Development of quality improvement methodologies In Calibration Laboratory leading to 6-Sigma

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Abstract— Starting with craftsmanship before in 17th century then, the invention of interchangeable parts (Eli Whetny, 1798), American system of manufacturing (18th century), moving assembly line (Ford, 1913), Scientific management (Taylor, 1915), statistical quality control (Shewhart, 1924), analysis of variance (Fisher, 1925), quality management (Juran, 1945), Japan quality evolution (Deming, 1954), zero defects (Crosby, 1979), and at last Six sigma which first appear in Motorola, 1986 by a Motorola engineer called Bill Smith.

1 Introduction

This study was applied to Type II calibration laboratory, that delivers measurement traceability to its customers in various measurement parameters via international accepted standards, calibrated in different primary laboratories, traceable to NIST. The work flow in the laboratory consists of three main stages, which are receiving the unit Under Test (UUT), performing calibration/adjust, and finally distributing UUT to the customer.

Laboratory is accredited to be compliant to the International Standard ISO/IEC 17025 in October 2007, it was apparent to the management that the laboratory had significant challenges to meet customer expectations once the accreditation was granted; production rate was decreased below the pre-accreditation rate, this was obvious in the monthly average production rate of the laboratory before and after the implementation of ISO/IEC 17025 requirements, causing the turnaround time (TAT) for the calibrated equipment to increase, and customers became dissatisfied.

The search focused on calibration/adjust operations in AC/DC, and RF/MW labs, using Six Sigma methodology to be the way to deploy the customers' needs/expectations (critical to quality) into the entire process stages.

2 Implementation Methodology

Six Sigma methodology consists of 5 stages (Define, Measure, Analyze, Improve, and Control) which will be discussed in the following sections.

2.1 Define Phase

The define phase consists of 3 stages:

- Identify Customer CTQs.
- Develop Project Charter.
- Define Process Map

2.1.1 Customer CTQ

Customer's surveys have been performed and customer complaints have been collected in order to identify the main customer CTQs.

A questionair was designed to asses 4 main aspects in provided service (TAT, Service quality, Reporting, and packing). Customer responses were analyzed and the result is shown in table -1

Table- 1

Aspect	Result
TAT	So late. Too much time to calibrate such instrument
Service Quality	Covers all functions and capabilities
Reporting	Just sufficient
Packing	As you received from the manufacturer

Questionair results led to the emergence of more tests to be able to know the sigma level of the provided service.

Data about electrical and microwave laboratory's equipments' turnaround time has been collected from the laboratory's database, calibration service was considered defective if TAT was more than 21 days.

The defects per unit DPU= Defects / (Unit*opportunity)
= 94/146 = 0.64
DPMO = 640000,

Current process sigma level is 1.1 (σ)

In order to well-define coustomer CTQ, the questionair fifth question was about the most important service aspect to the

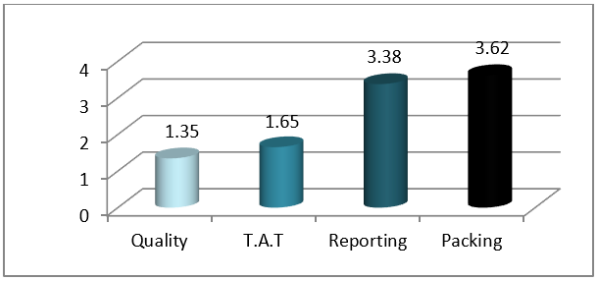


Figure 1 Questionnair fifth question

customer

Importance to the customers was in order, service quality, TAT, reporting, then packing.

After identifying external customers' CTQs, internal customers' CTQ also had to be identified. Internal customers (calibration technicians) feedback via management reviews indicates that internal customer's main requirement is to reduce the paper work, as they spend too much time filling reports, certificates, and many other paper work, associated with the implementation of the requirement of international standard ISO/IEC 17025 and the requirement of the accreditation of American association of laboratories accreditation (A2LA).

