Automation of Predictive Maintenance Using Internet of Things (IoT) Technology at University-Based O&M Project

James Ryan Fernandez, Yogi Tri Prasetyo, Satria Fadil Persada, and A. A. N. Perwira Redi

***Abstract*—Predictive Maintenance can be defined as a type of advanced maintenance that detects the onset of system degradation allowing causal stressors to be eliminated or controlled prior to any significant deterioration in component physical state. Thru Internet of Things (IoT) Technology, automation, and implementation of Predictive Maintenance are possible. The purpose of this study is to propose the implementation of Predictive Maintenance using IpT Technology at University-based Operation & Maintenance Project that aims to transform the current Key Performance Indicator (KPI) of PM to CM Ratio from 80:20 to 90:10. Six Sigma DMAIC Methodology and Data-Driven Predictive Maintenance Planning Framework were utilized as the methodology of this research. Research's results show that KPI, 90:10 (PM to CM Ratio) is achievable and maintenance cost can significantly reduce from 25% to 30%. Other valuable benefits are return of investment (10X), elimination of breakdown (70 - 75%), reduction in downtime (35% - 45%) and increase of production (20% - 25%). The proposed concept can be utilized in other industries to achieve high customer satisfaction percentages, sustainable operations, fault prediction, and online monitoring using PC or mobile applications.**

***Index Terms*—Predictive maintenance, internet of things (IoT) technology, six sigma DMAIC methodology, data-driven predictive maintenance planning framework.**

I. Introduction

Predictive Maintenance is a type of maintenance methodology that involves monitoring the health of an asset [1]-[10]. Asset's health is monitored in order to detect incipient failures and eventual degradation based on detection trends of component conditions using historical data [1]-[3], so that early action can be taken [4]. Thru Internet of Things (IoT) Technology, automating predictive maintenance can be acquired and implemented [5].

Internet of Things as part of an emerging technology platform in Industrial 4.0 was described as intelligent connectivity of smart devices by which objects can sense from one another and communicate using an internet network [8]. Internet network is a medium for billions of devices as the IoT, new paradigm quickly grows [2]. IoT has several applications like smart transportation, smart farming, smart health, smart cities, smart homes, energy management and facilities management [1]-[3].

Facilities Management (FM) Industry in Saudi Arabia has not yet adapted to predictive maintenance associated with IoT Technology despite of various benefits that may be achieved such as real-time asset condition monitoring, energy efficient monitoring and control without human intervention, to analyze and process machine faults in real-time, and minimization of total operational costs [7]. However, various factors are to be considered before commencing the implementation like IoT Sensor, Data, Centralized Data Processing Platform, Cloud Servers, Network, Software, Mobile Application and Information Visualization [7]-[9]. Information Visualization specifically Predictive Analytics and Prescriptive Analytics are the key features of these concepts enabling for the maintenance group to ease the decision making in providing solution to possible asset failure and to avoid its repetition [11]-[13]. Moreover, operational logic, facility conditions, live data streams, set points, control parameters, alarms, events, and trend logs are necessary for data collection [4].

The purpose of this study is to propose of implementation of Predictive Maintenance supported by IoT Technology at University-based O&M Project guided by Six Sigma DMAIC Methodology [14]-[17] and Data-driven Predictive Maintenance Planning Framework [4]. Aiming to transform the current Key Performance Indicator of PM to CM Ratio from 80:20 to 90:10 that will lead to customer satisfaction, sustainable operations, fault prediction, and online monitoring using PC or mobile application [8].

The rest of this paper is organized as follows. Section II covers the methodology for implementation of Predictive Maintenance using IoT Technology guided by DMAIC approach and Planning Framework. Section III presents the results after application of concepts and methodology. Then, Section IV will discuss the findings in details and comparison with the related studies. Lastly, conclusion and recommendation for other studies are provided in Section V.

II. Methodology

This study was based on Corrective Maintenance and Preventive Maintenance 2019 data retrieved from Computer Maintenance Management System (CMMS) at KSAU-HS O&M Project aiming to improve the set KPI from 80:20 to

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90:10 (PM to CM Ratio). This research employs the concepts of Predictive Maintenance using Internet of Things (IoT) Technology utilizing the Six Sigma DMAIC Methodology and Data-driven Predictive Maintenance Planning Framework for implementation [4].

