert scales are commonly utilized in quantitative research to gauge respondents' agreement with the provided questions. All responses were carefully reviewed to identify any reluctant respondents, missing values, and outliers. The ordinal Likert scale data was then transformed into successive intervals using Microsoft Excel for analysis. Prior to further analysis, MLR pre-assumptions, including data normality, variables multi-collinearity, autocorrelation, and heteroscedasticity, were assessed. All necessary classical assumptions were met in accordance with recommended thresholds.

4.1 Respondents profile

The respondents in this study consisted of 65 individuals, with the majority being male, accounting for 85%, while 15% were female. Regarding the respondents' working experience in GLSS, the majority (77%) had 1-10 years of experience, and 23% with over 11 years of experience. Approximately 62% of the respondents worked in companies familiar with LSS applications, and five respondents held certifications as Lean Six Sigma Yellow and Green belts. Furthermore, the educational background of the respondents revealed that 71% held degrees, while 9% had post-graduate qualifications. In terms of job positions, the majority of respondents were in managerial roles (37%), followed by executives (35%) and engineers (28%). The respondents represented three different wastewater sectors, with the manufacturing sector being the largest, accounting for 75% of the sample. Additionally, the majority of companies (86%) were certified under MS ISO 9001, and 69% had obtained MS ISO 14001 certification. Most of the companies were owned by Malaysian entities (65%), while 15% had ownership from the United States and Europe, and 20% had ownership from other Asian countries. The wastewater treatment technologies employed by the plants were distributed equally, with 32% utilizing biological processes, 32% employing physical-chemical processes, and 36% utilizing a combination of both. Lastly, a majority of the plants (63%) were categorized as small-scale, generating daily effluent volumes below 300 cubic meters.

4.2 Measurement model results

As shown in Table 2, this study utilized reliability analysis, specifically Cronbach's Alpha (CA), and MLR. Reliability analysis was conducted to assess internal consistency and measure the stability and consistency of questionnaire items. Items with a CA above 0.7 were considered reliable. All factors in this study exhibited CA values

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above 0.7, indicating good internal consistency among the enablers and their benefits. The highest mean score recorded was 4.69 for S1, representing ‘strongly agree’ on a scale of 1 to 5, while the lowest mean was 3.78 for item B7. Standard deviations ranged from 0.414 to 0.761. Additionally, factor analysis was used to simplify the analysis while retaining relevant information about the measured latent variables.

4.3 Multiple linear regression results

The study chose MLR due to its simplicity, given the small sample size of 65 respondents, and aims to understand the current scenario before advancing to more complex analysis. MLR analysis was conducted to examine the influence of IV’s (S, Env, C, R, and L) on the DV (OBs). The results of the regression analysis, presented in Table 3, demonstrate the independent variables significantly predict “OB”, $F(5, 59) = 7.535$, $p < 0.001$. This indicates that the five factors under study have a significant impact on WWTP operational benefits. Moreover, the coefficient of determination (R square) is 0.390, depicts that the model explains 39% of the variance in “OB”. The remaining 61% of the variance in the dependent variable is not accounted for by the IVs in this study. The model’s findings are statistically significant in demonstrating the simultaneous influence between the IVs and the DV.

4.4 Hypotheses results

This study seeks to investigate the effect of strategic, environmental, culture, resource and linkage based enablers on WWTP operational benefits. Additionally, coefficient were further assessed to ascertain the influence of each independent variables on the WWTP “OB”. H1 evaluates whether “S” significantly and positively affects the “OB”. The results revealed that strategic-based enablers has a significant and positive impact on operational benefits ($\beta= 1.641$, T = 3.683, p = < 0.001). Hence, H1 was supported. This relationship can be attributed to factors such as top management commitment, effective project leadership, consistent and accurate data collection, which have a substantial impact on the implementation of GLSS in the environmental service sector (Laureani and Antony, 2017; Singh et al., 2021). However, the environmental, resource, and linkage-based barriers did not show a significant effect on operational benefits, as indicated by the p-values exceeding the 5% threshold. Consequently, H2, H4, and H5 were not supported. Surprisingly, the culture-based enablers “C” demonstrated a significant and negative impact on WWTP operational benefits ($\beta = -1.600$, T = -3.112, p = 0.003). Therefore, H3 was supported in the opposite direction.

Titmarsh et al. (2020) argued that organizational culture can significantly influence the success or failure of LSS implementation. Hence, the presence of different multinational ownerships in treatment plants may have influenced these findings. To overcome this limitation, strong support from top management commitment and involvement, organizational readiness, and the implementation of an environmental management system emerged as the most significant enablers for successful GLSS implementation (Parmar and Desai, 2020). Additionally, although H2 was not supported in this study, the observed negative impact of environmental-based enablers on “OB” adds an intriguing dimension to the findings. This finding contradicts with previous studies Sagnak and Kazancoglu (2016), Ramos et al. (2018) also argued that an inadequate transportation system leads to an increase in CO_2 emissions. This finding suggest that GLSS implementation can have both positive and negative impacts on the environment depending on the implementation approach (Ruben et al., 2016; Singh et al., 2021). The results of all hypotheses are presented in Table 3.