Table 2 shows a definition for each customer's CTQ.

Table- 2 Customer CTQ

CTQ	Definition
Have an Accurate calibration	The calibration accuracy is the most important requirement to the customer. Applying the requirements of international standard ISO/IEC 17025 and having an accredit certificate from an accepted accreditation body is a good evidence to the customer that he has an accurate and traceable to national/international standards calibration.
Reduce turnaround time T.A.T	Reduce the total time that customer's instrument spend during the whole calibration process in the laboratory which starts from delivering the instrument and ends by receiving it back again.
Have good reports	Report is the only way by which the customer can know what has been done to his equipment. So, more illustrated details to the customer, more customer satisfaction the laboratory will have.
Good packing for their equipments.	Transportation in the laboratory is customer responsibility. So good packing is important to him to save his equipment from any damage during transportation
Reduce paper work (internal customer)	By applying the requirement of the international standard ISO/IEC 17025, the documentation system became more sophisticated than before, and the laboratory's technicians became loaded, applying this system (documentation) which negatively affects their performance.

After defining the main customers CTQ (table 3-8), a quality function deployment (QFD) matrix has been developed in order to translate the customer's CTQs to process CTQs. See figure -3.

The external customers' CTQs importance is ranked in the matrix from 1 to 4 as investigated via the survey, and the internal customer CTQ has been ranked in the matrix as the highest importance (4)

As been illustrated by the matrix, reducing the calibration cycle time is the most important process CTQ, see Pareto chart (figure-3)

Figure 3 Pareto chart for process CTQ

After defining the main process CTQ (reduce calibration cycle

New Chart			Customer Importance	HOWs: Reduce Calibration Cycle time	Minimize paper work	Accreditation	Enhance reporting process	Enhance packing
Direction of Improvement				↓	↓	○	↑	↑
WHATs	External Customer	Reduce Turn Around Time	3.0	◉	○	△	△	△
		Calibration Accuracy	4.0	△	△	◉	△	△
		Detailled Report	2.0	△	△	○	◉	△
		Good Packing	1.0	△	△	△	△	◉
	Internal	Reduce Paper Work	4.0	◉	◉	△	△	△
Weighted Importance				70.0	52.0	50.0	30.0	22.0
Relative Importance								

Figure 2 Quality Function Deployment

time), a calibration process flow chart has been developed (figure 4) to look deeply through the detailed process steps in order to develop Process drill down tree.

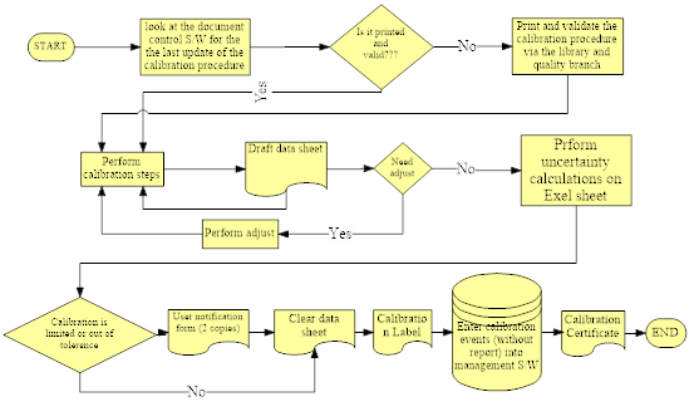


Figure 4 Calibration Process flow chart

After defining the process flow, a drill down tree has been charted to investigate what sub processes of the overall process can be modified to achieve the target (Reducing the calibration cycle time)

