Enhancement of Maintenance System Performance by Using Computerized Maintenance Management System (CMMS) at Private Hospital

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***Abstract*- Maintenance Management System is used to manage daily maintenance activities and planning guidelines for all the identified maintenance work activities. The purpose of this paper is to enhance the maintenance management system of private hospital in Kuwait state by using Computerized Maintenance Management System (CMMS) software to improve the overall equipment efficiency and maintenance indicators. It involves assessment of the impact of Maintenance Management Information System on the hospital building systems performance as well as the equipment maintenance performance. The assessment of impact of implementation of CMMS is identified through maintenance indicators such as Building Performance Index (BPI) and Maintenance Efficiency Index (MEI). These indicators have been developed specially for evaluation of the maintenance systems of health care facilities, where they are used here for the comparison of the periods before and after implementation of CMMS. The analysis reveals that there is a considerable increase in the Maintenance Efficiency Index and Building Performance Index and a simultaneous reduction in the maintenance expenses at the end of the period of the study.**

Keywords- Computerized Maintenance Management System; CMMS; Hospital Maintenance System; Building Performance Index

I. INTRODUCTION

Maintenance Management System is used to manage daily maintenance activities and planning guidelines for all the identified maintenance work activities [1, 2]. A Computerized Maintenance Management System (CMMS) is a computer software program designed to assist in the planning, management, and administrative functions required for effective maintenance [3].

The work by Labib [4] describes industrial research in which the implementation of a Computerized Maintenance Management System (CMMS) was used as an effective tool that supports decision making with the objective of achieving world-class manufacturing status. Acevedo, et al [5] define critical performance measures that become the driving force for specific benchmarking metrics and improvement techniques which enabled approaches of eliminating breakdown losses to be formulated.

Lavey and Shohat [6] developed a tool that can contribute to the complicated management of hospital facilities. They identified the principal factors affecting hospital performance, such as hospital size, occupancy, asset value, income and operating costs. These factors led to the development of seven Key Performance Indicators KPIs, four of which include hospital revenue. This paper offers a practical vision of the set of activities composing management, and the result of the paper is a classification of different maintenance engineering tools. The paper also discusses the proper use of each tool or technique according to the volume of data/information available.

II. THE IMPLEMENTATION OF THE NEW MAINTENANCE MANAGEMENT SYSTEM

Maintenance management system has become one of the major challenges for hospital under study (HADI Hospital) for the reasons as follows:

- Use of reactive maintenance or run to failure policy.
- CMMS is not in use.
- No priority of maintenance work orders.
- No attention to risk level.
- All works are attended on emergency basis.
- No attention to Quality of Work.

The first step is to have a solid feedback and a measure to know the problem of the maintenance management system. These steps can be achieved by the following.

A. Questionnaires and Surveys

A stratified sampling has been used to identify the tangible and intangible benefits of the old maintenance management system. The stratum's consisted of various departments including administration, housekeeping, hospital maintenance, IT and communication, biomedical, mechanical and electrical maintenance depts. A sample of 60 employees out of 240 employees at the rate of 10 employees per department was selected. The participants of the survey include manager, middle and junior level employees. All participants were provided with a standard survey questionnaire and were required to rate the hospital maintenance system as per the following Likert Scale:

- Very poor.
- Poor.
- Average.
- Good.
- Very Good.

B. Interviews

Interviews have been carried out with maintenance technicians to evaluate building systems performance rating for calculations of Building Performance Index. A mathematical analysis was done on the collected data which clarified a low level of aforementioned index that need to be improved.

C. Evaluation of Maintenance Parameters:

The data collection was collected from the records of the Maintenance department. They provide data about:

- Number of Breakdowns / month – it was used to calculate number of failures between Maintenance (NFBM).
- Total breakdown time in hrs / month.
- Period between consecutive maintenance during the year.
- Operating hrs. / day – used to calculate total equipment operating time between maintenance (TOBM).

III. RESULTS AND DISCUSSION

All the results of the analysis made during the project study were carried out. These data include the results of the survey, interviews, and the analysis of the maintenance records. The survey of the stratified sampling for the months was ranged from June 2009 to May 2010.

A. Data Analysis and Results

All data obtained from CMMS, surveys, interviews and maintenance records has been analyzed and incorporated in the aforementioned indicators using excel built in formulas to evaluate the Hadi hospital maintenance management system in order to evaluate the enhancement in maintenance system.

