Application of Lean Six Sigma in Water Testing Laboratory to Increase Efficiency and Enhance Customer Satisfaction

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Abstract

Laboratory testing is an important process which relies on scientific analysis to identify problems with services or a product. It provides analytical data on the quality of a product or service to support other process depending on the type of the industry. Laboratory test results impact many areas of our daily lives since the results produced are often used as the quality control of the product or a service.

This study examines root courses of why the laboratory under study was failing to meet customer's Service Level Agreement (SLA), and how those bottlenecks can be resolved through the application of Lean Six Sigma (LSS). The study seeks to identify critical factors within the laboratory and customers' perception about services they receive.

The research design used in this study is based on qualitative research. Brainstorming sessions and questionnaires were used to collect data about the causes leading to lack of fulfilling customer demands. LSS tools were then applied to minimise or eliminate wastes in order for the laboratory to operates effectively. Finally, personnel surveys were conducted to verify the effectiveness of LSS implementation and customer surveys were conducted to assess the level of satisfaction after LSS application.

After application of LSS, the results showed that the laboratory is now working in a lean environment, meeting customer demands while producing accurate and credible results timeously. It can, therefore, be concluded that bottlenecks were the cause on not meeting customer demand and they were eliminated through LSS application.

Key words
Lean, Six Sigma, Laboratory Testing and Water

1. Introduction

Water Testing Laboratory (WTL) is one of the departments within the organisation under study, which focuses primarily on the provision of analytical services such as testing water and water quality compliance in support of internal customers (Regions) within the organisation's area of supply. These services are also extended to external customers (District and Local Municipalities)

The results obtained from the laboratory assist in optimising water treatment plants, compliance in terms of final drinking water that is distributed to consumers as per Water Services Act No. 108 1997 Water National Legislation and meeting SANS 241:2015 drinking water standard requirements. This research is very significant as WTL plays a vital role in water sector, hence not producing valid, credible results timeously will affect end users at home who consume water since decisions cannot be made without the final test results from WTL.

Currently the WTL is struggling with high volume of customer complaints due to Service Level Agreement (SLA) not being met, recurring customer complaints/non-conformances, occurrence of variable lead times which compromise SLA with its customers, failing to achieve goals and objectives of the department; and due to all of the above mentioned, the accreditation is compromised which may result in losing business.

Therefore, the aim of this study is to apply Lean Six Sigma (LSS) in Water Testing Laboratory in order to increase efficiency, work effectively in a lean environment, enhance customer satisfaction, reduce number of customer complaints in order to sustain and maintain accreditation, save lives of consumers at home in terms of disease outbreaks, as well the continual improvement of the system.

1.1 Objectives

This study will explore the case of WTL activities on application of Lean Six Sigma, and more specifically, the study has the following objectives:

1. To identify root causes of the current issues in the Water Testing Laboratory.
2. To apply Lean Six Sigma in a Water Testing Laboratory in order to improve the effectiveness and efficiency of its operations.
3. To implement and maintain lean laboratory environment in order to enhance customer needs.

2. Literature Review

Lean Six Sigma (LSS) was originated in the electronics company Motorola and invented in 1986 as a methodology to reduce defects (Bhamu and Sangwan, 2014). Lean Six Sigma is a method that provides organisations tools to improve the capability of their business processes.

Lean (also known as Lean Production, Lean Enterprise and Lean Thinking) involves a set of principles, practices and methods for designing, improving and managing processes (Timans, Ahaus, van Solingen, Kumar and Antony, 2016).

Six Sigma, just like Lean, is a business management strategy used to improve the quality and efficiency of operational processes (Chiarini, 2014). Lean focuses on identifying ways to streamline processes and reduce waste, whereas Six Sigma aims predominantly to make processes more uniform and precise through the application of statistical methods.

Six Sigma and Lean combined results into the LSS which has become a popular tool to improve operational excellence in manufacturing based on the above literature this is supported by Kurdve et al. (2014) where Lean concentrates on cost reduction and efficiency is a perfect complement to Six Sigma's pursuits of accuracy and precision.

Recent literatures emphasise the application of Lean practices to laboratories in order to improve operational efficiencies (Garza-Reyes, Villarreal, Kumar and Molina Ruiz, 2016). Six Sigma is also identified as a key enabler of such improvement in laboratories (Nabhani and Shokri, 2009; Roesekar and Pohekar, 2014; Oosterhuis, Bayat, Armbruster, Coskun, Freeman, Kallner, Koch, Mackenzie, Migliarino, Orth and Sandber, 2018).

Lean tools are also proven to be effective where the generic causes resulting in increasing turnaround time of clinical laboratories were identified using lean tools and techniques such as Value Stream Mapping (VSM), Gemba, Pareto Analysis and Root Cause Analysis. VSM was used as a tool to analyse the current state of the process, and to design the future state with suggestions for process improvements (Gupta et al., 2018).

