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CONTINUOUS IMPROVEMENT PRACTICES OF THE LEAN SIX SIGMA PROCESS APPROACH WITHIN AN ENGINEERING PRODUCT TESTING CAPABILITY

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Abstract - The study assesses the impact of continuous improvement initiatives on performance. These initiatives were implemented to enhance the Lean Six Sigma process approach within an engineering product testing capability, thereby reducing long product testing turnaround and cycle times. The research methodology employs an interpretive approach, using a structured, open-ended questionnaire in sixteen focus group interviews. A descriptive approach using a structured online questionnaire administered to 100 engineering product testing personnel was also considered. Based on interview responses and a review of the literature, three major themes and nine subthemes were identified for qualitative data analysis. The paper presents 12 findings: three from an interpretive analysis and nine from a descriptive analysis. These findings indicate that engineering product-testing capabilities partially apply Lean Six Sigma principles; however, excessive turnaround and cycle times are observed. The paper obtained information from twenty-six product-testing capability facilities within a self-revenue-generating organisation. The study examines the practical implications of the current adopted performance status quo and presents several strategies to enhance output performance for the benefit of organisations. It is recommended that product-testing capabilities consider identified improvement opportunities and recommend solutions to address the causes and effects that lead to further increases in excessive turnaround and cycle times. Furthermore, the study's contribution identifies opportunities to strengthen state-owned revenue-generating product-testing capabilities, research-institution testing capabilities, and industrial and medical laboratories by applying or enhancing Lean Six Sigma to improve their product-testing performance.

Keywords – continuous improvement, cycle times, lean, six sigma, lead times, turnaround times.

I. INTRODUCTION

The study is conducted in an engineering product-testing facility, where several customers' products are brought in for testing; upon completion, test reports are issued to the customers. However, product testing capabilities struggle to meet established customer turnaround times, resulting in excessive cycle times. Testing capabilities conduct their activities using an established Lean Six Sigma process approach, which, by its nature, continually emphasises continuous improvement. Continuous improvement is understood as the planned implementation of efforts within a selected operational environment to achieve excellent performance within a reasonable time frame. The inclusion of continuous improvement initiatives within the product testing capabilities not only improved performance but also increased revenue by enabling more deliveries to be made on schedule.

To achieve maximum performance, continuous improvement initiatives should enable seamless integration among the adopted testing process, available skilled personnel, and capable testing facilities [1]. Therefore, given the background, to achieve effective turnaround times and reduce testing cycle time, the adopted Lean Six Sigma process improvement approach requires continuous improvement. Lean Six Sigma yields strong results when testing capabilities, personnel, available resources, and established standard operating procedures are integrated. It has the potential to eliminate non-value-added activities that contribute to rising cycle times and to control testing process variation effectively [2]. The paper assesses the extent to which current deployed Lean Six Sigma process improvement initiatives are continuously refined to manage excessive turnaround times and to reduce cycle times. A literature review of Lean and Six Sigma applications, success stories, and setbacks was conducted to identify the best practices to recommend for improving product testing capabilities. For this paper, the following objective is considered:

- to provide the knowledge necessary that can be used for effective improvement of the current deployed Lean Six Sigma testing framework, to improve testing cycle times and throughput.

The research objective above informs the development of a research question and a data collection instrument. The following research question was developed in light of the research objective.

- How can the Lean Six Sigma framework improve testing process performance and shorten testing cycle times?

The study conducts a literature review to gather information relevant to its research objectives. The gathered information, together with the analysis of research results, is used as input to develop recommendations for product testing to improve performance outcomes.

II. LITERATURE REVIEW

I. Lean

Engineering product testing capability is generally viewed as a set of environments equipped with an array of testing benches or stations, which are utilised during testing. Therefore, to effectively deliver test results to customers within agreed turnaround times, consideration of lean principles in the testing process is mandatory [3]. Lean has been around since the 1930s and is famously known as lean manufacturing in the automotive industry. Its momentous impact was realised forty years later, and Lean, as a process improvement initiative, is known on the production floors of the Toyota Motor Corporation [4]. Its efficiency was noted and popularised by the book “The machine that changed the world” [5]. Lean performance depends on the provision of the necessary resource capabilities and technical competencies. Lean is generally recognised as a process improvement initiative for customer value identification [6], and it promotes the deployment of value streams, resource flexibility, waste control, and the adoption of processes to deliver defect-free products or services [7]. It is flexible in delivering value across almost every sphere of service or product provision, provided that the selected principles are appropriate for a particular operation. Lean is considered the most cost-effective process improvement initiative because it requires minimal resources to achieve expected outcomes. Lean, as great as it can be, is not immune to potential setbacks, which are briefly discussed below.