A. Define Phase

Table I shows the number of PM and CM generated on CMMS in the year 2019. It addressed the overall performance of Operation & Maintenance of the university project. Indicating that Preventive Maintenance (PM) generated 96,343 work orders while our Helpdesk received 18,201 Corrective Maintenance (CM) Requests from end-user resulting in 84:16 (PM to CM Ratio).

TABLE I: PM AND CM COUNT PER MONTH WITH PM TO CM RATIO (2019)

Month	PM	CM	PM to CM Ratio
January	6338	1380	82:18
February	9975	1379	88:12
March	8532	1558	85:15
April	8909	1693	84:16
May	6738	1331	84:16
June	6861	1251	85:15
July	8731	1376	86:14
August	9786	1343	88:12
September	9189	1792	84:16
October	6962	1568	82:18
November	7323	1700	81:19
December	6999	1830	79:21
Grand Total	96343	18201	84:16

B. Measure Phase

In the Measure Phase, we used Performance Dashboard (Fig. 1 & 2) to quantify the percentage of asset-related and non-asset related CM Work Orders to verify if possible to achieve the 90:10 (PM to CM Ratio) using automated Predictive Maintenance and IoT Technology. The figures show that 72% of CM Work Orders relating to assets and can be resolved using the proposed concepts.

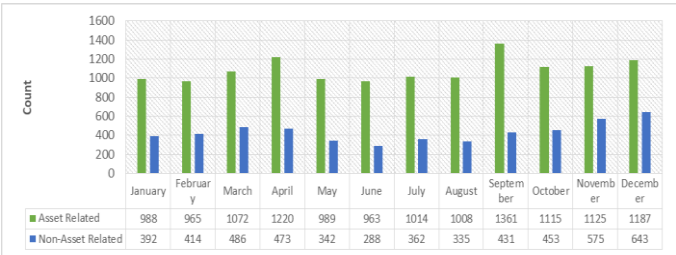

Fig. 1. Asset Related & non-asset related (2019).

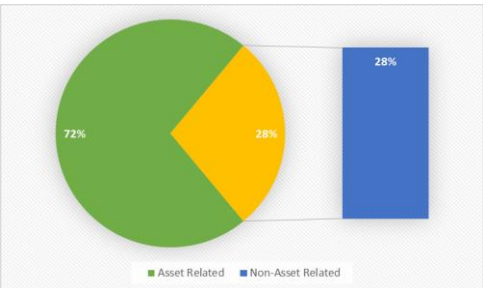

Fig. 2. Percentage ratio between asset related & non-asset related W.O.

C. Analyze Phase

Fish Bone Diagram (Fig. 3) was performed to analyze the cause of 72% Asset Related Corrective Maintenance Work Orders from the perspective of process / methods, manpower, system, and performance. The 8-root cause are possible for elimination by introduction of automated Predictive Maintenance using IOT Technology in KSAU-HS O&M Project.

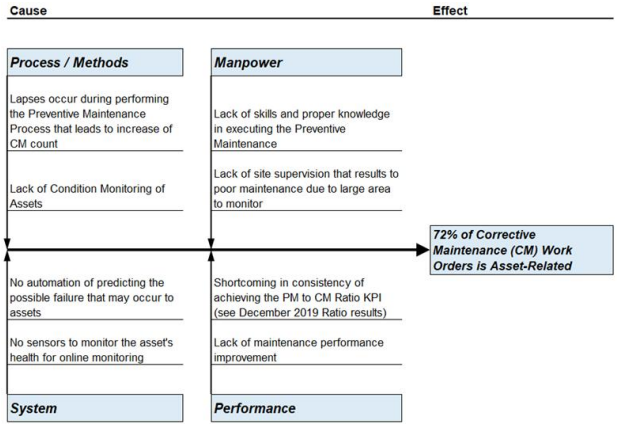

Fig. 3. Fish bone diagram.