Wolniak, Skotnicka-Zasadzień and Gębalska-Kwiecień (2018) indicated that brainstorming is most effective before application of LSS within the organisation in order to identify bottlenecks. Furthermore, they introduced effectiveness of certain tools within the laboratory environment. Through brainstorming, the seven wastes can be established and therefore prioritized as per Pareto Analyses.

According to Sanz (2019), Pareto analysis is a statistical technique in decision-making used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule), the idea that by doing 20% of the work you can generate 80% of the benefit of doing the entire job. This technique is also called the vital few and the trivial many.

QCs are often used to monitor use of quality controls which is defined as the use to monitor the performance of each test method. There are rules of the chart as per Shewhart methods that need to be followed before one can say results are accurate and credible. Most of the laboratory errors occur in pre-analytical process, which is mostly outside the laboratory, and this important situation has to be monitored by laboratory specialists (Zorbozan, 2019). Although the standard statistical methods in which the frequency is evaluated can reveal which error is more than the others, they cannot determine which error is needed due to the absence of accepted target values.

Sierra, Wagemann, Pol, Kendziorra, Herzog, Recker and Mueller (2015) describe a flowchart as a picture of the separate steps of a process in sequential order. It is a generic tool that can be adapted for a different purpose, and can be used to describe different processes, such as a manufacturing process, an administrative or service process, or a project plan. It is a common process analysis tool and one of the seven basic quality tools.

Cause and Effect Analysis was devised by Professor Kaoru Ishikawa, a pioneer of quality management, in the 1960s (Coccia, 2018). Although it was originally developed as a QC tool, it can also be used to discover the root cause of a problem, uncover bottlenecks in your processes and/or identify where and why a process isn't working (Liu; 2015)

5S method was developed at the beginning of the ‘80s by Hiroyuki Hirano in Japan and was first heard of as one of the techniques that enabled what was then termed “Just in Time Manufacturing”. This is an efficient and high-quality work needs a clean environment, safety and rigor. The 5S principle, Seiri, Seiton, Seiso, Seiketsu, Shitsuke, allows the creation of a functional working environment, with simple, precise and efficient rules (Veza, Gjeldum, Mladineo 2015).

3. Methods

The research design is based on a mixed method study. The qualitative research design was selected based with an aim of getting an insight on how customers perceived the service rendered by WTL, and also personnel perceptive on the activities they conduct in the laboratory and the willingness to change, and the quantitative research design was selected based on quantifiable data where scientific and statistical methods were used to analysed collect data for performance of the test methods, method validations as well as Quality Control charts.

Primary data was collected by using the structured questionnaires, brainstorming sessions conducted on different days, surveys as well as observations within WTL department, personnel within Operations department (internal customers) who deal directly with WTL in terms of results as well municipalities (external customers).

LSS Tools such as Brainstorming teams, Cause and effect diagrams, Quality control charts, Flow charts, 5S Concepts, 5WHYs and scientific processes (Method Validation) were also used to collect data. The secondary data was collected from the library searches and access to information gathered from WT. The questionnaires were divided to accommodate everyone who is directly and indirectly involved with water testing, including laboratory personnel, Operations department personnel and municipalities.

4. Data Collection

Through brainstorming, the seven wastes can be identified and therefore prioritised as per Pareto Analyses. Figure 1 below show bottlenecks/wastes that were identified in WTL by the brainstorming team.

Figure 1. WTL identified wastes

4.1 Measuring Wastes

Pareto analysis was selected as a tool to be used to measure each waste. Bottlenecks and wastes deterring the timeous distribution of accurate results were identified. Each waste was measured by looking at the occurrence in the past 12 months, Pareto analysis was then used in order to have a clear picture of the most problematic bottlenecks. (Figure 2)

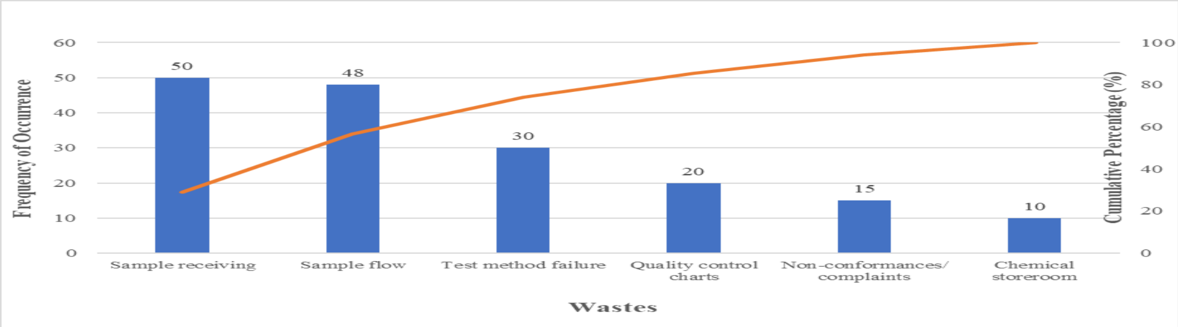


Figure 2. WTL wastes as per 80/20 rule

4.2 Analysing Wastes

Identified waste were defined by the brainstorming team as follows:

4.2.1 Sample Receiving

This is the major problem as it is referred to as the "Heart of the Laboratory" as this is the first activity to be performed by the laboratory from Water Treatment Plants (WTP). Samples are delivered by Samplers and the laboratory need to be ready for this activity, and one mistake in this activity can jeopardise the entire purpose as samples needs to be received and recorded accordingly with no confusion in sample identity.
In this process, one needs to be vigilant and pay attention to details. Also, there is a lot of paperwork involved in this process and record keeping is vital for traceability purposes as it is required for accredited laboratories. WTL uses manual receiving process since there is no Laboratory Information Management System (LIMS).