II. Lean Setbacks

Certain industries still refer to Lean as a set of tools and practices rather than as a process-improvement mindset, and this view has led the service sector to lose interest. Lean is viewed as a simplistic process improvement that takes no account of socio-cultural aspects [8]. Although it is recognised as a process improvement initiative, its inefficiency, as observed in Toyota's operations in Japan, doesn't generate interest in certain industries. It put more pressure on top management commitment. In some instances, lean is known to impose additional pressure on the resources assembled [9], as it always requires competence across all tasks.

III. Six Sigma

The origins of Six Sigma can be traced to the work of reliability engineer Bill Smith in the 1980s, and its impact on process improvement was acknowledged in 1995 [10]. Six Sigma is recognised as an effective waste-reduction methodology widely used in the automotive and electronics manufacturing industries. It is widely regarded as a resource for success, as it can deliver the breakthrough improvements necessary to achieve organisational operational objectives. Six Sigma facilitates improvement by using quality tools to track potential trends. Six Sigma principles enable the process owner to simplify adopted process subsystems to achieve optimisation. Six Sigma offers an advantage in capturing performance experience during task execution and presents an opportunity to analyse it further, which permits the application of the five-step Define, Measure, Analyse, Improve, and Control (DMAIC) methodological approach to improve process efficiency, emphasising the Plan-Do-Check-Act (PDCA) cycle. Six Sigma delivers high service quality when applied with appropriate monitoring strategies; however, its shortcomings persist in certain environments [3], and these shortcomings can still lead to performance deficiencies [11]. Six Sigma setbacks are discussed as follows.

The Six Sigma process improvement can be streamlined to deliver excellent results; however, one or another variation will always find its way to distract from the planned performance arrangement. In this view, certain process setbacks are accepted to a degree. Six Sigma's contribution to the healthcare environment is often viewed as limited in its ability to improve certain processes; however, its capacity to foster process creativity cannot be ignored. Six Sigma has the potential to deliver good results, but the implementation costs relative to the benefits cannot be justified, as results take a long time to observe [12].

IV. Lean Six Sigma

When deployed independently, Lean and Six Sigma deliver excellent output performance. Therefore, for engineering product testing capabilities to consistently deliver a competitive service to clients, a sustained pursuit of improved, reliable process approaches is necessary. Six Sigma has demonstrated its ability to improve existing processes beyond a reasonable doubt, yet its efficiency in healthcare operations has been hampered. In the same breath, Lean capabilities in advancing the agenda of improving the existing process approach to maintain constant positive output performance have been noted; however, the demands that it places on top management for its success are viewed as a setback, and the manner in which it enforces the agenda of resource increase as well as competence management. Therefore, integrating Lean and Six Sigma yields a seamless process-improvement approach known as Lean Six Sigma. Lean Six Sigma is generally known as process-product or team improvement initiatives that deliver excellent performance through collaboration and the use of an identified, approved, systematic organisational-adopted process approach.

V. Lean Six Sigma in product testing capabilities

Lean Six Sigma continuous improvement initiatives have been shown to enhance several product-testing capabilities, including those in forensic laboratories. Lean Six Sigma has been applied in the military health environment and in clinical and hospital laboratories. It has also been tested in the manufacture of weapons, the automotive and aviation industries, and food and health laboratories. Throughout its deployment initiatives, no literature reports on its success or failure, or on its setbacks, regarding the engineering product-testing capabilities of an organ of state for self-revenue generation. Therefore, this paper presents the extent to which Lean Six Sigma is deployed within engineering product testing capabilities and tabulates areas of concern and suggested solutions.

III. RESEARCH METHODOLOGY

An exploratory, interpretive, and descriptive approach was adopted. Qualitative data were collected through focus group interviews using a structured, open-ended questionnaire, with an initial sample of sixteen focus groups. Quantitative data were collected from a secondary sample of 100 product-testing capabilities personnel via a structured online questionnaire comprising 44 items, each assigned to a specific role or responsibility. The roles and responsibilities included executives, divisional heads, liaison officers, administrators, laboratory managers, senior test engineers, test engineers/officers, and testing operators. To achieve effective, value-added results, a sample that excluded zero-rate participants and included all product-testing personnel was used, ensuring that all personnel's views were captured and interpreted.

I. Data collection

Primary data were collected through continuous, comprehensive observations of the selected product-testing capabilities. The adopted testing process was observed end-to-end to understand how testing activities are carried out. Furthermore, sixteen focus groups were conducted. Secondary data were collected through an organisational knowledge review process, including annual performance reports. Lastly, a 44-item structured quantitative questionnaire was administered to 100 participants across five South African provinces. All participants were active product testers, assigned to their respective areas based on their roles and responsibilities. For both qualitative and quantitative data collection, questionnaires were developed in accordance with the established research objectives, and the information obtained through these questionnaires enabled an end-to-end testing process. Furthermore, participants' biographical information was considered to determine the assignment of relevant roles and responsibilities, as well as the required level of experience.

