Downtime Reduction on Medical Equipment Maintenance at The Directorate of Biomedical Engineering in the Jordanian MOH

https://doi.org/10.3991/ijoe.v13i02.6422

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Abstract—Medical tools needs to be managed efficiently and sensibly from the initial step of procurement till being damaged. This includes acquiring procedure, operative procedures and the maintenance policies used in this regards. Managing the maintenance of medical tools is vigorous for the patient, medical doctors and for the hospital itself. One of the main complications in healthcare sector today is the availability of medical tools, which is mainly affected by downtime deviation needed to repair the medical tools.

This research presents a process enhancement applied on the Downtime of the medical tools during the maintenance work in the Jordanian of Health Hospitals, based on adapted Six Sigma methodology- DMAIC- (Define, Measure, Analyze, Improve and Control). Data was collected from different locations for different tools to study and analyze the downtime problem and make the necessary actions to reduce it.

Keywords—Six Sigma, DMAIC, Clinical Engineer, Correction Maintenance, Downtime

1 Introduction

This paper discusses and investigates the application of Six Sigma (SS) concepts and tools in planning and execution of corrective maintenance activities and procedures used for maintaining and repair of medical equipment across the Jordanian Public Health Sector (JPHS).

Even though the notion of predominantly-corrective-maintenance (CM) practice is considered to be an indication of poor maintenance strategy according to universal maintenance practice standards (Alsyouf, I. 2007), this mode of practice remains the prevailing realm of maintenance activities in the medical sector (Gill Ginsburg, (2004) and would be extremely difficult to shift towards maintenance practice patterns employed in traditional production and manufacturing environments where considerable portions of these activities are executed through preventive (PM) and/or predictive maintenance (PDM) procedures. This is mainly due to the large contrast between these sectors in terms of applicability of different maintenance strategies. Apart from some minor, self-diagnostic features present in some types of medical equipment, the concept of condition monitoring can rarely be applied rendering PDM and the associated pre-failure maintenance actions extremely difficult to apply. Some basic PM activities may be applied on some mechanical systems, but these constitute a minor portion of critical equipment, and the benefits of such practice maybe further diminished by the fact that, in public sector hospitals and medical clinics, maintenance is carried out under centralized maintenance organization structure (Gill Ginsburg, (2004). The concept of operator-centered maintenance would also be difficult, if at all possible, due to the fact that the operators are predominantly medical staff who would rarely have any background in maintaining these equipment and where the attention is, understandably, aimed at the patient and not the equipment.

Availability is a keyword for devices used in patient monitoring, support and treatment.

This is obviously counteracted by any equipment failure and/or malfunction.

A study carried out by the World Health Organization (WHO) has shown that nearly 50% of medical devices in developing countries are either under-functioning, subject to improper usage or not maintained properly due to the absence of effective maintenance management policies (Regional Committee for the Eastern Mediterranean, 2006). Furthermore, the presence of a comprehensive national policy has been strongly emphasized for high-level utilization of medical equipment to be realized in these countries (Geeta, 2005).

According to the authors' knowledge the literature contains very limited information, compiled in very few studies, that cover the topic of maintenance management of medical equipment in developing countries.

One such study (Abdelbaset, 2004) evaluates performance, productivity and effectiveness of clinical engineering in The Palestinian Territories, which utilizes the Canadian Medical and Biological Engineering Society (CMBES) and the Association for the Advancement of Medical Instruments (AAMI) as benchmark guidelines, gives Ministry of Health (MOH) in Palestine and medical equipment administration a clear vision about the status of clinical engineering CE and other potential areas that need improvement (Abdelbaset, 2004). Another study by (Binseng, Richard, W, S, 2006) suggests the use of Global Failure Rate (GFR) as a promising benchmark for measuring CE's performance. (Carole, Noreen, 2004) emphasized on the shift towards the application of SS techniques and philosophies for any realistic improvements in CE's effectiveness as, the classical three-sigma-based approaches proved to be prone to unacceptable failure rates in such a critical application. DA Cook demonstrated a protocol for measuring downtime and availability for radiotherapy equipment depending on required time for Clinical, Quality Control and Maintenance Time (D A Cook, 1997). Other studies have emphasized the role of combining both SS and total productive maintenance (TPM) for actual realization of improved maintenance management effectiveness and for approaching World-Class Maintenance Process (WCMP) (R. Miniati, 2008) and (P. Milosavljević, K. Rall ,2005) .

