



جامعة إسرائيل
Isra University

Root Cause Analysis Technology to Improve Maintenance Management of Equipment in Water Treatment Plants

Prepared by:

Hussein Abdullah Awad Al-Mar'awee

Supervised by:

Dr. Walid Emar

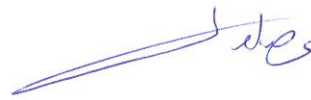
A Thesis

**Submitted to Faculty of Engineering as a Partial Fulfillment of the
Requirement for Master Degree in Engineering Project Management**

April 2020

نموذج التفويض

انا حسين عبدالله عواد، افوض جامعة الإسراء بتزويد نسخ من رسالتي للمكتبات او المؤسسات او الهيئات او الأشخاص عند طلبهم حسب التعليمات النافذة في الجامعة.

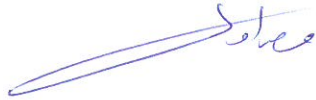
التوقيع: 

التاريخ: ١٥ / ١ / ٢٠٢٠

Isra University Authorization Form

I'm Hussein Abdullah Awad, authorize the Isra University to supply copies of my Thesis to libraries or establishments or individuals and persons on request, according to Isra University regulations.

Signature:



Date:

١٥ / ١ / ٢٠٢٠

COMMITTEE DECISION

This thesis (Root Cause Analysis Technology to Improve Maintenance Management of Equipment in Water Treatment Plants) Was Successfully Defended and Approved on 18 / 04 / 2020

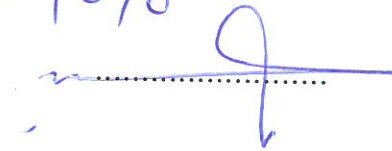
Examination Committee

Signature

Dr. Walid Emar, (Supervisor)

Associate Prof. of Automatic Control,


Electrical Engineering Department, Isra University, Amman, Jordan.

c.c. 10/0


Dr. Mohammed Al. Diabat Al. Btoush (Member)

Assistant Prof. of Engineering Project Management,

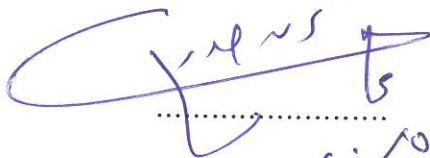
Civil Engineering Department, Isra University, Amman, Jordan.


Dr. Al. Diabat
c.c. 10/0

Prof. Dr. Omar A. Saraereh, (Member)

Professor of Wireless Communications Electrical Engineering

Department Engineering Faculty, The Hashemite University, Zarqa, Jordan.


c.c. 10/0

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿وَعَلَّمَكَ مَا لَمْ تَكُن تَعْلَمُ وَكَانَ

فَضْلُ اللَّهِ عَلَيْكَ عَظِيمًا﴾

صَلَّى اللَّهُ عَلَيْهِ وَسَلَّمَ

(سورة النساء: الآية ١١٣)

Dedication

الى...

وطني الجريح.... العراق

يارب اشهد يوم شفائك ونهوضك

مشرفي ... الدكتور وليد العمور

الى زوجتي العزيزة وفلذة كبدي اطفالي الاعزاء

كل من يتمنى لي الخير ...

الأهل، الإخوة، الزملاء، الأصدقاء

الى كل هؤلاء اهدي جهدي المتواضع .

To...

My wounded country Iraq

Lord, witness the day of your recovery and rise

My supervisor ... Dr. Walid Emar

To my dear wife and my liver pleasure, my dear children ...

Everyone who wishes me well...

Parents, brothers, colleagues, friends

To all of these I dedicate my humble effort

ACKNOWLEDGEMENTS

First of all, praise be to ALLAH for His uncountable blessings. I am deeply indebted to my Supervisor Dr. Walid Emar for his suggestions and guidance I would also like to express my thanks to the Department of Graduate Studies / Isra University, Amman / Jordan for its contribution to the completion of the research. I also thank all of my colleagues and graduate students in the department. I also extend my thanks and appreciation to all employees of the Anbar Water Directorate and the Ministry of Housing and Construction and public municipalities, especially the Fallujah Water Administration that I visited while collecting data and information. Special and sincere thanks to my wife for her support in completing this research, my dear children and all those who wished me success and success in this work. Many thanks to everyone who helped me in this work by providing advice or showing the path to success.