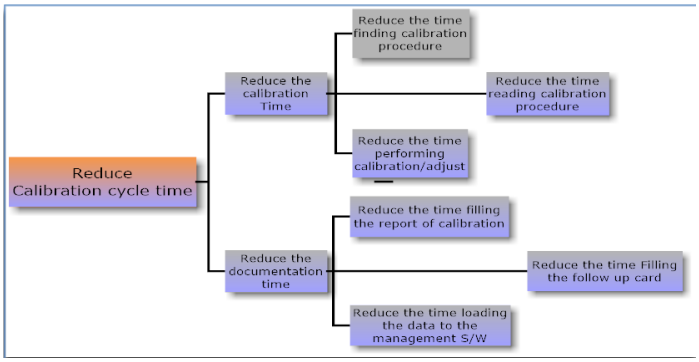


Figure 5 Calibration process Drill down Tree

2.1.2. Project Charter

Buisiness Case
Although applying ISO-IEC 17025 increased our laboratories' market share, Customers began to be dissatisfied with our service because of long Turn-Around-Time (TAT) of their equipments. ABC contract with the customers is to return its equipment in a period not exceeding 30 days. The management wants to improve its calibration service that it offers for its customers.

Problem statement
After applying ISO/IEC17025, TAT cannot be less than 30 days. A 30 days TAT will affect laboratory's customers' satisfaction and make a bad reputation which will definitely, reduce laboratory's market share.
Also, spending too much time in the documentation process that accompanies the calibration process affects the work flow in the laboratory and makes a bad work environment in the laboratory.

Goal statement
Reduce turnaround time for the customers' UNC and documentation time during performing calibrations from equipment delivery by the customer till equipment receipt by the customer to be 21 days. And Increase process sigma to 3.1 (□) by the end of November 2009.

Project scope
The team will mainly focus on the calibration process in the calibration cycle, which starts when the laboratory (calibration area) receives the UNC from the scheduling area, being ready for calibration and ends after the calibration has been done before sending the UNC to the scheduling area again for distribution.
Team Selection

The team was selected, such that it represents all branches of the laboratory Concerned with the change process, the team has the authority to access any data relevant to the problem to carry out the mission.

A plan was made to go through the six sigma methodology implementation, and project charter was approved from the top management as shown in figure -6

PROJECT CHARTER	
Project Leader: Ahmed M. H.	**Team Members:** 1- Metwally.S.T 2- Ahmed M. A. 3- Ossama A. M. 4- Ameer A. A. 5- Mohammed A. 6- Jana A. M. 7- Taha H.
Business Case: The management wants to decrease the T.A.T for calibration cycle to be 21 days. This will increase the UNC availability at the customer which will make advantage for our laboratory to increase its market share.	
Problem Statement: After applying ISO/IEC17025, TAT cannot be less than 30 days. A 30 days TAT will affect laboratory's customers' satisfaction and make a bad reputation which will definitely, reduce laboratory's market share.	**Goal Statement:** Reduce turnaround time for the customers' UNC and documentation time during performing calibrations from equipment delivery by the customer till equipment receipt by the customer to be 21 days. And Increase process sigma to 3.1 by the end of august 2009.
Project Scope: The team will mainly focus on the calibration process in the calibration cycle which starts when the laboratory (calibration area) receives the UNC from the scheduling area being ready to be calibrated and ends after the calibration has been done before sending the UNC to the scheduling area again for distribution.	
TIME LINE	**Target Date**
Project start:	1-6-2009
DEFINE	1-6-2009 TO 21-6-2009
MEASURE	22-6-2009 TO 30-7-2009
ANALYZE	1-8-2009 TO 21-8-2009
IMPROVE	21-8-2009 TO 1-11-2009
CONTROL	1-11-2009 TO 30-11-2009
Project complete:	30-11-2009