In light of the above, the objective of this study is to implement the concepts of SS in assessing and raising the efficiency of current CM strategies applied in maintaining medical equipment across the JPHS. The importance of this research effort comes from the obvious criticality of medical devices and the high cost associated with holding standby units used in case of equipment malfunction (Gill Ginsburg, (2004) as well as presenting a model for such studies in developing countries where similar economical and social circumstances exist.

2 Problem Statement

The main problem to be tackled through this study is the lack of reasonable availability levels reported for medical devices caused by significant equipment-downtimes, which in turn are the result of lengthy maintenance procedures practiced throughout JPHS. In our case only 52 % of the CM work-time has been reported as effective work of corrective maintenance EWCM (wrench time), while 48% is considered to be sown time. This by any reasonable measure is a large proportion that should be reduced by knowing the reasons behind this long DT and making necessary improvements to the work procedures of CM. Any reduction in CM times would result in an equal improvement in equipment availability leading to better patient service and satisfaction levels.

3 Methodology

Standard CM practice procedures were studied for potential improvements using the standard SS five-step DMAIC procedure; (Define-Measure-Analyze-Improve-Control). CM data were collected for 689 different medical devices comprising 15 fault categories associated with 5203 CM work orders for the study period of May **2002 to April 2009.** Factors affecting, and controlling, CM times, and hence downtimes were identified using the DMAIC procedure in association with ISHIKAWA diagrams, Pareto analysis, regression analysis and process capability analysis. The Sigma value was calculated according to the particular findings in this study and alternative CM route(s) have been devised whereby downtimes are anticipated to be significantly reduced with much higher patient and staff satisfaction levels.

3.1 Define Phase

This project aims to study the current practices of Corrective Maintenance in The Department of Biomedical Engineering (DBE) and then apply Six Sigma methodology to govern the factors affecting readiness of medical equipment within the JPHS, reduce downtime and find repair measures that take the longest processing times. Furthermore the proposal of several courses of action, for improved CM actions, is well-thought-out.

Several items have been identified and/or established by the researchers, as rules and limitations that should be adhered to, during the study period whereby enhanced CE's efficiency maybe realized. Means for implementing projects, project scope and statement, project crew, stakeholders and project milestones have also been identified.

3.2 Measurement Phase;

In the measurement phase data collection and necessary analysis for the current status assessment were performed through; constructing a flow chart for DBE CM process as shown in Fig. 1, and by identifying all stakeholders within the MOH/JPHS. This was influenced by the level of service provided to patients. Table 1 illustrates a list of served end-user.

Table 1. Numbers major DBE clients

Client type	Quantity
Hospital	30
Health center	685
Dental clinics	332
Pediatric and mother care clinics	348
Blood banks	23

Identification of complaint sources was partiality performed through a series of brainstorming sessions included researchers and DBE groups. A Cause and Effect Diagram (ISHIKAWA Diagram) was constructed as a result of this process, Fig. 1.

1. Collection of location-based data. Data were collected from different locations; seven public clinics which were located within several areas at different distances from the Amman, Table 4.3. This has been mainly done in order to evaluate the effects of geographical location on CM actions and its effectiveness. Fig. 2 shows percentages of medical tools and devices collected from each clinic.
2. Device-specific data collection. Data were collected for 689 medical equipment within the JPHS which were dealt with within DBE.
3. Work-order specific data collection. Data were collected for 5203 CM work orders covering around 15 fault categories from the CMMS, and spanning over the period May 5th, 2002 to April 1st, 2009.

3.3 Analysis Phase - Root Cause Identification and Verification.

In this phase analysis was made to identify the main sources contributing to lengthy downtimes of medical equipment.