1) Building Systems Performance (BPI) Analysis:

Building Systems Performance (BPI) is the index which monitors the usage fitness and the physical state of the building systems and different components within each system. This index was developed by giving specific scores to each of the building systems as a weighted score. The Weighting score of each building system (Wn) is obtained by dividing the life cycle costs of each system in the building against the total Life Cycle Costs of the building, according to the following formula [7]:

$$BPI = \sum_{n=1}^{10} P_n \times W_n \quad (1)$$

$$W_n = \frac{LCC_{i,j}}{LCC_i} \quad (2)$$

n= 1, 2, 3,….. 10

Where: $LCC_{i,j}$ is the Life-Cycle Costs for system j in building i, and LCC_i is the total Life-Cycle Costs of the building.

LCC = Capital Cost + Present worth of Maintenance — Present worth of Salvage value.

And Performance level (P_n) = [1 — (actual failed event / designed performance)]*100.

The value of the BPI index reflects the performance level of the building concerned, according to the following categories:

BPI > 80 indicates that the state of the building, and its resultant performance, are good or better;

70 < BPI ≤ 80 indicates that the state of the building is such that some of the systems are in marginal condition, i.e., some preventive maintenance measures must be taken.

60 < BPI ≤ 70 reflects deterioration of the building, i.e., preventive and break-down maintenance activities must be carried out; and BPI ≤ 60 means that the building is run-down.

The score denoted by Pn which represents the performance level of each system in the building and is represented by the combination of the physical state, typical failures or defects, and the policy governing its maintenance. Interviews with 10 of the maintenance technicians have been done to identify the level of performance of all the building systems at HADI Hospital. This is done for 10 principal building systems, which are shown in Tables I, II.

TABLE I PERFORMANCE RATING FOR THE BUILDING SYSTEM- HADI HOSPITAL– JUNE 2009 BPI–JUNE 2009

Building Systems	Performance Level - Pn	Weighting - Wn	Pn * Wn
1. Medical Gases	91.2	0.017	1.5504
2.Communication	89.1	0.011	0.9801
3. Structure	80.2	0.154	12.3508
4. Elevators	82.4	0.066	5.4384
5. Electricity	75.9	0.125	9.4875
6. Hvac	83.5	0.163	13.6105
7. Fire Protection	75.5	0.033	2.4915
8. Interior Finishes	77.8	0.414	32.2092
9.Exterior Envelope	66.1	0.01	0.661
10. Sanitary Systems	71.9	0.007	0.5033
Total BPI	–	1	79.2827

TABLE II PERFORMANCE RATING FOR THE BUILDING SYSTEM–HADI HOSPITAL–MAY 2010 JUNE BPI–MAY 2010

Building Systems	Performance Level - Pn	Weighting - Wn	Pn * Wn
Medical Gases	95.5	0.017	1.6235
Communication	90.2	0.011	0.9922
Structure	88.5	0.154	13.629
Elevators	90.2	0.066	5.9532
Electricity	81.8	0.125	10.225
Hvac	89.9	0.163	14.6537
Fire Protection	85.6	0.033	2.8248
Interior Finishes	88.44	0.414	36.61416
Exterior Envelope	79.8	0.01	0.798
Sanitary Systems	89.75	0.007	0.62825
Total BPI	–	1	87.94181

Tables I and II demonstrate the calculation of BPI before and after the implementation of CMMS. It can be noted that there is an 11% increase in the BPI during the 12-month period. Remarkable improvements in the sanitary and exterior envelope systems have been improved by 1%. Table I

indicates the BPI value for June 2009 is 79.28, which lies between 70 < BPI ≤ 80. It indicates the marginal conditions and hence requires some preventive measures to be taken at an immediate stage. Table II indicates BPI > 80 for May 2010 which indicates a good state of the building systems, and its resultant performance.

Table I shows that on an average, 11 % increase can be observed in the overall building systems during the 12 months. It can be noted that there is a minimum of 1% and a maximum of 25% variation in the performance of the systems during the twelve months period which can be attributed to the improvement in the maintenance and other operations as a result of implementation of the Maintenance information systems.