Figure 6 Project Charter

2.1.3. Process Map

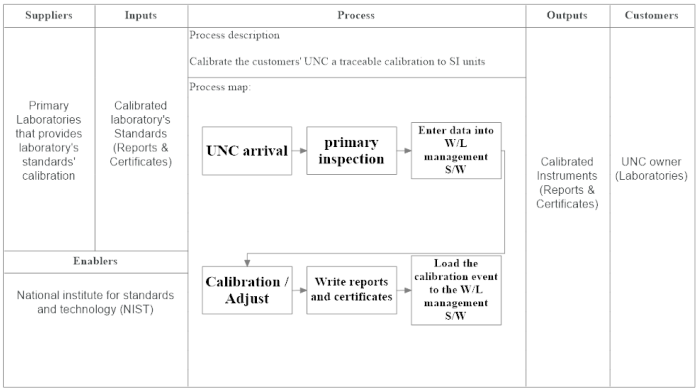


Figure 7 Process Map

2.2 Measure Phase

In this phase, the team focused on how to reach the main defects in the process and measure it accurately. To achieve this goal, the following steps was applied:

- Select CTQ Characteristics
- Define Performance Standard
- Measurement System Analysis

2.2.1. CTQ Characteristics

QFD shows that the defect of calibration service comes from long time,
spent in calibration process, reporting, and statistical analysis.
Calibration time data was collected from laboratory history to select UUT on which measure phase will be performed, the selected UUT was the most type of equipment consumes laboratory resources (percentage of the total workload), multiplied by how many times this UUT is received per year.
Collected data showd that digital multimeter (DMM) was the most kind of equipment, received from the customers so, an in-depth calibration time measurement was performed on that kind of equipment.

2.2.2. Performance standard

Operational definition: The improvement process was reducing the time spent in the calibration process itself, which was divided to 3 processes (calibration, uncertainty calculation, and reporting). Measurements were performed by 8 technicians, 5 calibration events for each technician, with a total of 40 calibration events measurements.
In each measurement, 3 processes were measured: calibration, uncertainty calculations, and reporting (Certificate, report of calibration, and calibration label) a measurement plan was established to the 8 technicians to perform total calibration process on FLUKE 8840 DMM.
Specification Limits: The upper specification limit was the maximum calibration time for the same model. (FLUKE Calibration: philosophy in practice)
Defect definition: The defect was defined as a calibration time that exceeds 60 min.

2.2.3. Measurement system analysis

Data collection: A plan was set to measure each process (Calibration – Uncertainty calculation – reporting) to the same UUT (Fluke 8840) by the same observer. All operators were briefed on the purpose of this experiment to minimize task time exaggeration, experiment result is shown in table

Table- 3 Measure Result

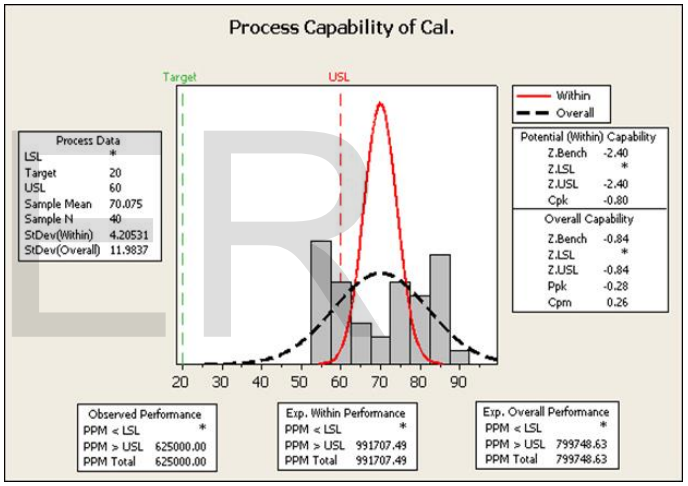
	Time (min.)					Time (min.)			
	Cal.	Unc.	Rep.	Total		Cal.	Unc.	Rep.	Total
Tech. 1	55	19	26	100	Tech. 5	77	19	14	110
	57	19	23	99		76	18	13	107
	56	20	22	98		77	19	14	110
	54	21	27	102		75	20	13	108
	53	20	29	102		74	21	12	107
Tech. 2	86	18	16	120	Tech. 6	55	22	28	105
	85	19	14	118		54	21	33	108
	84	20	15	119		56	21	31	108
	83	22	16	121		58	22	27	107
Tech. 3	80	21	15	116	Tech. 7	60	21	26	107
	57	21	30	108		87	20	14	121
	59	22	28	109		88	19	13	120
	58	23	26	107		86	18	13	117
	59	21	32	112		85	19	11	115
	60	22	29	111		84	19	12	115
Tech. 4	80	23	15	118	Tech. 8	65	22	14	101
	80	21	12	113		66	21	13	100
	79	22	13	114		68	23	12	103
	78	20	11	109		68	24	11	103
	77	19	13	109		64	23	15	102