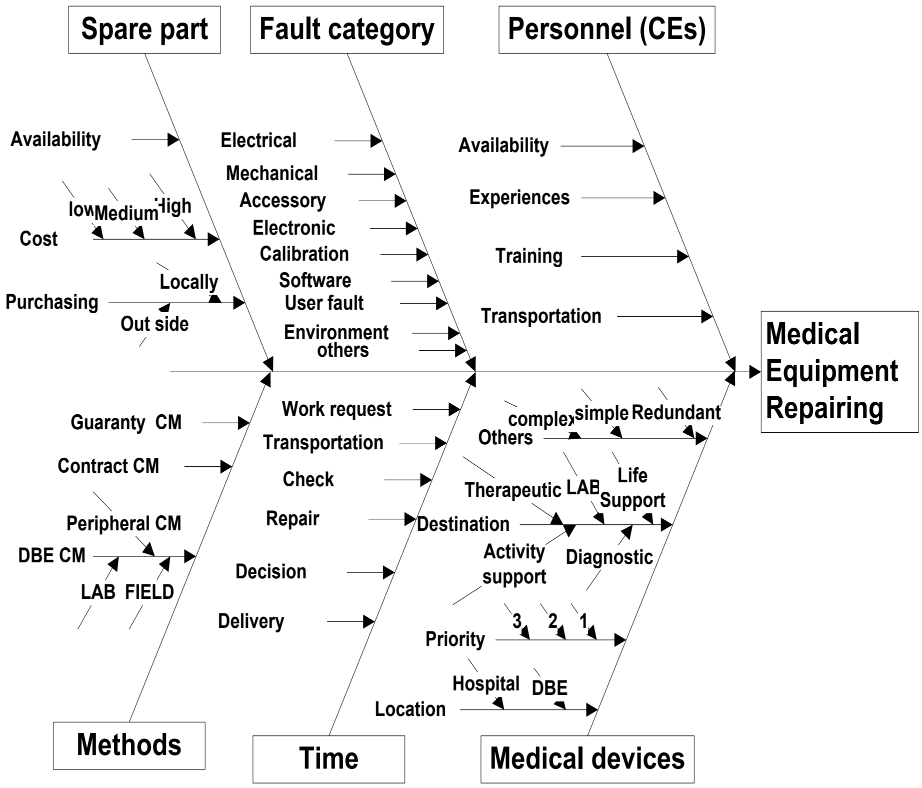

Fig. 1. Cause and Effect Analysis for Equipment Repair

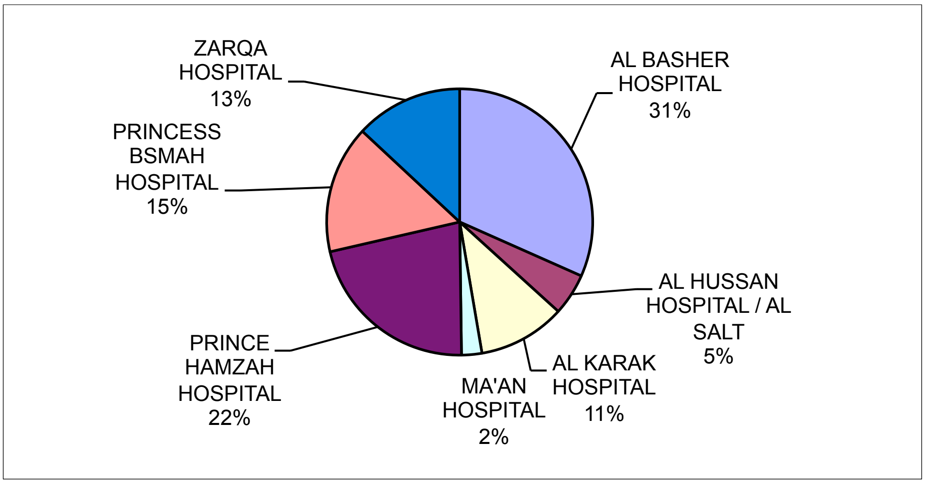

Fig. 2. Pie-diagram showing percentage of medical equipment used from each hospital.