2) Calculation of Maintenance Efficiency Index (MEI) for Hospital Building System:

Maintenance Efficiency Index (MEI) is an important tool or parameter to examine the maintenance inputs. It is calculated based on the Annual Maintenance Expenditure (AME), with respect to the physical and performance state of the building expressed by the BPI. MEI is an important index that quantitatively indicates the efficiency of spending of the available resources. Building age and occupancy are the other additional and most important factors need to be considered while calculating the relation between expenses and performance.

a) Annual Maintenance Expenditure (AMEav.) = Annual Maintenance Expenditure for the entire life cycle of the building.

b) Building Age Efficiency (ACy) is taken as 0.66 for June 2009 and 0.36 for May 2010.

i. Building occupancy is denoted by Occupancy Coefficient (OC).

ii. Occupancy Coefficient = actual occupancy / designed projected occupancy.

Tables III, IV show the complete calculation for the MEI at HADI Hospital for the two periods of June 2009 and May 2010. Table III shows that the calculated MEI for June 2009 is 0.38, which indicates the state of low budgetary investment, or high maintenance resource utilization efficiency, or both.

TABLE III HADI HOSPITAL MAINTENANCE CHARACTERISTICS–JUNE 2009
MEI CALCULATION FOR JUNE 2009

Item	Value
Average Built-up Area (m²)	18,000
Average Number of Hospital Patient Beds	125
Average Occupancy (Number of Beds per 1,000 m² Built-up Area)	6.94
Annual Maintenance Budget (AME)(KD per 1,000 m² Built-up Area)	261,364
Annual Maintenance Budget per m²	14.52
Annual Maintenance Budget per Patient's Bed	2,091
Actual Occupancy	182,955
Projected Occupancy	248,295
Occupancy Coefficient	0.74
Age Coefficient Acy	0.66
BPI	79.28

TABLE IV HADI HOSPITAL MAINTENANCE CHARACTERISTICS–MAY 2010
MEI CALCULATION FOR MAY 2010

Item	Value
Average Built-up Area (m²)	18,000
Average Number of Hospital Patient Beds	140
Average Occupancy (Number of Beds per 1,000 m² Built-up Area	7.78
Annual Maintenance Budget (AME)(KD per 1,000 m² Built-up Area)	250,555
Annual Maintenance Budget per m² Built-up Area	13.92
Annual Maintenance Budget per Patient's Bed	1,790
Actual Occupancy	192,927
Projected Occupancy	245,544
Occupancy Coefficient	0.79
Age Coefficient Acy	0.36
BPI	87.94

Whereas Table IV which shows the calculated MEI for May 2010 is 0.56 which indicates (a) desirable situation for maintenance efficiency and (b) reasonable use of maintenance resources. BPI, Manpower Source Diagram, Managerial Span of Control must also be considered important in evaluating the Overall effectiveness of maintenance. Maintenance Efficiency Index is subject to change, depending on the type of building: the more complex the building is, the wider the ranges of values, and vice versa.

3) Comparison of BPI and Maintenance Budget at Different MEI (June 2009–May 2010):

Figure 1 below shows the increase in Building Performance Levels and associated decrease in the Maintenance Budget for the periods June and May 2010, at Maintenance Efficiency Index of 0.38 and 0.56. It can be noted that the increase in the BPI and a reduction in Maintenance expenses resulted in an overall increase in the Maintenance Efficiency Index. The improvement of MEI during 12 months period can be attributed to the improvement in maintenance operations owing to implementation of CMMS.

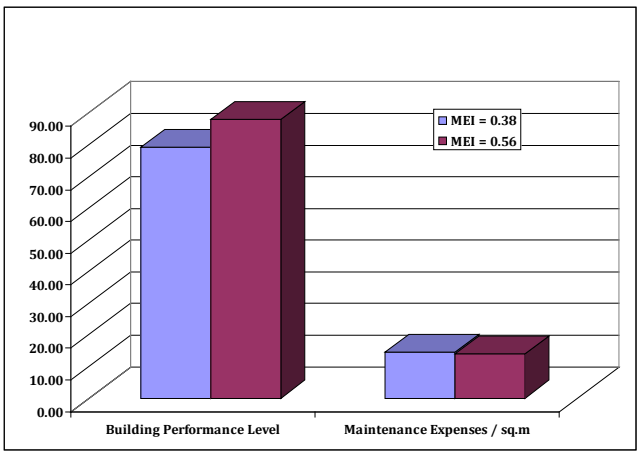

Figure 1 Maintenance budget vs. improved performance level for different levels of MEI

IV. RESULTS FROM EQUIPMENT MAINTENANCE PERFORMANCE ANALYSIS AT HADI HOSPITAL

A. Number of Equipment Breakdowns

Average number of biomedical equipment Breakdowns during the 12 months period is shown below in Table V.