4.2.2 Sample Flow

Sample received is followed by sample distribution, and this needs proper process on how to distribute samples in all sections of the laboratory, namely: Microbiology, Wet Chemistry, Sewage, Organic and Metal laboratories. In this activity, one needs to be mindful in terms of sample contamination, sample retention as some analysis requires sample to be tested at certain condition (temperature), specified time as per each test method to avoid deuteriation and sample preparation required.

4.2.3 Test Method Failure

Accredited laboratories are required to validate/ verify test methods before put to use to check how they behave in their environmental conditions; test methods are often adopted from Standard methods however method fail due to unknown reasons.

4.2.4 Quality Control Charts

Quality Controls (QCs) are used to monitor the performance of each test method, QCs shall be done prior to analysis in order to maintain confidence of calibration status. The process starts by analysing standard solutions which are expected to form a linear calibration curve with correlation coefficient (r^2) which is derived from the formula (x^2+y^2=r^2) of 0.995-1.000. There are rules of the chart that need to be followed before one can say results are accurate and credible. Those rules are mostly biasness in terms of mean, ± 2 Sigma (± 2δ) and well as ± 3 Sigma (± 3δ). These are often known as limits as per Shewhart, and the chart shall behave in a certain way in order to be sure that it is performing optimally (Clesceri, Greenbag and Eaton 2015).

WTL experience too much biasness which is defined as the deviation of the expected value from the true value (Phophan;2015). This biasness often leads to halting analysis and investigating the breaches of those rules that have occurred.

4.2.4 Non-Conformances

One of the ISO/IEC 17025:2017 standard for accredited laboratories clauses require non-conformances to be investigated in order to find the root cause of the problem. The laboratory has a lot of non-conforming work which mostly is from not meeting customer SLA. Although there is a procedure of non-conforming work, but the laboratory spends a lot of time trying to find the root cause, however the problem persists that clearly indicates that the laboratory has been treating symptoms not the real problem hence there is recurrence.

4.2.5 Chemical Storeroom

The problem starts on looking for a storeroom key where chemicals and salts are kept. This room shall be locked at all times since there are poisonous and flammable chemicals. It was noticed that the chemicals are not sorted in a manner that they can be easily retrieved. Personnel often spends too much time looking for a chemical which leads to having spending too much time instead of preparing reagents that will be used for customer samples analysis.

5. Results and Discussions

5.1 Sample receiving

Flow chart was selected as an appropriate tool for this bottleneck. Sierra, Wagemann, Pol, Kendziorra, Herzog, Recker and Mueller (2015) describe a flowchart as a picture of the separate steps of a process in sequential order. It is a generic tool that can be adapted for a wide variety of purposes and can be used to describe various processes.

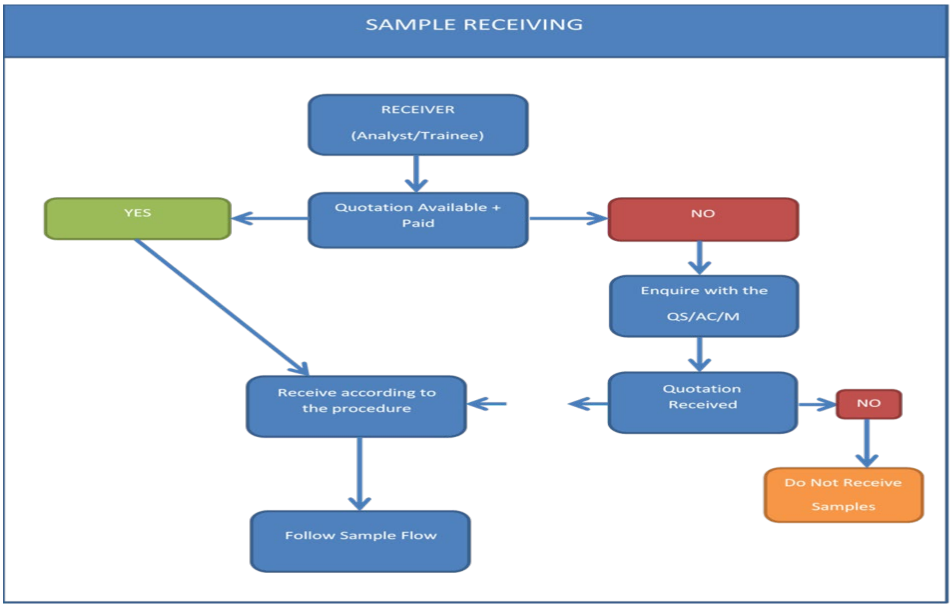


Figure 3. Sample receiving flow chart.