D. Improve Phase

Data-driven Predictive Maintenance Planning Framework proposed by Cheng *et al*. [4] and recommended layers for IoT implementation by Daissaoui *et al*., [1] were utilized in building the Predictive Maintenance Process Flow Chart (Fig. 4) and the System Design Process Chart (Fig. 5). These two charts represents the Improve Phase aiming for the elimination of 72% Asset Related Corrective Maintenance Work Orders from its total count.

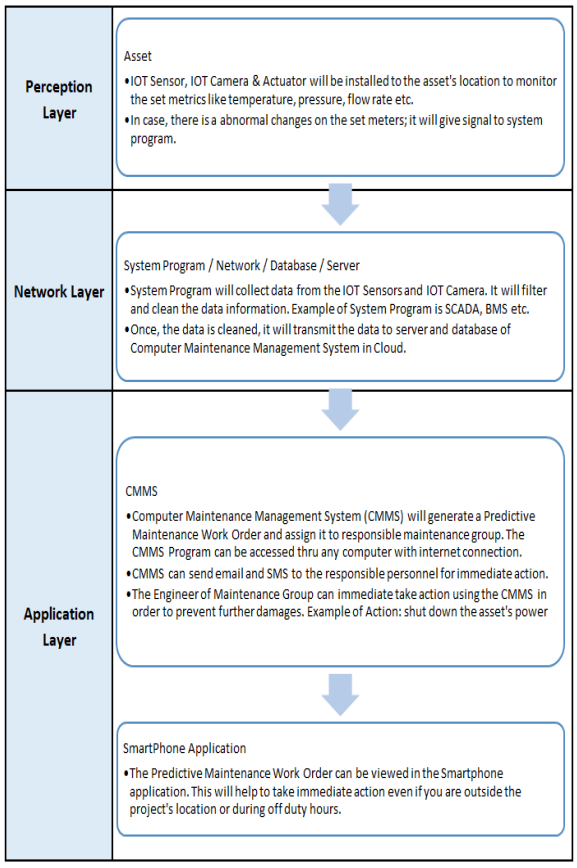

Fig. 4. Predictive maintenance process flow chart.

E. Control Phase

Table II exhibits the Process Control Plan during Control

Phase mitigating the control methods and response for every control items in the Process Chart.

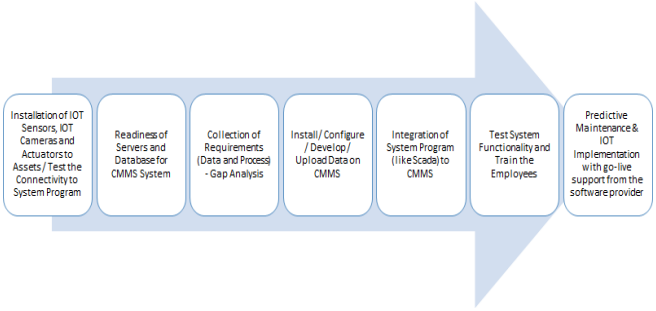

Fig. 5. System design process chart.

TABLE II: PROCESS CONTROL PLAN

Layers	Control Item (Based on Process Chart)	Control Methods	Frequency	Responsibility	Requirement	Response Plan
Perception Layer	Data Collected from Sensors	Audit Data Efficiency	Montly	IT Engineer	100% Accurate	Technical Consultant will validates the maintenance of data, devices & accessories conducted by responsible engineer
	IOT Sensor	Audit Device Efficiency	Montly	IT Engineer	100% Working	
	IOT Camera	Audit Device Efficiency	Montly	IT Engineer	100% Working	
	Actuator	Audit Device Efficiency	Montly	IT Engineer	100% Working	
Network Layer	Network	Monitoring	Daily	IT Network Team	100% Working	Technical Consultant will review the effiency of network, database, server and system program.
	Database	Monitoring	Daily	IT System Team	100% Working	
	Server	Monitoring	Daily	IT System Team	100% Working	
	System Program	Monitoring	Daily	IT System Team	100% Working	
Application Layer	CMMS	Daily Review	Daily	Administrator	100% Working	Business Consultant will review the data output from CMMS and Smartphone
	Smartphone Application	Daily Review	Daily	Administrator	100% Working	
	Maintenance Group Action	Audit Performance	Daily	Management	95% Performance Effiency	Work Control Center Manager will audit the performance of each department

Live graphical analytics and reporting dashboards (Fig. 6) are utilized in the Control Phase to monitor the performance of operation and maintenance.