TABLE V AVERAGE BIOMEDICAL EQUIPMENT BREAKDOWNS AT HADI HOSPITAL

Average Equipment Breakdowns at HADI Hospital	Jun. 2010 /Jul. 2010	Aug. 2010/ Sept. 2010	Oct. 2010/ Nov.2 010	Dec. 2010/ Jan.2 011	Feb. 2011/ Mar. 2011	Apr. 2011/ May 2011
Medical Equipment at HADI Hospital	2.33	2.00	1.87	1.27	0.80	0.07
Electrical and Mechanical Equipment at HADI Hospital	1.35	1.24	1.06	0.47	0.53	0.12

Figure 2 shows the average number of breakdowns of biomedical and Electrical/ Mechanical equipment reduced during the 12 months period. It is clear that the breakdown was at its maximum in June 2009 and became almost zero in May 2010. It can be concluded that this reduction is attributed to the Maintenance Management Information System that was fully implemented and was in action until 1st May 2010. It is observed that the number of breakdowns is higher for Bio-medical equipment is higher than the Mechanical/electrical equipment.

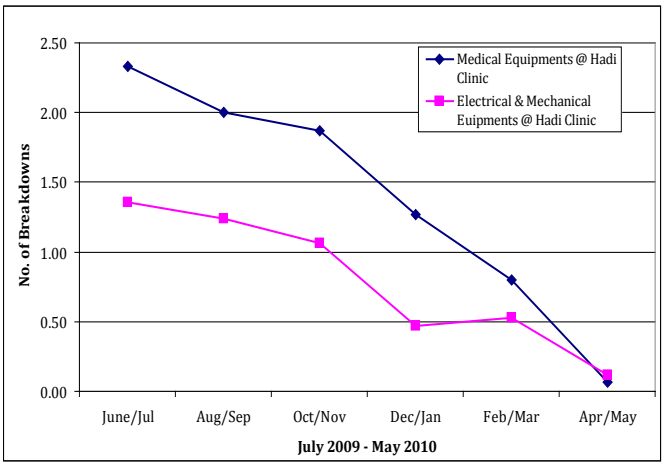

Figure 2 Average equipment breakdowns during 12 months at HADI Hospital

B. Equipment Breakdown Time

Average Breakdown time during the 12 months period is shown in Table VI.

TABLE VI AVERAGE EQUIPMENT BREAKDOWN TIME AT HADI HOSPITAL

Equipment Breakdown Time in Hours at HADI Hospital	Jun. 09/ Jul. 09	Aug. 09/ Sept. 09	Oct. 09/ Nov. 09	Dec. 09/ Jan. 10	Feb. 10/ Mar. 10	Apr. 10/ May 10
Medical Equipment	3.76	2.99	2.37	1.39	0.75	0.04
Electrical / Mechanical Equipment	1.09	0.92	0.72	0.33	0.14	0.005

Figure 3 shows the average breakdown time in hours for biomedical and Electrical/ Mechanical equipment reduced during the 12 months period. Breakdown time was found at the highest in Jun 2009 and reduced to the lowest in May 2010. This drastic reduction in breakdown time has resulted from the CMMS implementation. It can also be observed that breakdown time for Medical equipment is higher when compared to the other equipment. Around 65 % or higher reduction was achieved in Breakdown time with the implementation of CMMS.