It was noted that following flow chart (Figure 3) is easily interpreted compared to reading a word document procedure, although procedures are there, however sample receiving flow chart was made visible at a sample reception area.

5.2 Sample Flow

Flow chart was selected as an appropriate tool for this bottleneck, as it allowed distribution of samples in their respective sections while avoiding contamination and ensuring segregation of some areas. Sample flow was designed considering those sections that require sample preparation, customers' SLA per determinant and sample volume per analysis and section.

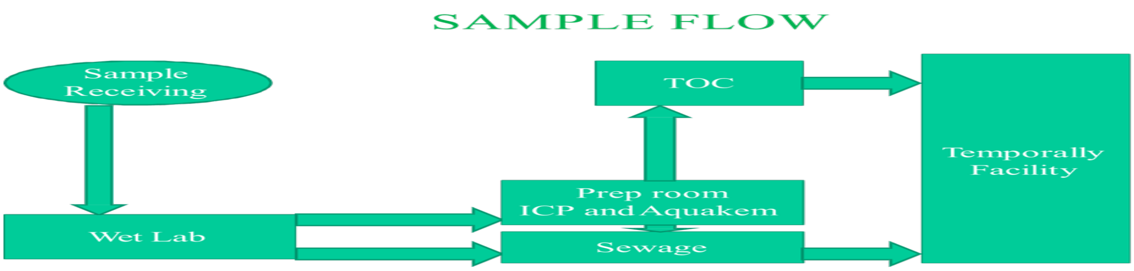


Figure 4. WTL sample flow

Figure 4 shows, all personnel were trained on sample flow as per flow chart was made visible in all sections of the laboratory including receiving area and storage facility.

5.3 Method validation

Test method failure was found to be due to meted not being thoroughly verified before put into use, also re-validation was not considered. The laboratory also verified methods using standard methods, however proper validation was not done as per SANAS TR26 document. (Table 1)

Table 1. Method validation of chloride, nitrate, aluminium, and iron

Parameter	**Chloride Results**	**Nitrate**	**Aluminium**	**Iron**
Linearity, Range & r^2	10 mg/l – 300 mg/l 0.9996	0.5 mg/l – 10 mg/l, 0.9995 0.230	0.10 mg/l – 1.50 mg/l 0.9990	0.10 mg/l – 1.50 mg/l 0.9999
Accuracy	SABS water check PTS samples were within the acceptable range (-2 < Z-score < +2) for all the determinants.	SABS water check PTS samples were within the acceptable range (-2 < Z-score < +2).	SABS water check PTS samples were within the acceptable range (-2 < Z-score < +2) for all the determinants.	SABS water check PTS samples were within the acceptable range (-2 < Z-score < +2) for all the determinants
Recoveries	Potable water: 85% - 99% Surface water: 85% - 94% Ground water: 93% - 119%	Potable water: 84% - 116% Surface water: 86% - 110% Ground water: 90% - 116%	Potable water: 81%-104% Surface water: 85%-101% Ground water: 94%-103%	Potable water: 110%-112% Surface water: 81%-110% Ground water: 102%-119%
Repeatability Precision	10 mg/l: %RSD = 0.77% 150 mg/l: %RSD = 0.26% 300 mg/l: %RSD = 0.42%	0.5 mg/l: %RSD = 0.92% 5.0 mg/l: %RSD = 0.32% 10 mg/l: %RSD = 3.66%	0.10 mg/l: %RSD = 1.19% 0.50 mg/l: %RSD = 1.18%	0.10 mg/l: %RSD = 0.86% 0.50 mg/l: %RSD = 1.67%
Reproducibility Precision	100 mg/l: %RSD = 3.92%	5 mg/l: %RSD = 3.19%	0.50 mg/l: %RSD = 4.49%	0.50 mg/l: %RSD = 3.82%
Limit of Detection	1.62 mg/l	0.25 mg/l	0.01 mg/l	0.01 mg/l
Limit of Quantification	2.42 mg/l	0.28 mg/l	0.04 mg/l	0.03 mg/l
Reporting limit	10 mg/l	0.5 mg/l	0.10 mg/l	0.10 mg/l
Bias	+4.23%	+2.16%	+1.2%	+0.4%
Specificity/ Selectivity	Recovery: 85% - 119%	Recovery: 84% - 116%	81% - 104%	81% - 119%

After revalidation of these test methods, no method failures were noted and the evident was made by the proficiency testing schemes supplied by SABS, as obtained results were within desired Z-scores as per Figure 5 below.