Data from both instruments were recorded, coded, and analysed descriptively and interpretively using the Statistical Package for the Social Sciences (SPSS, version 25). Qualitative data were analysed using major and minor themes, and additional literature was consulted throughout the interpretation of these themes to support the argument. Quantitative data were measured on a five-point Likert scale, with the agree-to-disagree scale used for Sections E34-E44, presented as ‘strongly disagree’ coded as 1, ‘disagree’ coded as 2, ‘undecided’ coded as 3, ‘agree’ coded as 4, and ‘strongly agree’ coded as 5. In addition, for quantitative analysis, Factor Analysis was performed to identify the latent dimensions underlying the measured variables and to assess their correlations.

III. DATA ANALYSIS

The qualitative data were analysed using an interpretive approach, in which three major themes and nine subthemes were identified to assess the association between the information gathered and the established research objectives. Meanwhile, quantitative analysis was conducted using exploratory factor analysis, which yielded two empirical factors comprising nine variables. Further to this, quantitative analysis utilises the KMO measure and Bartlett's test to assess the correlations amongst the established variables and to determine whether factor analysis is feasible for the collected data.

I. Participants' background

For qualitative analysis, 16 focus groups were conducted with 132 participants across four business clusters, each comprising 8 to 10 participants. Table 1 outlines participants' roles and responsibilities.

Table I. Roles and Responsibilities

A2 My position within the product testing capabilities is					
Engineering product testing capabilities roles and responsibilities		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Previous Executive	3.0	3.0	3.0	3.0
	Divisional Head	2.0	2.0	2.0	5.0
	Liaison Officer	3.0	3.0	3.0	8.0
	Administrator	10.0	10.0	10.0	18.0
	Laboratory Manager	21.0	21.0	2.0	39.0
	Senior Test Engineers / Officer	16.0	16.0	16.0	55.0
	Test Engineers / Officers	39.0	39.0	39.0	94.0
	Testing Operators	6.0	6.0	6.0	100.0
	Total	100.0	100.0	100.0	

Table 2 shows the participants' educational qualifications. Out of 100 responses obtained from the quantitative online questionnaire.

Table II. Educational Qualifications

A3 My highest educational qualification is					
Engineering product testing capabilities educational qualifications		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than Grade 12	1.0	1.0	1.0	1.0
	Grade 12	10.0	10.0	10.0	11.0
	Technical Diploma (N3-N6)	7.0	7.0	7.0	18.0
	National Diploma – Administration	13.0	13.0	13.0	31.0
	Technical National Diploma (S1-S4)	19.0	19.0	19.0	50.0
	Bachelor's Degree Business	3.0	3.0	3.0	53.0

	Bachelor's Degree Scientific	12.0	12.0	12.0	65.0
	B-Tech / Honours Degree	23.0	23.0	23.0	88.0
	Master's degree Scientific	5.0	5.0	5.0	93.0
	Master's degree Business Administration	5.0	5.0	5.0	98.0
	PhD / D-Tech Qualification	2.0	2.0	2.0	100.0
	Total	100.0	100.0	100.0	

II. Qualitative analysis

Three questions were formulated to elicit the information necessary to achieve the research objective. From the collected data, three major themes were identified, each with three subthemes, for a total of twelve themes to be analysed. The following are the questions asked and the responses provided by participants during the focus group interviews.

Question 1: What can be done to the current resource competence and equipment layout to increase the efficiency of the testing process?

A. **Theme 1: Resources Competency.**

Quote F-G1 "Let us start with the human power first; we need to skill personnel, and we should also allow these engineers to apply their theoretical knowledge to better our performance". Product testing capabilities need to enhance the competency of its resources. Resources include workstations, testing equipment, and personnel, such as a test engineer with the necessary knowledge, skills, and abilities. In contrast, competency is viewed as a unique set of knowledge and capabilities deemed necessary.

Subtheme - Equipment Reliability

Quote F-G16 "Our equipment breaks every now and then, and it took time for us to get it fixed because there is no service technician situated onsite…." The quotation confirms that some of the testing equipment is unreliable. Therefore, reliable delivery timelines can be agreed with customers only when equipment performance is guaranteed. Equipment reliability ensures that testing can be conducted without failure.

Subtheme - Equipment Durability

Quote F-G2 "On equipment, we need a robust maintenance plan that we follow to keep our equipment ready for our testing requirements. The participant attests that the equipment is not durable enough to withstand extensive hours of labour testing. Durability is defined as the ability of a product testing bench or workstation to withstand testing activities under normal conditions. The frequency of equipment deployment dictates durability and can help identify reliable testing equipment. Equipment durability can also be used to determine performance compatibility."

Subtheme-Resource compatibility (compatible)

Quote F-G9 "We need to feel appreciated, and we expect our HR to provide relevant technical courses that can boost our morale and advance our technical skills interest'' The quote confirms that skills compatibility is a challenge within the assembled team. Resource compatibility refers to the ability of the assigned technical team to test multiple requirements at a single station. The lack of crucial technical training provided by human resources weakens skills compatibility (Fernando & Wulansari, 2021:191-210).