2.3 Analyze Phase

The following steps were applied in analyze phase:

- Establish Process Capability
- Process Performance
- Identify Variation Sources

2.3.1. Process Capability



Process capability has been charted using the data collected in the measure phase. The current process standard deviation equals to 11.98 with 625000 ppm defects (more than 60 min. calibration time).

Figure 8 Process Capability

2.3.2. Process performance

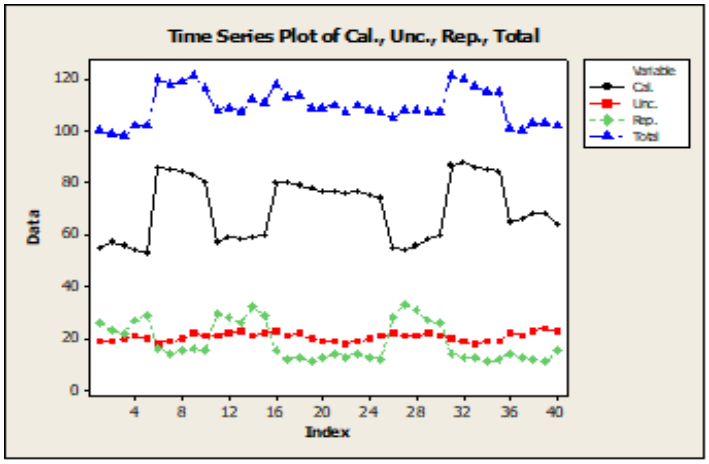


Figure 9 Process performance

2.3.3. Variation sources

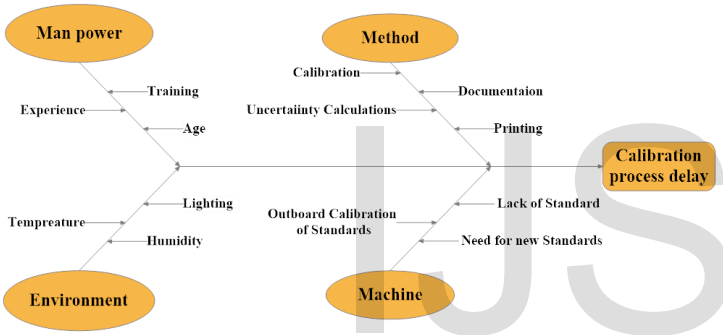


Figure 10 Variation Sources

2.4 Improve Phase

The following steps were applied in analyze phase:

- Screen Potential Causes
- Discover Variable Relationships
- Improvement methodology

2.4.1. Screen Potential Causes

Vital Xs that may affect the calibration process delay are explained. Alternatives of those Xs will be tested in order to achieve the best solution. The alternatives are: change the calibration method, increase technicians training, and reduce the documentation.

One of the three vital Xs is a critical element that need to be changed (Changing the calibration method) and the other two Xs are operating parameters that need to be increased or decreased (increase technicians training and reduce the documentation). Tow-levels, full factorial experiment was designed in order to test the significance of the suggested vital Xs and the interaction between them. Three factors (are put into experiment with 2 possible levels for each.

Table- 4 DOE factors levels

Factor	Level 1 (-1)	Level 2 (1)
Technicians training	Under training	Expert technician
Calibration method	Manual calibration	Automated calibration
Documentation	Normal	computer forms

2.4.2. Variable Relationships

Experiments have been performed in the same environmentally controlled laboratory, by the same standards, on the same unit under calibration and at the same time of the day. And measurements have been taken by the same person. All these condition and constrains has been set to enhance results reliability. Experiment result is shown in (table 5) below.