HUSSEIN ABDULLA AWAD

2020 / /

TABLE OF CONTENTS

COMMITTEE DECISION	II
DEDICATION	IV
ACKNOWLEDGEMENT	V
TABLE OF CONTENTS.....	VI
LIST OF TABLES	I
LIST OF FIGURES	XI
LIST OF ABBREVIATIONS.....	XIII
ABSTRACT.....	XV
Chapter: One Introduction	1
1.1 Background	1
1.2 Problem Statement.....	3
1.3 Research Importance	4
1.4 Research Aim and Objectives	4
1.5 Research Questions and Hypotheses	5
1.6 Justification of the study	7
1.7 Research Methodology	8
Chapter: Two Literature Review	10
2.1 Introduction	10
2.2 Maintenance	10
2.3 Failures.....	12
2.4 Failure Causes	14
2.5 Previous Studies	15
2.6 Summary and Gaps from Literature	22
Chapter Three: Equipment Maintenance Methodology	24
3.1 Introduction	24
3.2 The Adopted Methodology	25

3.3 Data Collection Method	26
3.4 The Concept of Maintenance	29
3.5 The importance of Maintenance	29
3.6 The Objectives of Maintenance	31
3.7 Maintenance Policies	32
3.8 Requirements for the Application of Maintenance Management.....	35
3.8.1 Data	35
3.8.2 Criteria of Reliability Engineering	36
3.8.3 Analysis Techniques	37
Chapter Four: Results and Discussion.....	50
4.1 Introduction	50
4.2 Research Background for water projects in Fallujah - Iraq.....	50
4.3 Fallujah project WTP	53
4.4 Evaluation of the Criteria for Selection the Maintenance Policy	61
4.5 Evaluation and Determination of Critical Equipment Using Pareto Analysis	65
4.6 Fault Tree Analysis Techniques (FTAT).....	73
4.7 Maintenance Policies in the WTPs Project	78
4.8 Fish Bone Strategies and Cause and Effect Diagram.....	84
4.9 AnalyticHierarchyProcess(AHP).....	86
4.9.1 Azrakya Project WTP/AHP Process	87
4.10 Validation Test with a Questionnaire	97
4.10.1 Questionnaire Strategic Survey and Formulation.....	98
4.10.1.1 Questionnaire Messaging form	99
4.10.1.2 Questionnaire Structure.....	100
4.10.2 Satisfaction Measurement of the Validation Test	103
Chapter Five: Conclusions and Recommendations.....	105
5.1 Introduction	105

5.2 Conclusions	106
5.3 The Limitations and Recommendations	107
References	110
Appendix A-R	117
Appendix: A1-R1..... Stations of the Cement Project	117
Appendix: A2-R2..... Stations of the old Project	128
Appendix: A3-R3..... Stations of the new AL-shuhada Project	137
Appendix: A4-R4..... Stations of the AL- tahade project Project	148
Appendix: A5-X1..... Weight mode At the station	160
Appendix:..... (Validation Test with Questionnaire)	161
ملخص باللغة العربية	1

LIST OF TABLES

Table 3.1: Results of the first query of the Azrakya new project equipment / year	27
Table 3.2: Results of the second query for the failure mode of the Azrakiya project equipment / year.....	28
Table 3.3: comparison between corrective and preventive maintenance	34
Table 3.4: Classification of probability of failure detection	43
Table 3.5: Clarification of the occurrence of failure.....	43
Table 3.6: rating of risk.....	43
Table 4.1: Results of the first query of the Azrakya new project equipment / year	54
Table 4.2: Results of the second query for the failure mode of the Azrakiya new project equipment / year.....	54
Table 4-3: Estimation of the criteria of reliability engineering for the Azrakiya project equipment / year.....	56
Table 4-4: Estimation of the criteria of reliability engineering for the project equipment failure mode (Azrakiya new project)	57
Table 4-5: Frequent failure mode resulting from the calculations of the Azrakiya project	58
Table 4-6: Values of times and reliability parameters of failure mode for the Azrakiya new Fallujah project.....	60
Table 4-7 Values of times and reliability parameters for the Azrakiya new project equipment.....	61
Table 4-8: Pareto analysis based on the frequency of failures for the Azrakya new project equipment.....	62
Table 4-9: Pareto analysis based on the downtime times for the Azrakiya new project equipment.....	62
Table 4-10: Pareto analysis according to the frequency of failure occurrences for the Azrakya new project equipment	63
Table 4-11: Pareto analysis according to the downtime of the failure mode for the Azrakya project equipment	64
Table 4-12: Critical failure modes in the Azrakiya WTP project (82.86% of the total number of failures)	69
Table 4-13: Critical Failure modes in the Azrakiya WTP project (85.54% from downtime)	70
Table 4-14: Pareto analysis result of other projects according to the frequency of failure mode is shown in the appendix (Critical).....	71