Question 2: During working hours, how do you spend your time while waiting for the work/testing sample to get to your working station?

B. Theme 2: Idle Time Management

Quote F-G9 "There is no spare time here, even if you find yourself having to be free, you 'I find yourself looking for something else to do, and our environment doesn't offer some opportunity for us to share our best practise, where we share our systematic testing approach to better our ways of testing" The participants' views confirm that idle time is utilised to perform other duties. However, it is unclear whether the work performed is planned. A testing planning schedule contributes to the management of activities. Idle time can be managed through proper activity planning, thereby preventing the waste of waiting time.

Subtheme - Effective Time Utilisation.

Quote F-G14 "On a few occasions, when there is little work to be carried out and some of our teams are free, these individuals spend time updating documents such as paperwork, performance, and trivial maintenance, as well as housekeeping. This confirms that the testing team utilises the available time at their discretion, without proper guidance. From a discrete testing perspective, effective time utilisation can be viewed as a process in which a strict proportion of the testing period is spent testing a product on designated testing benches or testing stations to achieve expected and stated customer outcomes, within the set time frame, and that would assist in achieving set testing targets."

Subtheme -Testing Target Realisation.

Quote F-G10 "For the past three months, we've lost testing time due to inconsistent laboratory testing conditions. The facilities maintenance department controls the lab conditions, and they are struggling to maintain these conditions". The quote confirms that testing targets are not always met. For effective target-setting in product testing, certain crucial elements must be established within the product testing capabilities (Wei, 2021:1925-1960). These elements include, but are not limited to, available technical skills, suitable testing conditions, reliable testing equipment, resource competence, and a capable workforce [12]. Therefore, to maintain consistency, environmental testing conditions need to be well managed. The risks associated with environmental testing conditions shall be mitigated, and a realistic, strict containment plan shall be developed [13] to manage their continued existence.

Subtheme-Resource Utilization

Quote F-G5 "As I said to you earlier, we have fewer staff and additional work. Therefore, we are always on the go, completing tasks. We have lost many staff members during the Voluntary Service Package, and our workload has not decreased. The quote confirms that, in certain testing capabilities, the resources provided aren't sufficient to handle the workload. To ensure effective service delivery, promote success, and achieve efficient turnaround times in product testing, available testing resources should be deployed according to their performance capabilities, and sufficient resources should be provided [14]."

Question 3: Given the workload of the product-testing equipment, please outline the current maintenance process.

C. Theme 3: Testing Equipment Maintainability

Quote F-G3, "Our technicians are responsible for performing maintenance, as they check the equipment readiness prior to being used; we call out for external service providers when there is a major breakdown on our equipment." This confirms that the testing equipment is maintained internally and has limited capabilities. Maintenance is understood as an effort undertaken within product testing capabilities to restore and maintain the performance of testing equipment so that it can deliver expected test outputs. The equipment inspection process is used to gather the status of testing equipment [15].

Subtheme - Established Maintenance Principle.

Quote F-G13 "The equipment is spot-checked on a daily basis, and there is a known maintenance plan in place, but we feel that some equipment maintenance plan programs can be reduced to quarterly" The quote confirms maintenance, but periods can be adjusted. To ensure effective test outputs, product testing equipment must be kept in good working order at all times, and a proper maintenance plan must be established and adhered to. This principle helps preserve the operational performance of testing equipment and extend its lifespan. Maintenance plans are precise documents designed to record scheduled maintenance for all in-house testing equipment [16].

Subthemes - In-House Maintenance Service

Quote F-G7: "There is no planned maintenance for our laboratory setup. We should have done it, but I was tasked with it; however, due to gaps in my knowledge, I didn't complete it. So, we are expected to do things without proper knowledge of how to do them. The quote confirms that in-house maintenance is considered, but not everyone within the organisation has the necessary knowledge and skills. In principle, the availability of personnel with maintenance skills within product testing capabilities helps facilities address urgent maintenance needs effectively. In-house maintenance skills can help testing facilities assess the required level of maintenance. The advantages of having an internal maintenance team include effective problem diagnosis and prompt restoration of the equipment to its original condition without interrupting the testing process [17]."

Subtheme - External Service Provider

Quote F-G14 "As far as we are aware, no approved service provider has been appointed to date near our facilities, and our equipment was last serviced in 2022. This quote indicates that services critical to testing capabilities, when provided by external service providers, are poorly managed. To ensure the effective performance of testing equipment, reliable strategies for maintaining testing facilities must be established and sustained to manage lead and turnaround times [18]."