Fig. 6. Graphical analytics and reporting dashboard (example).

III. RESULTS

This section covers the results from the application of Predictive Maintenance using the Internet of Things (IoT) Technology at University-based Operation & Maintenance Project utilizing the Six Sigma DMAIC Methodology and Data-driven Predictive Maintenance Planning Framework [4].

A. CM Count Reduction

The total Corrective Maintenance Work Orders that generated from the year 2019 was 18,201. Out of the total CM count, 13,007 were related to asset failure. After application of Predictive Maintenance, 72% is expected to be reduced or eliminated from the total CM Work Orders. This will result in a new count of CM Work Orders which is 5,194.

B. Improved Key Performance Indicator

The goal of this study is to transform the current Key Performance Indicator of PM to CM Ratio from 80:20 to 90:10. Based on the results from 2019 records, the goal of this paper was achieved (refer to Table IV) and transformed the PM to CM Ratio from 84:16 to 95:05. The changes show that PM Work Orders is composed of 95% while CM Work Orders are only 5%. This indicates an excellent operation & maintenance performance that surpasses the new set Key Performance Indicator.

TABLE III: NEW CORRECTIVE MAINTENANCE COUNT AFTER APPLICATION OF PREDICTIVE MAINTENANCE

Month	CM Old Count	CM-Asset-Related	CM New Count	% Total Reduction
January	1,380	988	392	72%
February	1,379	965	414	70%
March	1,558	1,072	486	69%
April	1,693	1,220	473	72%
May	1,331	989	342	74%
June	1,251	963	288	77%
July	1,376	1,014	362	74%
August	1,343	1,008	335	75%
September	1,792	1,361	431	76%
October	1,568	1,115	453	71%
November	1,700	1,125	575	66%
December	1,830	1,187	643	65%
Grand Total	18,201	13,007	5,194	72%

TABLE IV: NEW KPI (PM TO CM RATIO)

Month	Old PM to CM Ratio	New PM to CM Ratio
January	82:18	94:06
February	88:12	96:04
March	85:15	95:05
April	84:16	95:05
May	84:16	95:05
June	85:15	96:04
July	86:14	96:04
August	88:12	97:03
September	84:16	96:04
October	82:18	94:06
November	81:19	93:07
December	79:21	92:08
Grand Total	84:16	95:05

C. Cost Benefit Analysis

According to independent surveys conducted by (Sullivan *et al.*, 2010), the initiation of a functional predictive maintenance program can reduce the maintenance costs from 25% to 30%. Operation and Maintenance Budget allotted to the main contractor by University-based O&M Project for 5 years is SAR 650,000,000.00. In this regards, applying cost benefit analysis into minimum and maximum cost reduction percentage (Table V & VI) will help to gain further insight to its financial benefit:

TABLE V: COST BENEFIT ANALYSIS (25%)

Cost	Amount (SAR)	Benefit	Amount (SAR)
University Operation & Maintenance Budget for 5 years (KSA)	SAR 650,000,000.00	Predictive Maintenance with IOT Technology Implementation	SAR 650,000,000.00 x 25% = SAR 162,500,000.00
Total Cost	SAR 650,000,000.00	Total Benefit	SAR 162,500,000.00
Cost-Benefit Ratio			01:25

The new total cost is SAR 487,500,000.00 after deducting the minimum maintenance costs reduction (25%).

TABLE VI: COST BENEFIT ANALYSIS (30%)

Cost	Amount (SAR)	Benefit	Amount (SAR)
University Operation & Maintenance Budget for 5 years (KSA)	SAR 650,000,000.00	Predictive Maintenance with IOT Technology Implementation	SAR 650,000,000.00 x 30% = SAR 195,000,000.00
Total Cost	SAR 650,000,000.00	Total Benefit	SAR 195,000,000.00
Cost-Benefit Ratio			01:30

The new total cost is SAR 455,000,000.00 after deducting the minimum maintenance costs reduction (30%).