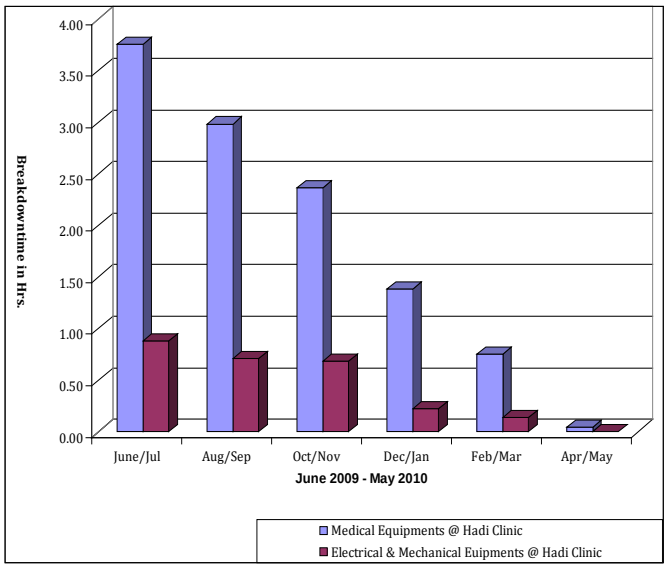

Figure 3 Equipment breakdown time in Hrs. at HADI Hospital

C. Mathematical Analysis of Equipment Performance at HADI Hospital

Maintenance Reliability Indicators for the medical, mechanical and electrical equipment at Hadi Hospital as shown in Tables VII, VIII were calculated as given by the following equations:

$$\text{Availability, } A = MTBF / (MTBF + MTTR) \quad (3)$$

$$\text{Failure Rate, } \lambda = \text{No. of failures between Maintenance / Total operating time between failures in Hrs} \quad (4)$$

$$\text{Mean time between Failure, } MTBF = 1/\lambda \quad (5)$$

$$\text{Mean Time to Repair, } MTTR = \text{Total Breakdown Time / Number of Failures} \quad (6)$$

Where:

MTBF = Mean Time between Failures.

MTTR = Mean Time to Repair.

TOBF = Total Operating Time between Failures.

NFBM = No. of failures between Maintenance.

$$\text{Availability (A)} = MTBF / (MTBF + MTTR) \quad (7)$$

All these indicators are used to evaluate the improvement in the reliability of all hospital equipment. It can be observed from the analysis which is illustrated in the Tables VII, VIII that the equipment operating hours per day which is calculated as the average of every two months to the end of the research period has decreased gradually especially after the implementation of CMMS, which in turn increases the equipment availability or decreases its failure rate.

TABLE VII ANALYSIS OF MEDICAL EQUIPMENT PERFORMANCE

Medical Equipment at Hadi Hospital	Jul-09	Sep-09	Nov-09	Jan-10	Mar-10	May-10	Operating Hrs. / Day	TOBM	NFBM	Λ	MTBF	MTTR	A
Analyzers	1.79	0.25	0	0.21	0	0	12	2160	3	0.0014	720.00	0.75	0.9990
Anesthesia	2.15	1.12	0	3.01	0.54	0	10	1800	7	0.0039	257.14	0.97	0.9962
Patient Monitoring	3.11	0.15	0	1.14	2.24	0.01	18	3240	6	0.0019	540.00	1.11	0.9980
Centrifuges	5.14	3.16	2.22	1.01	0	0.05	8	1440	11	0.0076	130.91	1.05	0.9920
CT Scanners	2.21	3.15	1.16	0.22	0	0.005	8	1440	6	0.0042	240.00	1.12	0.9953
Dental Equipment	4.38	3.91	2.15	0.11	1.12	0	9	1620	7	0.0043	231.43	1.67	0.9928
Diagnostic Equipment	5.36	3.21	2.22	1.5	1	0	12	2160	8	0.0037	270.00	1.66	0.9939
Dialysis	1.11	2.19	2.02	1	0.12	0.003	7	1260	6	0.0048	210.00	1.07	0.9949
ECG / MRI / X-Ray / Ultrasound	6.89	7.12	5.55	3.14	1.03	0.01	8	1440	12	0.0083	120.00	1.98	0.9838
Surgical	8.29	7.13	6.44	5.99	2.12	0.59	8	1440	15	0.0104	96.00	2.04	0.9792
Laboratory	3.33	4.26	3.88	1.08	1.9	0	10	1800	14	0.0078	128.57	1.03	0.9920
Lasers & IPL's	3.21	2	4.21	0	0	0	10	1800	9	0.0050	200.00	1.05	0.9948
Microscopes	1.05	0	0.12	0.29	0	0	8	1440	3	0.0021	480.00	0.49	0.9990
Sterilizers	4.17	3.12	2.21	0	1.1	0	12	2160	10	0.0046	216.00	1.06	0.9951
Other Medical Equipment	4.21	4.01	3.33	2.1	0.1	0	14	2520	8	0.0032	315.00	1.72	0.9946