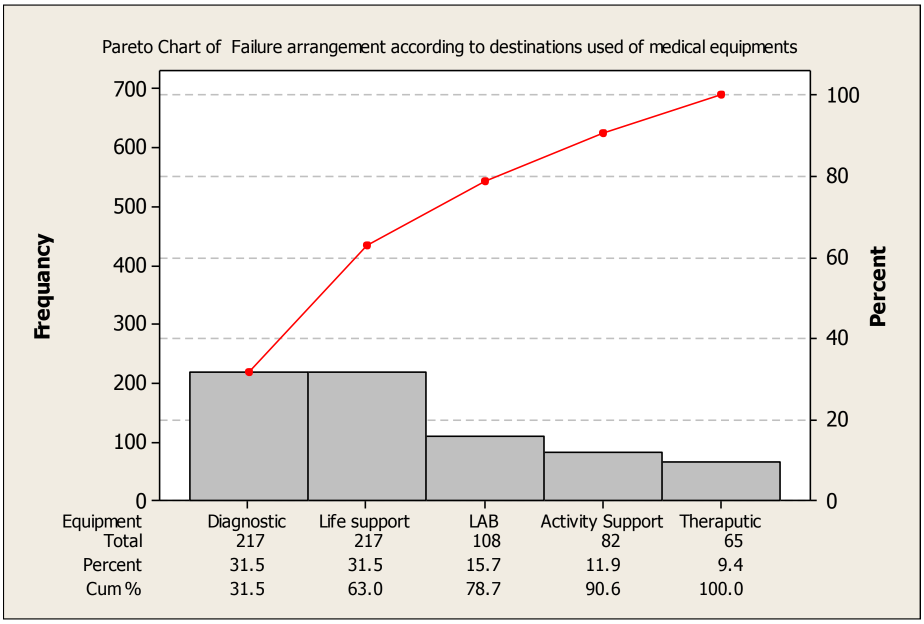

Fig. 3. Pareto Chart Represent Destinations of Use Medical Equipments

Analysis According to Group of Use and Priority: Fig. 3 shows the percentage of breakdowns allocated to different groups of equipment. It can be shown that the highest percentages lie within equipment of Diagnostic and Life support followed by Laboratory equipment, Activity support services and, finally, Therapeutic equipment, respectively.

Another type of analysis of available information was based on device priority ranking as adopted by DBE, as follows:

- Priority-1 devices including ventilators, anesthesia machines, blood gas analyzer, MRI and CT-scan equipment.
- Priority-2 devices including blood warmer, hematology analyzer, centrifuge, and electrolyte analyzer.
- Priority-3 devices including bio-mixer, ophthalmic meter, densometer and medical balances.

The criteria for this periodization is a multi-faceted one and depends mainly on the importance of specific device to the hospital or medical center for provision of medical services to its patients, the presence of alternative (standby) devices and the location of the respective hospital or medical centre.

Fig. 4 shows the work made for CM devices with priority-1.