Table- 5 Full factorial design experiment's results

Run	Training	method	Documentation	cycle time
1	Expert	Manual	Computer forms	110.5
2	Under training	Manual	Normal	132.3
3	Expert	Manual	Normal	116.5
4	Under training	Automated	Normal	45.0
5	Under training	Automated	Normal	44.6
6	Expert	Manual	Normal	123.0
7	Under training	Manual	Normal	134.0
8	Under training	Manual	Computer forms	121.0
9	Under training	Manual	Computer forms	119.0
10	Under training	Automated	Computer forms	25.5
11	Expert	Automated	Normal	41.3
12	Under training	Automated	Computer forms	26.0
13	Expert	Manual	Computer forms	109.6
14	Expert	Automated	Computer forms	23.2
15	Expert	Automated	Computer forms	22.8
16	Expert	Automated	Normal	40.5

A cube representation of the result is shown in figure 9, the variation of the process according to the change of each factor is shown in figure

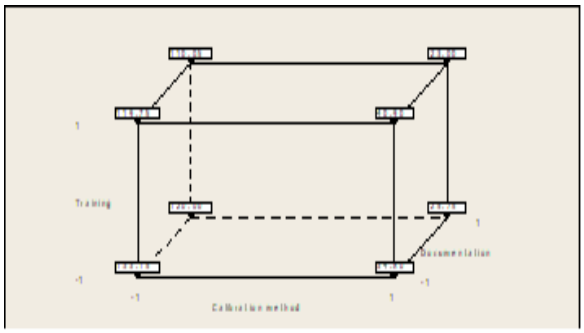


Figure 11 Experiment cube representation

2.4.3. Improvement methodology

Convert the manual calibration to automated calibration was the obvious solution - in cause and effect diagram alternatives - to solve the calibration process delay problem.

There were 4 remedies about converting manual calibration into automated one.

1-Design a procedure for each equipment part number, using a general purpose programming language

2-Buy an automated Calibration procedure software (SURE CAL) for each equipment part number.

3- Buy an automated Calibration software (MET/CAL), then buy a procedure for each equipment part number.

4-Buy an automated Calibration software (MET/CAL), then design a procedure for each equipment part number.

In remedy selection matrix, each remedy has been rated for each criterion using 1-2-3 scale.

Table- 6 Remedy selection matrix

Criterion	1	2	3	4
Low Price	3	1	2	3
Ease of design	1	3	3	2
Ease of implementation	2	3	3	3
Connection to data base	1	1	3	3
Uncertainty calculation	1	3	2	3
Resistance to change	1	2	2	1
Designing time	1	3	3	2
Capability to Improve	3	1	1	3
Effectiveness	1	5	3	3
Total	**13**	**19**	**22**	**24**

Management decide to implement FLUKE MET/CAL calibration, and train laboratory personell on procedures writing. The following table shows calibration time enhancement, using FLUKE MET/CAL software.

Table- 7 Manual VS Automated Calibration

№	(P/N)	M	A	Saving %
1	8840A	109	19.7	81.93%
2	45	110	20	81.82%
3	3458A	215	55	74.42%
4	77	55	20	63.64%
5	73	54	19	64.81%
6	23	55	20	63.64%
7	MT568	55	20	63.64%
8	DM544	55	19	65.45%
9	PM 3394	185	35	81.08%
10	LT564A	165	38	76.97%
11	2465A	128	54	57.81%
12	465	110	24	78.18%
13	2235	110	26	76.36%
14	1740	112	26	76.79%
15	TDS 1010	68	23	66.18%
16	TDS 620A	148	45	69.59%
17	HP 8640B	186	65	65.05%