TABLE VIII ANALYSIS OF MECHANICAL/ELECTRICAL EQUIPMENT PERFORMANCE

Electrical and Mechanical Equipment of Hadi hospital	Jul-09	Sep-09	Nov-09	Jan-10	Mar-10	May-10	Operating Hrs. / Day	TOBM	NFBM	λ	MTBF	MTTR	A
Elevators	0.02	0.75	0.3	0	0.11	0	16	2880	4	0.0014	720	0.295	0.9996
Boilers	0.22	0	0	1.1	0.21	0	24	4320	4	0.0009	1080	0.3825	0.9996
Masonry	0.11	0	0	0	0.04	0	4	720	2	0.0028	360	0.075	0.9998
Fire Protection	0.65	0	0	0	0	0	0.021	3.78	1	0.2646	3.78	0.65	0.8533
generators	0	0	0.5	0	0	0	0.044	7.92	1	0.1263	7.92	0.5	0.9406
HVAC	1.1	0.25	0	0	0.3	0	24	4320	4	0.0009	1080	0.4125	0.9996
Transformers	0	0	0.51	0	0.21	0	24	4320	8	0.0019	540	0.09	0.9998
Lighting equipments	2.1	2.31	0.28	0.45	0	0	24	4320	2	0.0005	2160	2.57	0.9988
Plumbing	3.44	2.16	1.03	0	0.51	0	18	3240	5	0.0015	648	1.428	0.9978
Sheet Metal	1.12	0.11	0.57	0	0	0	24	4320	7	0.0016	617.1429	0.2571	0.9996
Beds	2.11	1.05	1.14	0	0.65	0	24	4320	5	0.0012	864	0.99	0.9989
C-Arms	2.11	1.13	0.12	0.87	0	0	24	4320	13	0.0030	332.3077	0.3254	0.9990
Cameras	0	0	0	0.03	0	0	24	4320	6	0.0014	720	0.005	1.0000
Stretchers	1.12	2.45	3.11	0.01	0.25	0	4	720	1	0.0014	720	6.94	0.9905
Furniture	0	0	0	0.13	0	0	8	1440	10	0.0069	144	0.013	0.9999

1) Mean time Between Failures for Medical Equipment:

From Figure 3 and Table VII, it can be shown that Analyzers, patient monitoring and microscope medical equipment has the Highest MTBF and surgical equipment show the lowest MTBF.

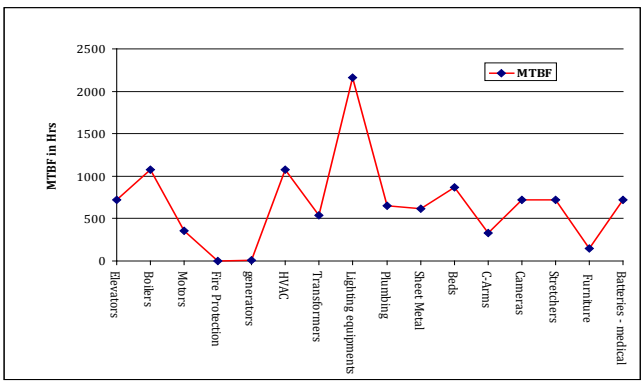

Figure 4 Mean time between failures for medical equipment

2) MTBF for Biomedical and Mechanical/Electrical Equipment:

From Figure 5 it can be seen that MTBF is the highest for the lighting equipment whereas the lowest for Fire protection and generators.

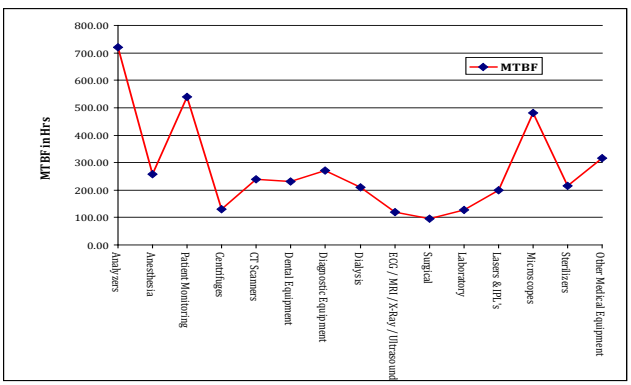

Figure 5 Mean time between failure for electrical and mechanical equipment

3) Equipment Failure Rate and Availability Percentage:

Another important analysis was done to identify the failure rate and availability percentage for both biomedical and electrical/mechanical equipment. Figs. 6, 7 indicate the inverse relationship between the failure rate and availability of equipment. Fire protection and generator equipment show lower availability due to higher breakdowns in the given period of maintenance; hence it is required to direct special focus towards the maintenance strategies for generator and fire protection equipment.