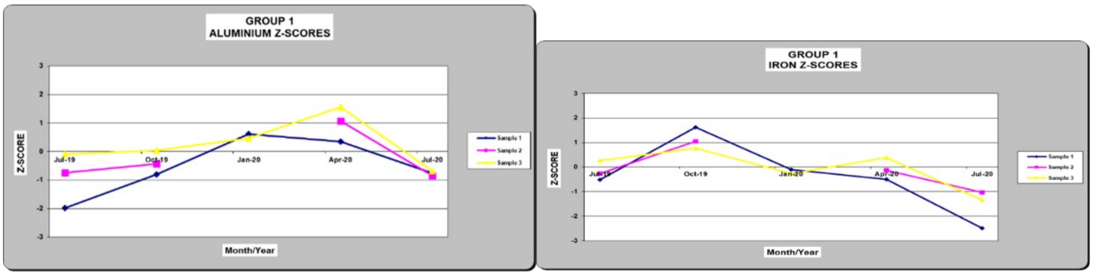


Figure 5. SABS PTS Z-scores (Aluminium and Iron)

As per Figure 5, all Z-score are within ± which is regarded as satisfactory. It can be concluded that after validating these test methods, accurate, reliable, and credible results are now obtained in WTL, therefore test method failures has been eliminated.

5.4 Quality control charts

Quality Control charts tool was selected for this waste as per SANAS TR-26 document as opposed to Shewhart rules which are currently adopted by WTL. Methods are validated based on TR26 document and it clearly states that the QC limits must be 90% to 110% of the "true" value. When the validation is complete, a minimum of 33 QC results must be used to establish the limits as follows:
Mean (ẍ) = sum of the QC results/ number of the QCs, Standard deviation (SD) = {(∑XI - X)2 / (N-1)} ½

Relative standard deviation (RSD) = SD x 100%/ ẍ Acceptable RSD must be ≤10%, UCL= 1.10 ẍ ;+Bias = 1.05ẍ, -Bias= 0.95ẍ and LCL = 0.90ẍ

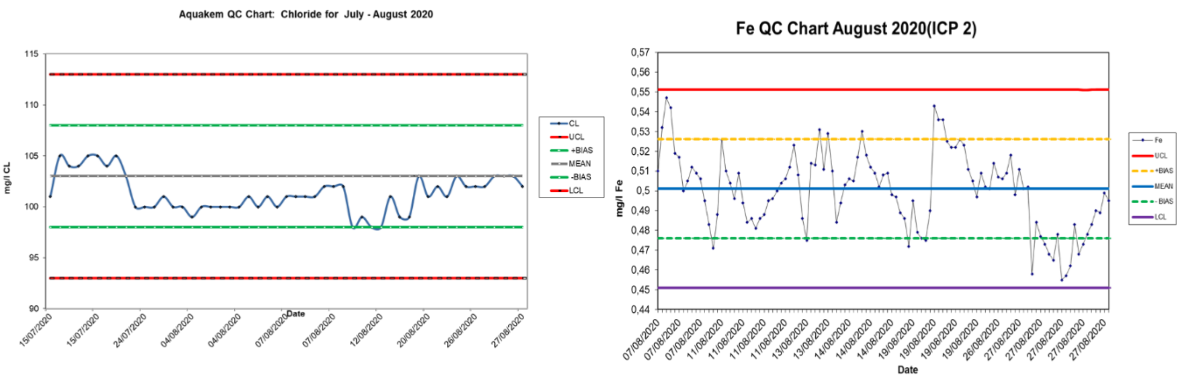
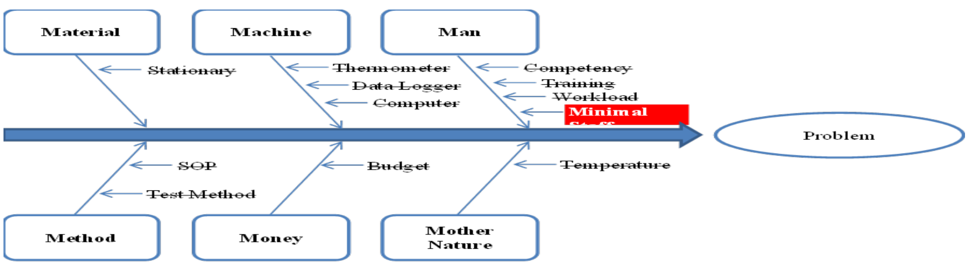


Figure 6. Chloride and Iron QC chart

After adopting SANAS TR-26 document, no positive or negative biases were noted as displayed in Figure 6 and the results were obtained on time as no work was halted.

5.5 Non-Conformances

During sessions with brainstorming team, it was found that there is no appropriate tool adopted by WTL to address non-conforming work which is the results of recurrence and lead times to customer complaints. Therefore, Cause and Effect diagram tool which is widely known as Fishbone diagram and 5WHYs were adopted to investigate non-confirming work.
The procedure was then amended to include tools and personnel were trained on how to use such tools and this was applied as per figure 24. Number of non-conformances decreased gradually after using tools and addressing bottlenecks as per 2018/19 and 2019/2020 non-conformances diagrams (Figures 7 and 8).