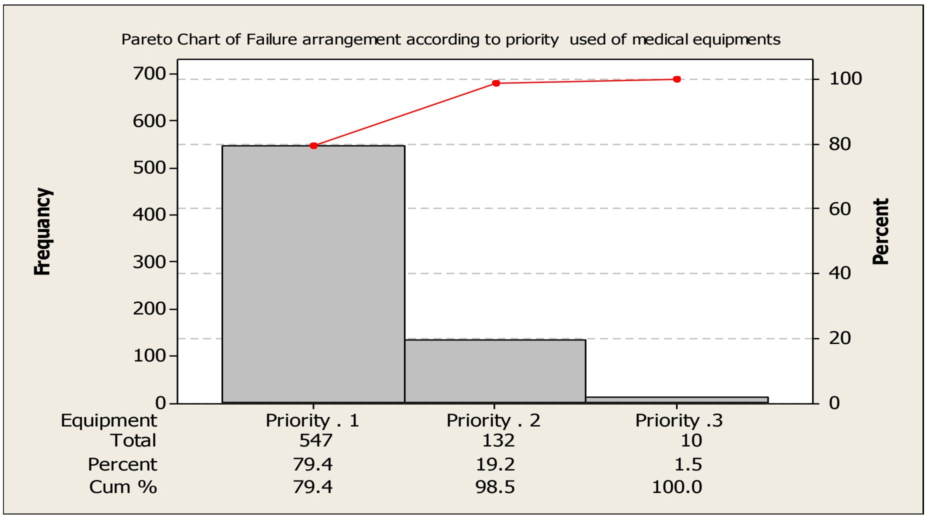

Fig. 4. Pareto chart represent failure arrangement according to priority of medical equipment.

Analysis According to Fault Category: In this stage, analysis was done for sixteen fault classes identified; depending on the specific (or main) corrective action carried out by CMMS. These included: electrical, mechanical, electronic, software, calibration, installation, transportation, accessories, cleaning, environment, user fault, misuse, false alarm, scrap, training, and other (unclassifiable).

From Fig. 5 it can be seen that the mainstream of fault causes, fall within the electrical, mechanical, accessory and electronic.

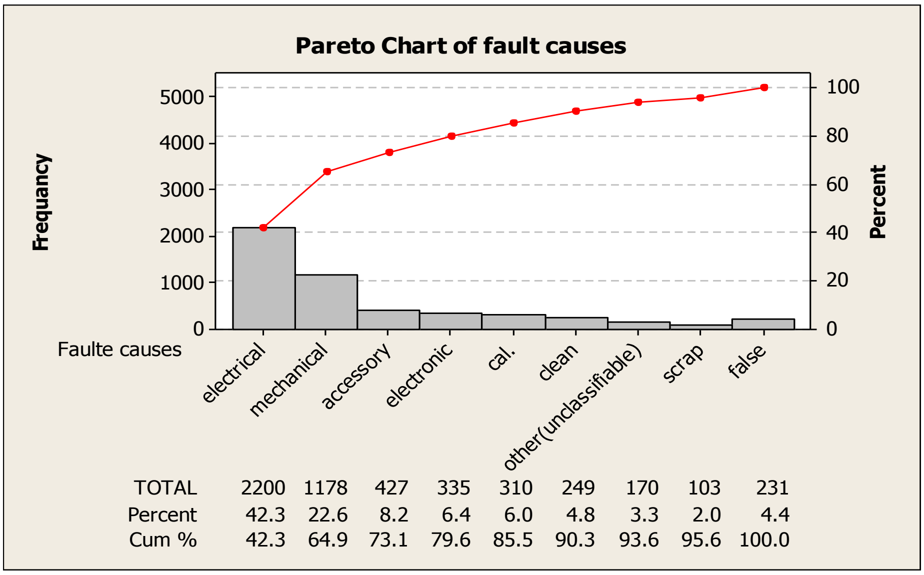

Fig. 5. Pareto chart for failure arrangement according to fault category

Sigma Value Calculated: Sigma value was calculated in order to assess the performance efficiency of CM work at the DBE depending on **DT** as shown in Table 4.2. To calculate sigma value for DT, DPMO should be calculated by using this mathematical relationship as shown below:

$$\text{DPMO} = \frac{\text{No. of defect}}{\text{Defect opportunities} \times \text{No. of units}} \times 10^6$$

and then convert value of DPMO to sigma value using calculator for Six Sigma

4 Phase Four: Improvements - Possible Solution(s)

This research study targets to make the necessary enhancements for the present CM procedures for medical devices within the JPHS. This has been attained through the following steps:

1. Selection of a pilot place (hospital) for suggested improvements based on Six Sigma methodologies. Prince Hamzah Hospital (PHH) in Amman has been selected for this purpose.
2. A problem-solving team has been recognized, in order to suggest improvements on current CM actions. The team included personnel from the following:
   (a) DBE and Prince Hamzah Hospital administrations.
   (b) Laboratories clinical engineers at DBE.
   (c) Anesthesia clinical engineers group at DBE.
   (d) X-ray clinical engineers at DBE.
   (e) Clinical engineers from the medical equipment workshop at Prince Hamzah Hospital

The team was accustomed with Six Sigma benefits, tools, importance as a quality method used to reduce defects and advantages in possible DT reduction of medical equipment. Figure 6, shows the flow chart for the old CM procedures practiced across PHH.