IV. QUANTITATIVE ANALYSIS

Eleven questionnaires were developed to collect data from 100 participants. The collected data were analysed using factor analysis; variables/items such as setup time were excluded because their communality values were lower than the matrix coefficient. Meanwhile, the equipment layout was excluded because its Measure of Sampling Adequacy was less than 0.6. Furthermore, the factors (components) deemed necessary to gather the knowledge required to improve the currently deployed Lean Six Sigma testing framework were identified. Achieving suitable reliability in workload, processes, and equipment, testing process validation, resource maintenance, and team collaboration are critical to reliable testing. Meanwhile, process observations, ease of movement, and reductions in human labour are critical to achieving working conditions. From Table 3, Kaiser-Meyer-Olkin's Test of Sphericity for variables E34–E44 is 0.824, which is greater than 0.6 ($0.824 > 0.6$). Sphericity is significant at a P-value of less than 0.05 ($p < 0.05$). Here, the p-value is 0.000, indicating a strong correlation across sections E34-E44 of the dataset.

Table III. KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling		0,824
Bartlett's Test of Sphericity	Approx. Chi-Square	229,766
	df	36
	Sig.	0,000

I. Exploratory Factor Analysis

Of the 100 responses collected using 44 questions, a factor analysis was conducted to reduce the data and identify a minimal set of factors. Table 4 illustrates the 44 questions identified.

Table IV. The 44 Questions Identified

Variable Names	Questions/Statements
Section A: Demographics	
A1	My business cluster is ....(Business Cluster)
A2	My position within the product testing capabilities is.... (Occupation)
A3	My highest educational qualification is …... (Qualifications)
A4	My years of experience with laboratories (Years in service)
Section B: Lean Six Sigma application to reduce cycle times and to improve the quality of outputs.	
B1	Housekeeping within the testing facilities is well maintained. (*5 S Maintenance)*
B2	An equipment readiness check is performed before the testing process begins. (*Equipment Readiness*)
B3	The current team's competence is assessed when accepting customers' test samples. (*Resource Competence*)
B4	Received customers' product samples are inspected, identified, and preserved as necessary. (*sample traceability*)
B5	The current testing equipment layout increases the number of test outputs. (*Workflow*)
B6	In-process monitoring, or inspection, is carried out during testing. (*quality in process*)
B7	The current assembled resource competence reduces testing rework and cycle times. (*waste reduction*)
B8	The risk assessment procedure is considered prior to the testing process commencing. (*Cost of Quality)*
B9	Test reports within the testing facilities are released to their respective customers within a reasonable time. (On-time delivery)
B10	Test reports for outsourced testing activities are effectively received within a reasonable time. (*Supplier Efficiency*)
B11	Test reports for in-house testing process activities are effectively released on time. (*Resource Reliability*)
Section C: Management of cycle time increments to improve performance output.	
C12	Waiting for a test sample to move from one testing station to another contributes to longer cycle times. (*Waste of waiting*)
C13	Product samples in the testing flow move from one testing station to another with minimal interference. (*Continuous Flow*)
C14	Testing target performance is set based on reasonable cycle times. (*Planned Objectives*)
C15	Incoming testing samples are inspected for quality, identified, recorded and preserved as necessary. (*Product Preservations*)

C16	Testing samples are drawn from the storage area using sample requisition slips, job card systems, or testing plans. (*Samples Extraction*)
C17	Sample preparation is performed prior to actual testing. (*Sample Preparation*)
C18	Special or urgent testing requests contribute to excessive cycle times. (*Urgent Test Request)*
C19	New customer testing requirements are utilised to advance the current testing capabilities. (*Improvement through requirements*)
C20	Testing requirements that cannot be met internally are outsourced to external service providers. (*Capability Outsourcing*)
C21	The current testing equipment layout contributes to effective testing turnaround times. (*lead times reduction)*
C22	The current deployed testing process approach effectively delivers test reports on time. (*process effectiveness*)
Section D: Maintenance of good testing practises, through reduction of cycle times and performance improvement.	
D23	The current testing process effectively eliminates non-value activities. (*performance enhancement*)
D24	The current human performance influences the increase in testing facilities' performance. (*human power*)
D25	The current product testing stations are sufficiently utilised. (*equipment utilisation*)
D26	There is adequate work for testing officers within the testing facilities. *(enough testing activities*)
D27	Transfer of skills within the testing facilities is carried out through teamwork. (*knowledge transfer*)
D28	Testing officers may rotate between laboratories. (*Skills Increase*)
D29	The established testing process map makes non-value-added activities visible. (*Process Transparency*)
D30	The skills of test officers are enhanced and retained through training and knowledge transfer. (*Capability Retention*)
D31	A product testing plan is used to pull out samples from the sample storage area. (testing plan)
D32	The current deployed testing process approach controls quality and reduces waste, improving testing lead times. (***Quality Control)***
D33	The established resource maintenance plan supports initiatives to reduce lead time. (*Resource Maintenance*)
Section E: Means to establish a more strategic and Localized Lean Six Sigma Laboratory Testing Framework.	
E34	A shorter setup time for testing equipment increases testing output performance. (*Set up Time*)
E35	The equipment layout makes it easy to move samples and personnel during testing. *(Equipment Layout)*
E36	Customers visit the testing facilities from time to time to witness testing processes. (*Process Observations*)
E37	The testing equipment layout makes it easy to access from one working station to another. (*Ease of Movement*)