Table 2 Measurement model result.

Main Criteria	Sub-criteria	Mean	Min	Max	SD	Cronbach’s Alpha	Factor Loading
Strategic-based enablers (S)	Top-management commitment, involvement and support (S1)	4.69	4.00	5.00	0.465	0.871	0.884
	Effective project leadership (S2)	4.55	3.00	5.00	0.560		0.789
	Rewards and incentives for the employee (S3)	4.01	3.00	5.00	0.573		0.770
	GLSS supportive organizational infrastructure (S4)	4.15	3.00	5.00	0.592		0.688
	Performance measurement system (S5)	4.21	3.00	5.00	0.545		0.744

	Consistent and accurate data collection (S6)	4.45	3.00	5.00	0.613		0.828
Environmental-based enablers (Env)	Carbon reduction initiatives (Env1)	4.37	3.00	5.00	0.601	0.894	0.734
	Environmental friendly packing of products (Env2)	3.95	3.00	5.00	0.648		0.764
	Incentive to produce green products (Env3)	4.17	3.00	5.00	0.698		0.767
	Practices of green design (Env4)	4.12	3.00	5.00	0.625		0.756
	Environmental friendly transportation (Env5)	3.88	3.00	5.00	0.625		0.775
	Green operational practices (Env6)	4.11	3.00	5.00	0.562		0.829
	Market demands for green products (Env7)	4.09	3.00	5.00	0.579		0.867
Cultural-based enablers (C)	Selection and retention of employee (C1)	4.38	3.00	5.00	0.604	0.848	0.724
	Teamwork (C2)	4.54	3.00	5.00	0.533		0.736
	Effective communication among departments (C3)	4.40	3.00	5.00	0.553		0.798
	Effective scheduling (C4)	4.28	3.00	5.00	0.545		0.768
	Employee empowerment (C5)	4.17	3.00	5.00	0.651		0.703
	Share project success stories (C6)	3.96	3.00	5.00	0.448		0.682
	Organizational culture and ethics (C7)	4.06	3.00	5.00	0.555		0.676
Resource-based enablers (R)	Understanding of GLSS methodology (R1)	4.52	3.00	5.00	0.533	0.774	0.674
	Project selection and prioritization (R2)	4.22	3.00	5.00	0.515		0.698
	GLSS awareness program and training (R3)	4.43	3.00	5.00	0.585		0.791
	Fund for operational expenditure (R4)	4.35	3.00	5.00	0.543		0.765
	Financial benefits sharing among employees due to GLSS (R5)	3.98	3.00	5.00	0.515		0.691
Linkage-based enablers (L)	Supplier relationship management (L1)	4.25	3.00	5.00	0.613	0.881	0.847
	Customer satisfaction and delight (L2)	4.15	3.00	5.00	0.565		0.851
	Understanding customer demand (L3)	4.20	3.00	5.00	0.617		0.896
	Linking GLSS to buyer-suppliers (L4)	4.02	3.00	5.00	0.673		0.790
	Integrate GLSS to core business processes (L5)	4.12	3.00	5.00	0.484		0.739
Operational benefits (OBs)	Increase in customer satisfaction (B1)	4.66	4.00	5.00	0.477	0.958	0.827
	Increase in the level of quality of service and processes (B2)	4.57	4.00	5.00	0.499		0.883

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Reduction in delivery and/or service times (B3)	4.51	3.00	5.00	0.615	0.893
Reduction in variability in processes (B4)	4.43	3.00	5.00	0.558	0.857
Increase in staff morale (B5)	4.14	3.00	5.00	0.634	0.808
Reduction in activities that do not add value (B6)	4.38	4.00	5.00	0.490	0.795
Increase in staff satisfaction (B7)	3.78	3.00	4.00	0.414	0.744
Greater positioning of the company (B8)	3.86	3.00	5.00	0.526	0.747
Increase in efficiency and effectiveness (B9)	4.41	4.00	5.00	0.497	0.844
Increase in teamwork (B10)	4.27	3.00	5.00	0.761	0.886
Change in culture; from correction to prevention (B11)	4.55	3.00	5.00	0.560	0.873
Greater use of statistical tools to solve problems (B12)	4.52	4.00	5.00	0.503	0.841
Reduction in customer complaints (B13)	4.08	3.00	5.00	0.567	0.698

*N valid = 65

Table 3 Multiple linear regression result.