5 Why's
Q: Why were the results of the raw data (19/03/2020) transfers not done?
A: Transfers were done on the computer and the analyst forgot to put in the signature on the raw data sheet to indicate that they were transferred.
Q: Why was the worksheet not signed?
A: It was an oversight and when the checks were done, the laboratory had only one personnel competent on the test methods in question due to Lockdown. The Checker signed the worksheet book to indicate that the results were checked before they were sent to the client.

Figure 7. Fishbone diagram and 5whys used in one of WTL non-conformances.

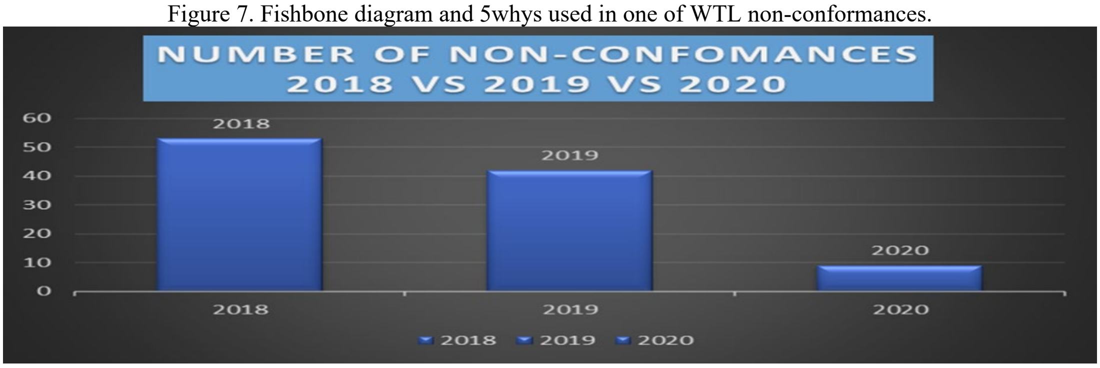


Figure 8. Number of non-conformances before and after LSS application

It is evident that the number of non-conformances has decreased after applying Cause and effect diagram as well as 5whys (Figure 7) when investigating non-conformances. In addition, meeting SLAs with customers lead to the decrease of non-conformances as illustrated in Figure 8 wherein there were huge number of non-conformances/complaints in 2018 and 2019 as compared to 2020 when the application of LSS was implemented

5.6 Chemical Storeroom

5s concept tool was applied for chemical storeroom. as per following:
Sort: all unnecessary chemicals were removed from the storeroom and expired chemicals were grouped together awaiting waste removal.

Set in order: storeroom was then organized by grouping chemicals according to sections, test methods and clear labelling was displayed for efficient use (Figure 9).

Shine: Cleaning roster was documented, and supervisors inspect area regularly.

Standardise: 5S was then incorporated in the standard operating procedure (figure 9)

Sustain: Sustainability is an ongoing process; the area is kept tidy, and chemicals are in their designated areas.

Figure 9. 5S concept applied in chemical storeroom.

5.7 Results on Customer Satisfaction and personnel feedback

This section presents monitoring of application of LSS by doing customer surveys and personnel feedback with the aim of determining if application of LSS tools did increase efficiency, created lean environment, and assisted in meeting SLAs with customers in order to enhance customer satisfaction.

5.7.1 Water Testing Laboratory (WTL) Personnel

Questionnaires for WTL personnel covered the effectiveness of LLS tool within the laboratory, the main target was to discover if all the changes made did add value. Although brainstorming was done with the same team, however it is necessary to get an understanding in terms of research objectives and the level of satisfaction from the team who perform tasks on day-to-day basis.

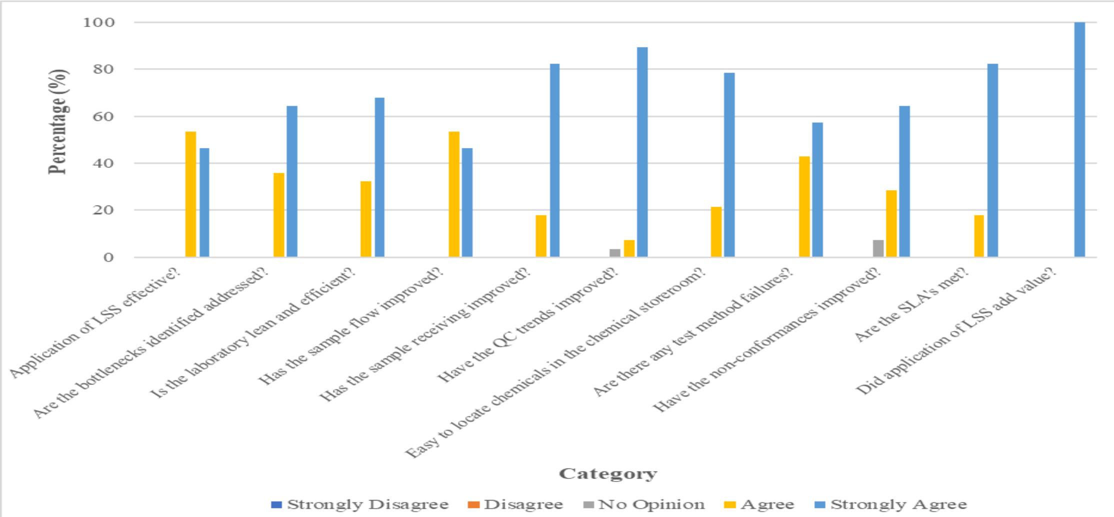


Figure 10. Effectiveness of LSS application per category (WTL personnel)