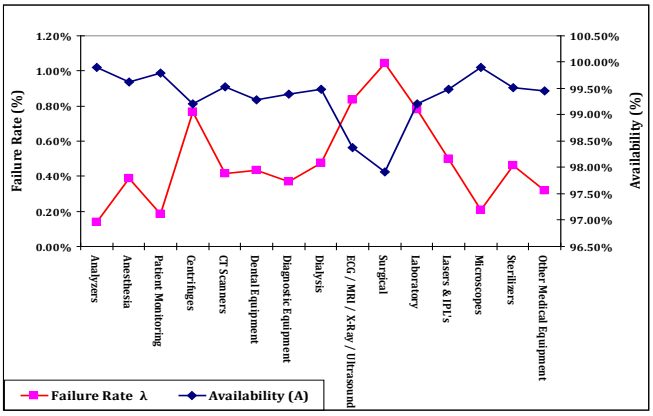

Figure 6 Availability vs. Failure Rate for different medical equipment at HADI Hospital

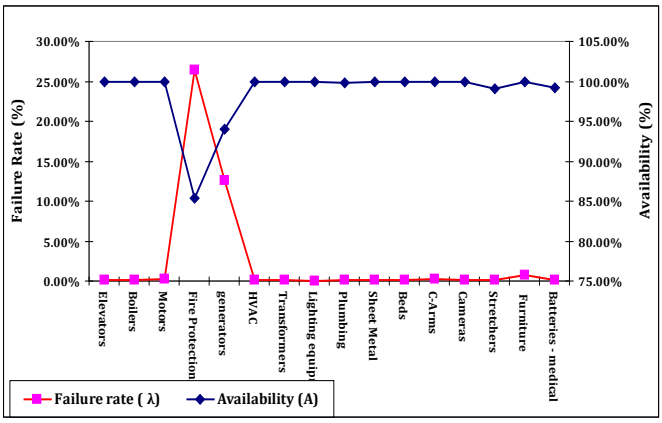

Figure 7 Availability vs. Failure Rate for different mechanical and electrical equipment at HADI Hospital

Figure 8 shows a Spider plot representing greater area for the Intangible benefits as a result of CMMS implementation. Fig. 8 shows lower area for the intangible benefits before the implementation of CMMS.

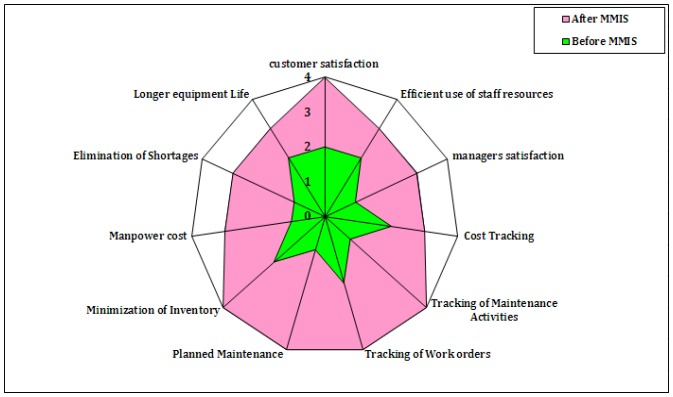

Figure 8 Spider plot representing improvement in the intangible benefits due to implementation of CMMS

V. CONCLUSIONS

The conclusions drawn from the hospital analysis are as follows:

- To make the maintenance planning system effective, it is essential to keep track of all the corrective maintenance jobs and preventive maintenance inspections. For large processing hospitals these cannot be handled manually. The objective of CMMS is to facilitate the management of the maintenance resource, to monitor maintenance efficiency, and to provide appropriately analyzed management information for further consideration. It is therefore important for the hospital to implement CMMS.

- It can be concluded that TPM is a maintenance strategy ensured with the application of appropriate tools or following thoroughly all the pillars performance. Data shows that no such tools are in use in the hospital, as a result, the maintenance management system is weak.

- The Hadi hospital should actively benchmark its maintenance services against other organizations. Benchmarking is essential to search for optimum methods for Maintenance Management practices in order to improve the overall effectiveness of operations and maintenance of the hospital.

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