D. Other Benefits

Other benefits after application of Predictive Maintenance according to Sullivan *et al*., 2010:

1) Return of investment: 10 times

The estimated total cost of predictive maintenance program is SAR 15,000,000.00. Based on the Cost Benefit Analysis, the implementation cost had resulted to return of investment (ROI) of 10 to 13 times more.

2) Elimination of breakdown: 70% to 75%

The elimination of breakdown reached up to 72% based on data collection.

3) Reduction in downtime: 35% to 45%
4) Increase in production: 20% to 25%

IV. Discussion

Results of application of Predictive Maintenance with Internet of Things (IoT) Technology utilizing the Sig Sigma DMAIC Methodology and Data-driven Predictive Maintenance Planning Framework of Cheng *et al*. [4] improved the Key Performance Indicator from 84:16 to 95:05 (PM to CM Ratio) due to elimination of 72% Corrective Maintenance Asset-related Work Orders.

Maintenance cost reduction amounted to SAR 162,500,000.00 based on minimum reduction cost percentage of 25% and it may extends up to SAR 195,000,000.00 in 30% cost reduction. Similar to study conducted by Rohit Dhall *et al*. [6] for an IoT-based predictive connected car maintenance approach; the total maintenance cost reduction resulted to 30%. In addition, other benefits were achieved such as multiple return of investment, elimination of breakdown, reduction in downtime and increase in production which is comparable to previous studies [7], [10], [18]-[21].

Asset health was addressed through the real-time monitoring using PC and mobile, fault prediction, energy efficient monitoring and control without human intervention, condition-based monitoring, and maintenance analytics and reporting dashboard [1], [6], [7], [9]. The results concluded that application of Predictive Maintenance with Internet of Things (IoT) Technology delivered compelling benefits and improvements in the operation and maintenance of University-based Project.

Moreover, an idea of integration of artificial intelligence to current solution can bring-out an AI Assistant to maintenance team. The possibility of seeking a technical advice from an AI Assistant to resolve an asset failure based on accumulated data from history, IoT sensors and predictive modelling can ease the work, increase accuracy and efficiency of a technician or an engineer without prior knowledge of a repair situation. This also ensures that the repair is completed right at the first time. In addition, an AI Assistant is expected to continuously learn and support the operation and maintenance of a project.

V. Conclusion

This research paper presented the effectiveness of automating Predictive Maintenance using Internet of Things (IoT) Technology at University-based O&M Project in terms of improving key performance indicator (PM to CM Ratio), reduction of received Corrective Maintenance Work Orders, maintenance reduction cost (25% - 30%), return of investment (10 to 13X), elimination of breakdown (70 - 75%), reduction in downtime (35% - 45%) and increase of production (20% - 25%) utilizing the Six Sigma DMAIC Methodology and Data-driven Predictive Maintenance Planning Framework of Cheng *et al*. [4].

A. Limitations

Internet of Things (IoT) Technology are one of the emerging technology platform in Industrial 4.0 and using this technology in automating the Predictive Maintenance brings out the maximum potential of the proposed maintenance methodology in the O&M Project. However, there are other technologies that can be explored and utilized in implementing Predictive Maintenance such as Artificial Intelligence. More advanced technologies can be expected to rise in the upcoming years that will lead for huge improvement in the field of Facilities Management.

B. Future Research

The researcher suggested exploring more detailed step by step procedures on application of Internet of Things (IoT) Technology in Predictive Maintenance in the current study that incorporates review of literatures from previous studies to view research gaps, a customized predictive maintenance framework with defined technical modules, a process flow diagram that compares the before and after implementation, asset's health dashboard and other benchmarks to support the study. The applicability of combination of Internet of Things (IoT) Technology and Artificial Intelligence in the operation and maintenance can be also examined in Facility Management Projects in order to acquire more beneficial impacts in the organization, society, and environment.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

JRF conducted the research, analyzed the data, and prepared the manuscript; YTP supervised; SFP and AANPR reviewed and edited the manuscript; all authors had approved the final version.

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