E38	The deployed testing process eliminates excessive human labour. (*Human Labour Reduction*)
E39	The product testing workload within the testing facilities is manageable. (*Suitable Workload*)
E40	Process control tools are utilised to assess the effectiveness of the adopted testing process. (*Process Reliability*)
E41	*The current testing laboratories can meet the required testing standards. (Equipment Reliability)*
E42	The testing facilities are equipped with means to detect possible testing faults. (*Testing Process Validity*)
E43	The product testing facilities maintenance schedule/plan is established and adhered to. (*Maintenance Plan*)
E44	The working culture within the product testing facilities motivates teamwork. (*Team Collaboration*)

Factors are identified by examining intercorrelations among variables. To perform factor analysis, the correlation coefficient should be $r > 0.3$. Bartlett's Sphericity test is significant ($p < 0.05$), and the KMO value is 0.6 or higher. Eleven questions were administered to achieve this objective, and two responses were excluded from the results due to noncompliance with factor-analysis requirements. Therefore, this analysis focuses on nine items.

The items or variable identified that are determined to gather knowledge necessary that can be used for effective improvement of the current deployed lean six sigma testing framework were loaded on two empirical factors such as Reliable testing capabilities that explaines 25.248 % of the total variance, with an eigenvalue of 3.523,, with a mean value of 3.375 (67.5%) at a standard deviation of 0.77538, and produces six items/variable. Meanwhile, a Suitable working conditions factor accounts for 15.130% of the total variance, with an eigenvalue of 1.312, a mean of 3.396 (67.92%), and a standard deviation of 0.76936, and yields three (03) items/variables.

Furthermore, the identified variables indicate that all anti-image matrices from datasets E34–E44 exceed 0.6. The lowest Measure of Sampling Adequacy (MSA) value is 0.659 at component E36 (process observations), while the highest is 0.883 at E38 (human labour reduction). Table 3 presents common variance data ranging from 0 to 1. The lowest recorded variance is 0.205 at E37 (free movement), whereas the highest is 0.572 at E44 (team collaboration). Table 3 depicts the rotated factor matrix. Of the two identified factors, six items (0.704, 0.670, 0.642, 0.561, 0.479 and 0.408) load above 0.3 on factor 1, and only three items (0.598, 0.532 and 0.435) load above 0.3 on factor 2. The data demonstrate strong correlations within sections E34–E44. Figure 1 shows the scree plot for datasets E34–E44. Only two factors have eigenvalues greater than 1, and these components account for most of the total variability in the dataset. These components are 3.523 and 1.312. The plot begins to stabilise at the third point, 0.912, forming an elbow shape.

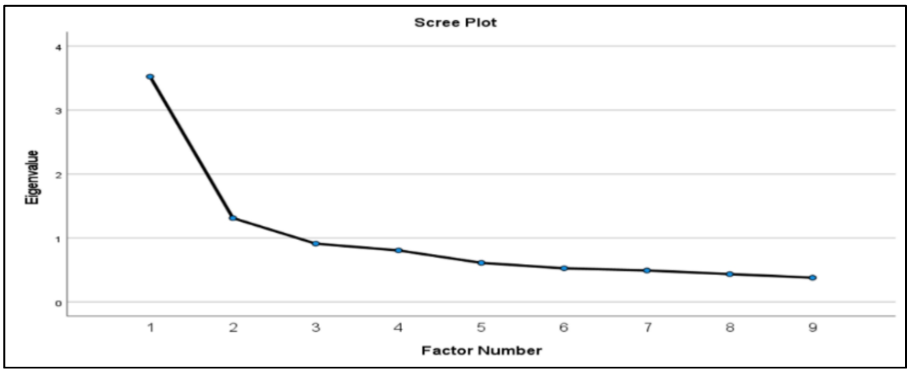

Figure I. Scree plot for data set E34 – E44,

5.1 Qualitative

The data were collected through face-to-face interviews, analysed, and, on completion, areas of concern were identified and recorded as findings. These findings were presented to the senior management team of the product testing capability for validation. Some results were accepted as accurate reflections, and others were acknowledged for further consideration.