Fig. 7 shows a new proposed CM action to follow-up through CEs in PHH workshop for medical devices CM process. Process capability study was made after the suggested improvement, Fig 7. The process is centered around the target while the Cpk value has improved from" 0.10" to "0.20" demonstrating the effective potential improvements of the suggested new practice.

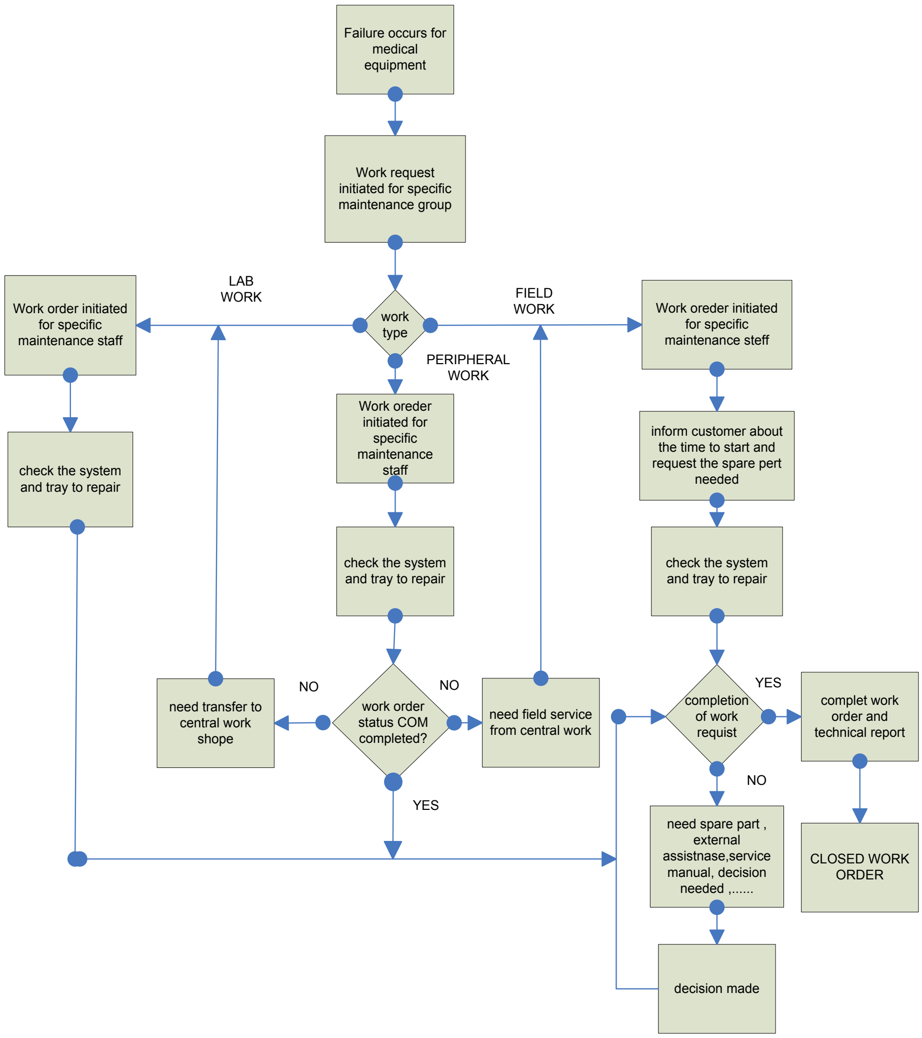

Fig. 6. DBE Repair Process Flow Chart

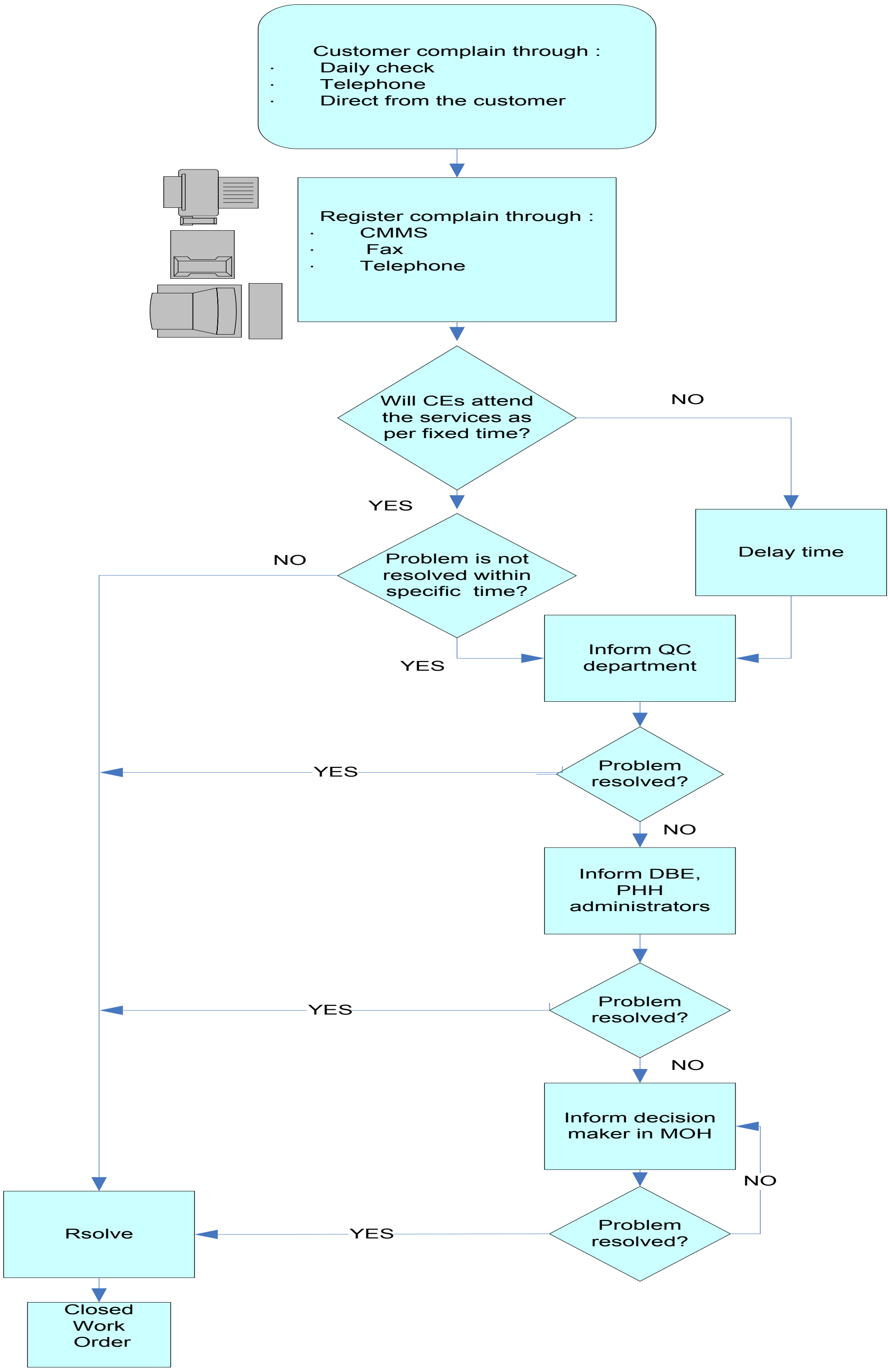

Fig. 7. New proposed CM action plan

5 Control; Sustain the Gain

Control phase is an essential and necessary for any performed work that needs continuous monitoring and improvement. It is imperative to control CM activity and take measurement for maintenance procedures, equipment performance and any faced problems continuously in order to find best practice, worst practice trends and appropriate solutions that enable the implementation of CMs in a safe, fast, high-quality and cost-effective manner with desired levels of customers satisfaction.