Zooming onto Figure 10, majority (82.1%) of WTL personnel strongly agreed that SLAs are now being met which was a major problem, however this will be verified by customer surveys. The laboratory is lean in terms of working environment, wastes have been eliminated through application of LSS and all process have been improved effectively and efficiently. The effectiveness of LSS application is 100% agreed by personnel with responses from agreed to strongly agreed. No disagreement was noted for any category.

5.7.2 Operations Department (Internal Customers)

This section focuses on personnel from the Operations Department which are internal customers. The questionnaires were sent to 18 personnel and only 15 responded, with a response rate of 83%.

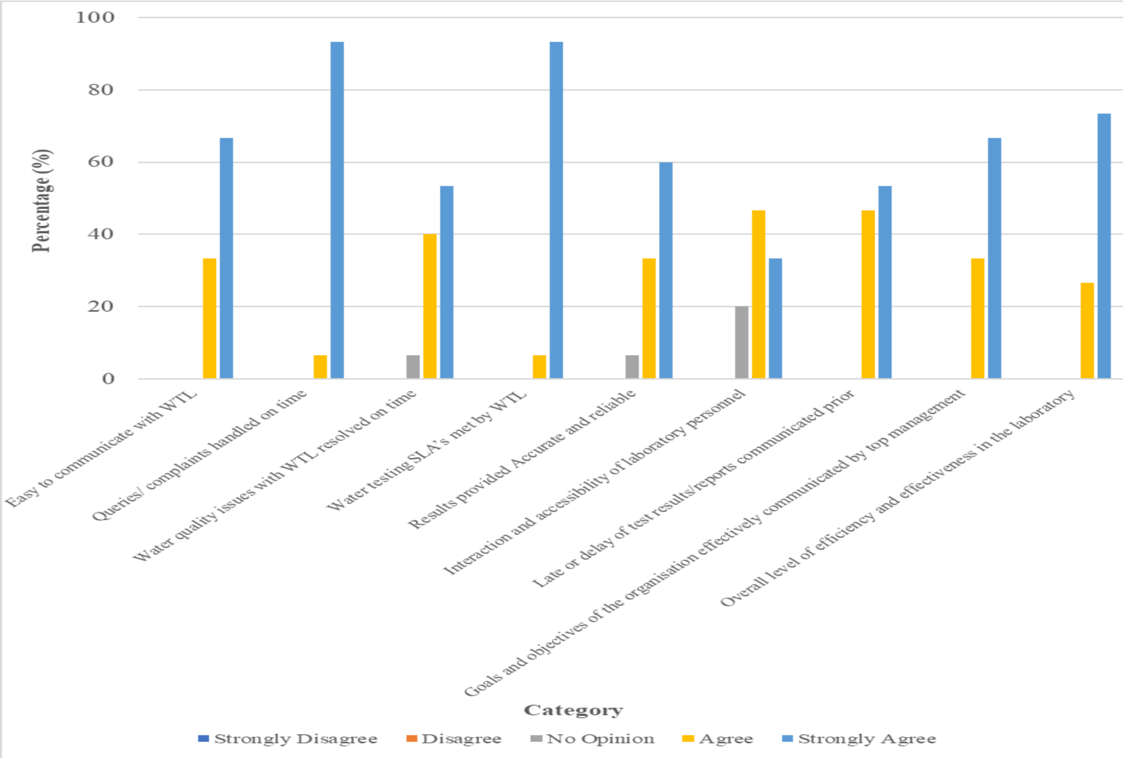


Figure 11. Responses of operations department (Internal customers)

From Figure 11, it was observed that customers are now satisfied with accuracy and reliability of test results they obtain from the laboratory. SLAs are being met, communication with departments is effective, customer complaints/non-conformances are handled in time as highlighted in figure 29. Majority of customers (93.3% strongly agreed and 6.7 agreed) agreed that SLAs are now being met, and complaints are now being handled in time. This shows an improvement within the laboratory and customers seem to be satisfied with services rendered by the laboratory.

5.7.3 Overall Municipality Scores

This section concludes on the overall results obtained from five municipalities per category. Analysis per category is important because it provides an insight of how all external customers perceive services that they receive from WTL after application of LSS with the aim of improving and enhancing customer satisfaction. Figure 12 provides results of overall municipality per category.