2.5 Control Phase

Implement Process Control

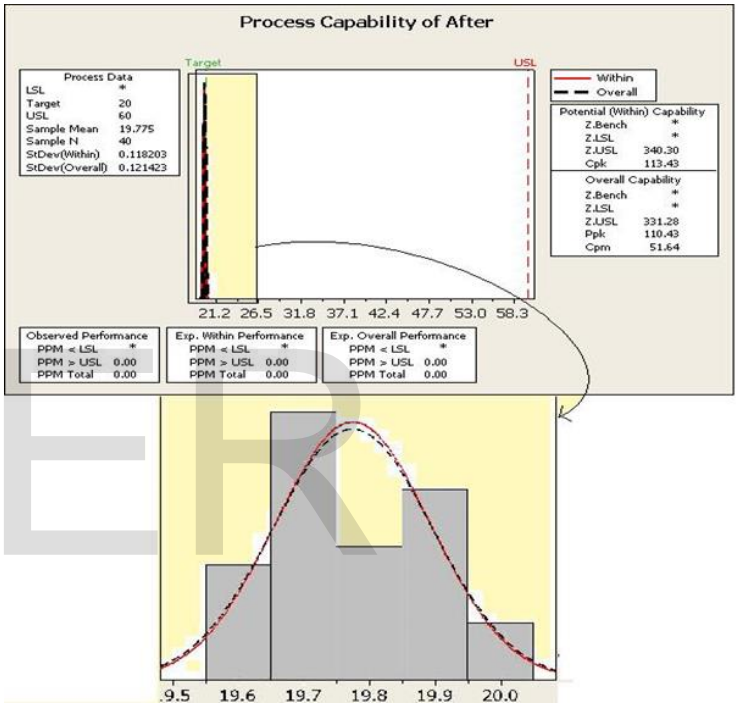
The following steps were applied in control phase

- Define & Validate Measurement
- Determine Process Capability
- Implement Process Control

2.5.1. Define & Validate Measurement

Time plan was established to collect automated calibration time of FLUKE 8840A, calibrated by the same 8 technicians, 5 times for each with total 40 measurements (same process made in measure phase).

2.5.2. Determine Process Capability



As shown in figure 12, the defects (time above 60 minutes) equal to zero and the target (20 minutes) was reached. An individual point's chart of the results is shown in figure 13. There is neither uncertainty calculation, nor reporting time as the uncertainty calculation and reporting is done

Figure 12 Process Capability

Data about electronic laboratory equipments' T.A.T has been collected from the laboratory's database in the period from 1-10-2009 to 1- 12-2009. Of a total of 54 instruments. The defects per unit DPU= Defects / (Unit*opportunity) = 3/ 51 = 0.058
DPMO = 58000 , Current process sigma level is 3 (σ)

2.5.3. Implement Process Control

A mistake proofing methodology has been developed to perform 3 main tasks:

a- All equipments that have MET/CAL procedure will not be calibrated manually

Figure 13 Calibration time Individual Chart

b- Establish and follow a plan for writing MET/CAL procedure for UUT that does not have, according to their priority.

c- MET/CAL calibrated Instruments calibration time (which generated by MET/CAL) has to be charted in control chart for each instrument and review these charts after every calibration to ensure a controlled process

The mistake-proofing methodology was achieved as follows:
Instrument part number which has a written MET/CAL Procedure are submitted by engineering branch to schedule branch. Schedule branch in his turn, will tag any received instrument that have automated procedure with "AUTOMATED CALIBRATION" tag including MET/CAL procedure name and revision (figure 14) before entering the laboratory for calibration.