5.2 Quantitative

Results obtained show that factor 1, "reliable testing capabilities," has a Cronbach's alpha of 0.790, indicating good reliability. Meanwhile, factor 2, "suitable working conditions", maintains a Cronbach's Alpha of 0.523, indicating poor reliability, but its inter-item correlation mean of 0.268, which falls between 0.2 and 0.4, confirms that the data is reliable irrespective of the Alpha value obtained. Therefore, based on the obtained Cronbach's Alpha value of 0.801 for the entire section E34 – E44, considering the remaining nine (09) items, it is concluded that the results are valid and reliable. Table 4 presents a summary of item statistics,
including the mean inter-item correlation, which confirms the reliability of these three items for factor two.

Summary Item Statistics							
	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Inter-Item Correlations	0,268	0,201	0,311	0,110	1,547	0,003	3

Table 4. Summary of item statistics, presenting the inter-item

V. RESULTS AND DISCUSSION

For qualitative research, three major themes were developed from the collected data, taking into account the reviewed literature and the research objective set to address sections E34-E44. Resource competencies were established and maintained to ensure effective testing performance. However, the extent to which the established resources are reliable for end-to-end testing services, durable over extended periods without failure, and compatible with other testing activities was found to be effective to some extent, as the results show excessive turnaround times and consistently long testing cycle times. Idle time management was partially effective, as available testing time was utilised to cover other activities, even though those activities were not part of daily testing services.

This confirms that testing time utilisation, testing target realisation, and resource utilisation were managed to some extent; however, the results show excessive turnaround time and consistently long testing cycle times. Testing equipment maintainability was partially addressed, as a maintenance process was in place. However, the extent to which the established maintenance principles were practised to handle maintenance activities, the level of competence of the in-house maintenance team to effectively resolve maintenance issues, and the time it took for the external service provider to attend to maintenance requirements were found to be effective to some extent, as the results show excessive turnaround time and consistently long testing cycle times.

I. Quantitative

Factor 1: The factor's mean value of 3.375 (67.5%), with a standard deviation of 0.77538, indicates that personnel who perform work that affects output quality are undecided or unsure about whether product testing capabilities are reliable enough to complete testing activities on time. Meanwhile, 1.625 (32.5%) strongly disagree to disagree that these capabilities are effective and reliable for conducting testing activities and delivering within reasonable time frames. Factor 2: The factor's mean value of 3.3966 (67.932%), with a standard deviation of 0.76936, indicates that personnel who utilise these resources for testing are undecided or agree that the working conditions for product testing are suitable. Meanwhile, 1.609 (32.068%) strongly disagree to disagree that product testing capabilities, facilities, or equipment provide suitable working conditions for testing personnel. The Spearman's coefficient was greater than 0.3, indicating a strong correlation. The Bartlett's Test of Sphericity showed a significant p-value ($p < 0.05$). The KMO Measure of sampling adequacy was 0.824, exceeding 0.6 and indicating that the dataset is suitable for factor analysis. For factor 1, Cronbach's Alpha of 0.790 indicates acceptable internal consistency. Meanwhile, factor 2, with a Cronbach's Alpha of 0.523, demonstrates poor reliability; however, its mean inter-item correlation of 0.268 falls between 0.2 and 0.4, confirming that the data are reliable irrespective of the Alpha value obtained.

II Proposed solutions

Figure 2 Testing equipment general set-up shows the general set-up of testing equipment, carefully designed to highlight critical areas for consideration prior to and during the testing process. This flow demonstrates critical areas to consider for effectively managing reliability performance. It also supports the management of expected testing activities, including labour durability, testing volume, and compatibility with critical testing requirements. Meanwhile, Figure 3 Testing inquiry phase shows the testing inquiry phase, carefully developed to demonstrate controls that can be considered to maintain testing capability performance and to tolerate the extent to which these testing facilities are subjected. Further to that, it strategically promotes suitable working conditions that can contribute to effective output performance and promote effective management of testing cycle times.