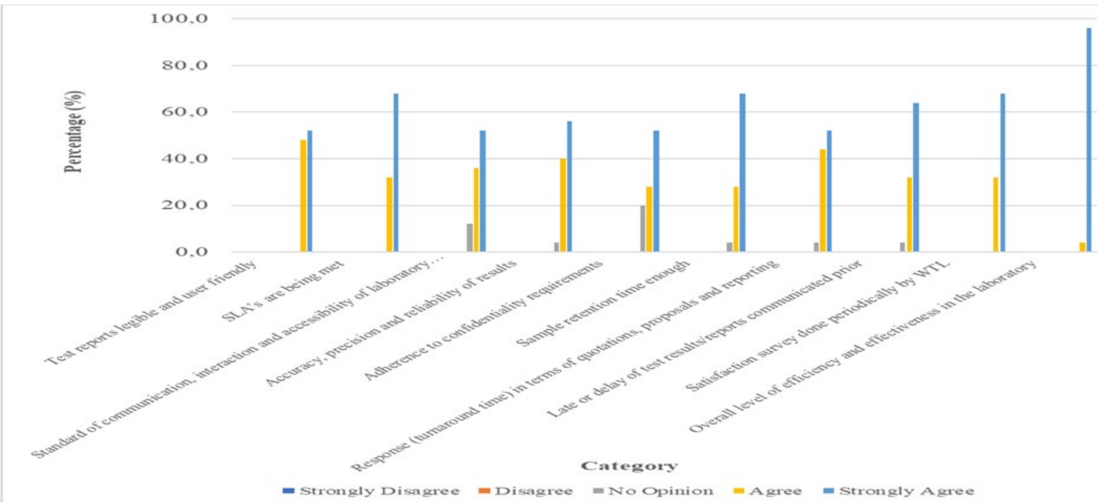


Figure 12. Overall scores of municipalities (external customers) per category

Figure 12 above gives a clear insight of the level of satisfaction expressed by external customers after LSS application. 68% of customers strongly agree with SLAs being met. For reliability, accuracy, and validity of WTL test results, 56% of customers strongly agreed and 40% agreed, this is a huge progress since this has been a major problem. Customers are pleased with overall efficiency of the laboratory with 96% of them strongly agreeing to it. None of the customers are dissatisfied with the service rendered by WTL after application of LSS.

Overall Analysis of Results

From the analysis and discussions of findings of this study, it is clear that brainstorming teams were successful in identifying bottlenecks/wastes that lead to customer dissatisfactions. All identified wastes were the root causes of inefficiency of the laboratory leading to failure in meeting SLAs with customers. The application of LSS tools was a success with accurate selection of the appropriate tools, hence there was an improvement since these were implemented.

Internal and external customers are now satisfied with the laboratory services and WTL is now meeting SLA's confidence in producing results that are accurate, valid and credible. Also, the communication between laboratory and the customers has improved which makes it convenient for customers to continue with their tasks of optimising water treatment plants.

WTL can now confidently say that they are producing credible, accurate results timeously; customer satisfaction is enhanced; and now the working environment is lean, efficient, and effective after waste removal.

6. Conclusion

The root causes of not meeting customer SLAs as well as of not working effectively were identified through brainstorming teams and they were regarded as waste as per LSS concept. This exercise was a success since waste were addressed by means of LSS application. LSS was applied on each waste identified in order to improve the efficiency of the laboratory and its operations. This was a success as the method failure, number of non-conformances, credibility of results as well as meeting of SLA was improved.
Customers SLA are now being met, which was the major problem within the laboratory with the customers having to optimise the Water Treatment Plant and comply with Water Services' Act and SANAS 241 based on the results obtained from the WTL. Since the SLA's are now being met, customers are now making sound decisions in terms of water quality and plant optimisation so that the community can consume clean and safe water without any outbreak.

Based on the customer surveys conducted with both internal and external customers, the application of LSS has enhanced customer satisfaction. The number of non-conformances has decreased gradually which were derived from the customer complaints. The survey results from customers and WTL personnel, WTL has improved its processes through application of LSS and the laboratory is now working in a lean environment with improved processes.

The entire laboratory is now working effectively and efficiently, and personnel seem to be pleased with the results obtained from LSS application is now performing well in terms of meeting customers SLA's, delivering accurate and reliable test results, working in a lean environment effectively, however the current need to be sustained with measures put in place.

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Biography

I am a PhD candidate at the University of Johannesburg (South Africa). I have obtained a master's degree in Operations and Quality Management from University of Johannesburg, Post Graduate Diploma in Management from Northwest University, B-tech Degree in Quality from Durban University of Technology and a National Diploma in Analytical Chemistry from Mangosuthu University of Technology. I have a total of 17 years working experience specialising ISO systems. My expertise includes but not limited to; Laboratory methods and techniques (Chemistry and Microbiology), Quality Management Systems (ISO 9001 and ISO 17025) lead auditing, internal and external auditing, documenting Quality documents according to relevant standard, risk assessment, root cause analysis including corrective and preventive actions, quality awareness, application of Lean and Six Sigma tools, supplier and customer surveys including evaluations, kaizen philosophies for continuous improvement. In these years of working, I have achieved implementation and maintenance of ISO 9001, certifications as well as ISO 17025 accreditation, achieving SMART gaols and objectives of the organisation, promoting quality awareness as well as obtaining desired scores from customer surveys.