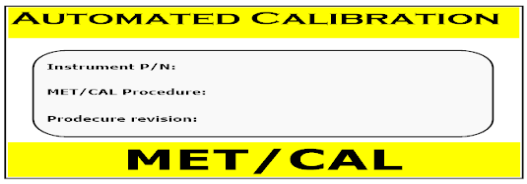
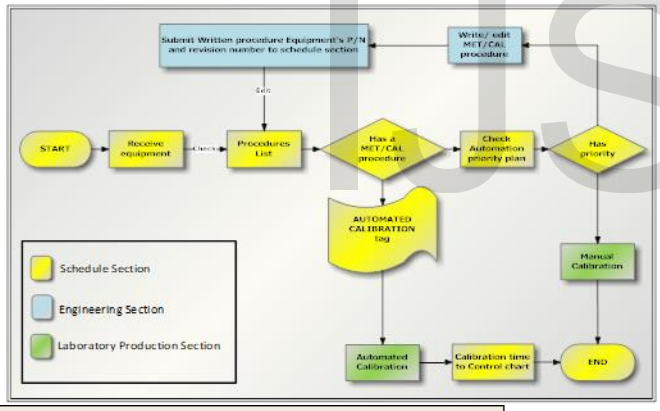
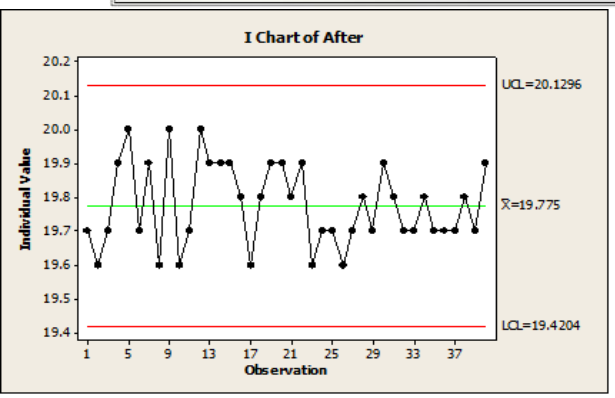


Figure 14 Automated Calibration Tag





After automated procedure has been performed, instrument calibration time control chart shall be updated with the new calibration time to ensure that calibration time is within control specification See flow chart figure 15

The process starts when schedule bracnch receives the instrument, and checks MET/CAL procedure availability in the MET/CAL procedures list, which is submitted and updated via engineering section. If there is a procedure for the received instrument, "AUTOMATED CALIBRATION" tag shall be attached with it, and then submitted to laboratory to calibrate, and return it back to schedule section. By calibrating the instrument, calibration time (automatically calculated by MET/CAL) shall be entered as a new record to the instrument related control chart (schedule section). Control charts shall be reviewed monthly in scheduled monthly meetings.
If there is no MET/CAL procedure for the received instrument, schedule section shall decide whether a new procedure will be generated for it, or not, according to instrument priority in the automation plan (the average calibration time within last 2 years).
If a MET/CAL procedure shall be generated, instrument shall be transferred to engineering section to generate the procedure, and update the MET/CAL procedures list, then transfer the instrument to laboratory for calibration. Else, the instrument shall be transferred to laboratory for manual calibration.

3. Conclusion

Implementing Six Sigma at laboratories, large or small, must be a company-wide initiative. All laboratories can save money by reducing the causes of defects in product and improving Service and sales causing greater customer satisfaction. Larger companies like GE, Motorola, Honeywell, and Ford have the resources to implement Six Sigma at full force. Since Six Sigma has become a quality standard, many smaller laboratories are trying to decide whether or not to implement Six Sigma.
Overall, the data shows that there are benefits and challenges in implementing Six Sigma at small Calibration laboratory. The three most important requirements for successful Six Sigma deployment were found to be management support, cost of implementation and fear of cultural change. These three requirements served as challenges for all companies regardless of size. The benefits of Six Sigma are great. Laboratory reported increased profitability and employee and customer satisfaction associated with Six Sigma implementation. Based on the findings of this study, we can conclude that benefits such as trained quality professionals in statistical control, increased profitability, improved employee job satisfaction, and success in quality components are important reasons to deploy Six Sigma.
The results obtained from this study conclude that the benefits of implementing Six Sigma at small laboratories companies do outweigh its cost.

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