Model	Regression Weights	Unstandardized Coefficient		Standard Coefficient	T	Sig.	Results
		β	Std. Error	β			
Constant		28.394	7.925		3.583	< 0.001	
Strategic	S→OB	1.641	0.445	0.737	3.683	< 0.001	Supported
Environmental	Env→OB	-0.412	0.372	-0.226	-1.108	0.272	Not supported
Culture	C→OB	-1.600	0.514	-0.783	-3.112	0.003	Supported
Resource	R→OB	1.137	0.585	0.394	1.943	0.057	Not supported
Linkage	L→OB	1.048	0.575	0.426	1.821	0.074	Not supported
F Value				7.535			
Sig.				< 0.001			
Adjusted R square				0.338			
R square				0.390			

Note; p-value = 0.05

5. Conclusion

The results indicate a high level of agreement among participants regarding the importance and implementation of each GLSS enablers (Singh et al., 2021) and the operational benefits (Gastelum-Acosta et al., 2022) of WWTP in Malaysia. This finding emphasizes the significance of implementing GLSS to improve plant performance. Management involvement is crucial in organizations as it determines the allocation of skills human, technical, and economic resources needed for successful implementation (Yadav and Desai, 2017; Laureani and Antony, 2017). Additionally, the results reveal significant relationships among most of the GLSS enablers, except for environmental, resources, and linkage-based enablers (McDermott et al., 2022).

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This research contributes theoretically by introducing and examining a framework of GLSS enabler dimensions within WWTP operation contexts. Notably, strategic and culture enablers are important for GLSS implementation in Malaysian WWTPs. Key factors include top management commitment, effective project leadership, and precise data collection. Active management support and resource provision are crucial for successful implementation. Additionally, securing resource allocation, funding, employee training, and external consultant expertise are essential. Robust research findings endorse the stability of the proposed framework.

Practically, the study guides WWTP organizations in adopting GLSS enablers for sustainable operations, emphasizing GLSS strategies to enhance wastewater treatment processes. Management support for effective teamwork, communication, and scheduling fosters sustainability-focused organizational culture and ethics. Integrating GLSS into core business strategies aligns with Sustainable Development Goals (SDGs), promoting environmental, social, and corporate governance principles.

As a pioneering study on GLSS enablers with OBs in wastewater treatment sector, it has limitations. There is a need to expand the sample size for future analysis of variables affecting WWTP operational performance to ensure successful GLSS implementation. Moreover, this finding emphasizes the significance of exploring different organizational cultures in Malaysian WWTP operations in future research, as there are various types of ownership in the manufacturing and services sectors that are equipped with this environmental control equipment. Furthermore, the study demonstrates the suitability of the measurement instruments in exploring GLSS adaptation readiness in the WWTP sector, which can be further refined using factor analysis and structural equation modelling approach. In conclusion, this study effectively addresses all the questions posed in the questionnaire.

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Appendix A

Part 1

Kindly rate the following benefits of implementing the Green Lean Six Sigma initiative in your company on a scale of 1 to 5 by "√" mark in the appropriate box.

Question	Strongly Agree 5	Agree 4	Neutral 3	Disagree 2	Strongly Disagree 1
Increase in customer satisfaction.					
Increase in the level of quality of service and processes.					
Reduction in delivery and/or service times.					
Reduction in variability in processes.					
Increase in staff morale.					
Reduction in activities that do not add value.					
Increase in staff satisfaction.					
Greater positioning of the company.					
Increase in efficiency and effectiveness.					
Increase in teamwork.					
Change in culture; from correction to prevention.					
Greater use of statistical tools to solve problems.					
Reduction in customer complaints.					

Part 2

Kindly rate the importance of the Green Lean Six Sigma enablers for implementation in your company on a scale of 1 to 5 by "√" mark in the appropriate box.

Question	Strongly Agree 5	Agree 4	Neutral 3	Disagree 2	Strongly Disagree 1
Top management commitment, involvement and support is critical.					
Effective project leadership is critical.					
Offering rewards and incentives for the employees is crucial.					
Having GLSS supportive organizational infrastructure is necessary.					
Consistent and accurate data collection is crucial.					
Carbon reduction initiatives are important.					
Environmental friendly packing of products is important.					
Incentive to produce green products is important.					
Practices of green design are critical.					
Environmental friendly transportation is important.					
Green operational practices are critical.					
Market demands for green products is significant.					

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Selection and retention of employee is important.
Teamwork is important.
Effective communication among departments is crucial.
Effective scheduling to solve problem is important.
Employee empowerment is essential.
Share project success stories among teams is important.
Organizational culture and ethics are critical.
Understanding of GLSS methodology is crucial.
Project selection and prioritization are crucial.
GLSS awareness program and training is essential.
Fund for operational expenditure is critical.
Financial benefits sharing among employees due to GLSS is important.
Strong supplier relationship management is essential.
Customer satisfaction and delight is crucial.
Understanding customer demand is critical.
Linking GLSS to buyer-suppliers enhances sustainability.
Integrate GLSS to core business processes is essential.

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