As we can see in the improvement phase, Tables 2 and 3, sigma value increase from 2.881σ to 3.708 σ and on the long run we expect this value to increase even further after new procedures have been put into action and have been rectified.

Table 2. Identify Sigma level for downtime before improvement

Maintenance Action/ Repair	**Average Downtime /**	**Assumption Average**	**Number Of Case**	**Number Of Defects**
Electrical	4.3379	3	2227	746
Mechanical	4.552	4	1201	417
Electronic	29.733	25	341	114
Accessory	5.0931	4	430	129
Total cases	4199			
Opportunities	4			
Total defects	1406			
Shift	1.5			
Calculated				
Defect Per Unit	0.335			
DPMO	83710.407			
% Defect	8.371			
% Yield	91.629			
Process Sigma	**2.881**			

To maintain the improvement achieved, following activity must be included:

- Plans, strategies, maintenance procedures and logistic work must be controlled continuously through Quality Control department.
- Making control charts to asses CEs performance and downtimes for medical devices.
- Checking stability and capability of the CM process.

Table 3. Identify Sigma level for Downtime after improvement

Maintenance Action/ Repair	**Average Downtime /**	**Assumption Average**	**Number Of Case**	**Number Of Defects**
Electrical	1.756	3	41	4
Mechanical	1.545	4	33	1
Electronic	7.3	25	10	1
Accessory	1.423	4	26	0
Total cases	110			
Opportunities	4			
Total defects	6			
Shift	1.5			
Calculated				
Defect Per Unit	0.055			
DPMO	13636.364			
% Defect	1.36			
% Yield	98.636			
Process Sigma	**3.708**			

- Improved CM procedure must be standardized and documented.
- Control charts should also be employed for relevant supply chain management activities and be used for further refinement of current procedures.
- Activate penalties system for the delay in the processing of order requests, execution, delivery time and reception process.
- Peripheral workshop employees must be given more attention, qualified technically and managerially and strict control program covering all activities should be implemented.
- Controlling CEs productivity by using new managerial methods and daily work sheets.
- Implementing PPM frequently and on the time.
- Analyzing CEs productivity continuously to any issues that need to be resolved.

6 Conclusion

Through this research, we can see that applying Six Sigma methodology –DMAIC- in Corrective Maintenance for medical equipment can reduce the Downtime and increase availability with high quality correction process that satisfies customer needs. A multiple regression model of the downtime was developed. This model could be used to show the decision maker which variables are mostly affecting the downtime, and what decisions should be made regarding such variables to reduce their effects on the downtime.

It was shown from the present model that the main factors affecting the down time were check time, decision time and the delivery time, not the actual maintenance time. Therefore, a lot of work should be made to minimize their effect on the downtime. The model indicates that the staff availability was not the main factor affecting the downtime. There are many other factors that have negative effect on the downtime such as: delay by the maintenance staff in the detection, devices failure, delay in the registration requests for the service, CM not performing as it should be, delay in the closing of work orders and others.

A small modification on the CM process has been shown to have a great affect on increasing the sigma level from 2.881 to 3.708. This modification did not incur any extra cost on the organization. Other corrective action needs some budget to be implemented such as the availability of the spare parts.

According to RPN analysis, attention is needed for high risk medical equipment, especially Bio-chemistry analyzer, Blood gas analyzer, Hematology analyzer, X-ray machine, and ventilator devices

Applying Six Sigma methodologies and its philosophy is among the best options for Maintenance Management Systems (MMS) to achieve improvements in CM, minimizing downtime, reducing cost, customer satisfaction and reach world class maintenance practice levels.

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Submitted 18 November 2016. Published as Resubmitted by the authors 05 January 2017.