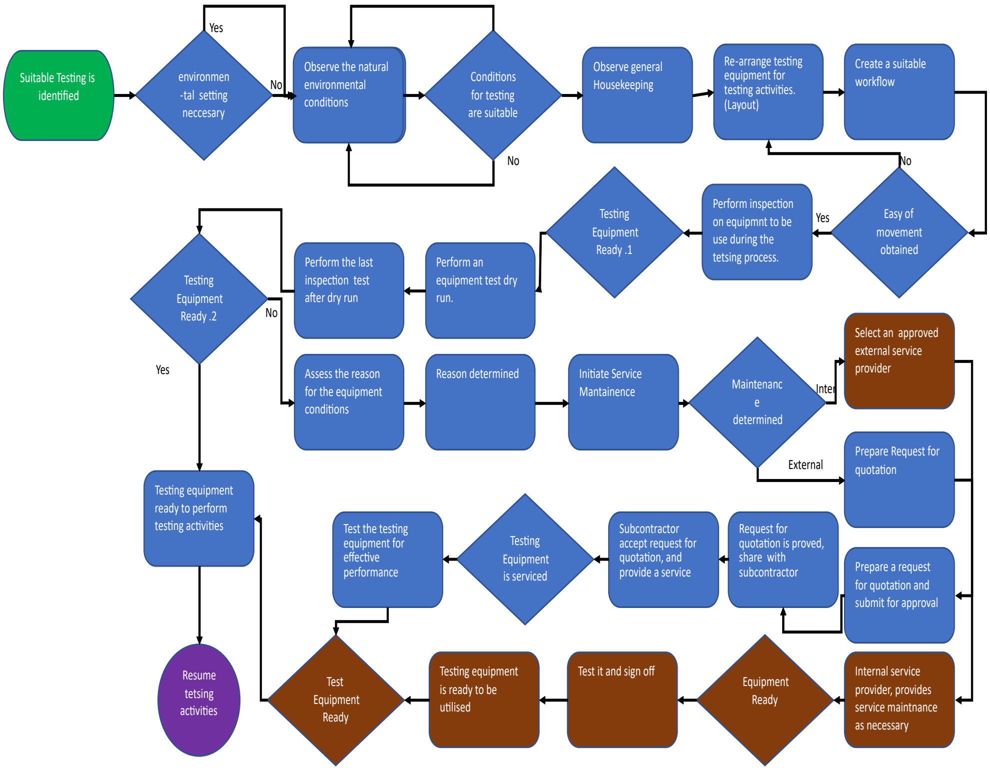

Figure 2. Testing equipment general set-up (authors')

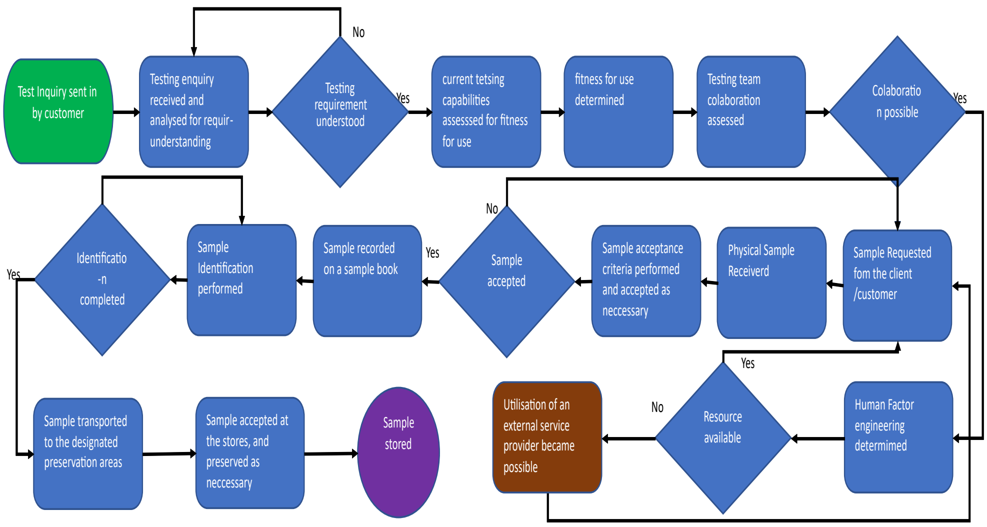

Figure 3. Testing inquiry phase (authors')

The information recorded provides critical insights to inform improvements to the currently deployed product testing framework. Therefore, consideration of the information provided will help reduce the noted excessive testing turnaround and cycle times. The engineering product testing capabilities will use the information provided to keep testing equipment ready for testing activities, utilise the time allocated for testing activities, take ownership and control to maintain the quality of work completed by external service providers, and deliver within the committed turnaround times for the benefit of the customer.

VI. SUMMARY

The paper presents the research background and rationale. A literature review examines the origins of Lean and Six Sigma, their setbacks, and their synthesis. The paper further presents Lean Six Sigma contributions across several testing capabilities and identifies the benefits and potential challenges. Throughout the reviewed literature, positive effects of Lean Six Sigma on testing capabilities were noted. However, information on engineering product-testing capabilities from a self-revenue-generating state organ was insufficient. The paper presents the adopted research methodology, data collection methods, and data analysis. It further presents the adopted reliability-check process. Lastly, the discussion of the research results, summary, and conclusion. To address the research question, two carefully designed process maps, based on research findings, are proposed for consideration before testing begins to effectively manage excessive turnaround and cycle times.

VII. CONCLUSION

The study shows that the knowledge required to improve engineering product testing capabilities can be applied within the Lean Six Sigma framework, and that this outcome depends on effectively considering the following factors. Resource efficiency and reliability can be achieved when suitable testing equipment, a maintenance programme, workloads, and team collaboration are effectively considered. In addition, suitable working conditions can be achieved when the testing process is transparent, the layout of testing equipment is effective, and human labour is reduced. Lastly, to effectively manage idle time, capable resources shall be provided, and testing and maintenance schedules shall be used and monitored.

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