Table 4-15: Pareto analysis results of other projects according to the downtime time are figured out in Appendix (A).....	72
Table 4-16: Calculation of the probability of failure of equipment for the new Azrakya project Fallujah water	74
Table 4-17: The results of Pareto analysis of the probability of failure of equipment for the new project Fallujah water Azraq	75
Table 4-18: Critical failure modes weighing - 84.15% of all probabilities of failure modes for the Azrakya project WTP	76
Table 4-19: Critical failure modes weighing - 84.15% of all probabilities of failure modes for the Azrakya project WTP	77
Table 4-20: Weight mode (Intake Pump A1) At the station.....	79
Table 4-21: Pareto analysis of failure mode for the projects of the water treatment plant stations	79
Table 4-22: Maintenance policies followed and proposed	81
Table 4-23: Policies of the proposed maintenance for critical modes	83
Table 4-24: Pairwise order of measures for WTP in Fallujah Azrakya project.....	88
Table 4-25: P normalized & W max Approximations	89
Table 4-26: Values of sub-criteria P * W max	89
Table 4-27: Random Consistency values (RI).....	91
Table 4-28: Alternatives with respect maintenance performance / Azrakya project WTP	92
Table 4-29: normalized of Alternatives with respect maintenance performance/ Azrakya project WTP	93
Table 4.30: Alternatives to sub-criteria/ Azrakya project WTP. Intake Pump A1	93
Table 4.31: Analytic Hierarchy Process of Alternative / Azrakya project WTP.....	96
Table 4.32: Results Validation Test and Questionnaire paragraphs	100
Table 4.33: Questionnaire paragraphs for methods used and results obtained.....	102
Table 4.34: Validation Test for Intake Pumps	103
Appendix Table A1-K1: Stations of the Cement Project	117
Appendix Table P1 Stations of the Cement Project:	126
Appendix Table Q1: Stations of the Cement Project	127
Appendix Table A2-K2: Stations of the old Project	128

Appendix Table P2: Stations of the old Project).....	136
Appendix Table Q2: Stations of the old Project.....	136
Appendix Table A3-K3: Stations of the new AL-shuhada Project	137
Appendix Table P3: Stations of the new AL-shuhada Project.....	147
Appendix Table Q3: Stations of the new AL-shuhada Project	147
Appendix Table A4-K4: Stations of the AL- tahade project Project	148
Appendix Table P4: Stations of the AL- tahade project Project	158
Appendix Table Q4: Stations of the AL- tahade project Project	158
Appendix Table A5-X5: Weight mode At the station.....	160

LIST OF FIGURES

Figure 2.1: (Bath Tub Curve) Operation time (hour, Revolution, Kilometer/ hr.). Topical curved of failure ration	14
Figure 3.1: Flowchart of the research methodology	25
Figure 3.2: Maintenance Policies.....	33
Figure 3.3: Maintenance management methods	36
Figure 3.4: Pareto Diagram.....	40
Figure 3.5: Basic logic gates	41
Figure 3.6: the General Shape of the Fishbone.....	45
Figure 3.7: General Model of the Hierarchy.....	48
Figure 4.1: Project (Azrakya) Fallujah water treatment project Flowchart).....	52
Figure 4.2: Pareto analysis chart for the Azrakya project, WTP of equipment according to the frequency of failures	66
Figure 4.3: Pareto Analysis chart for the Azrakya project WTP of equipment according to the downtime.....	66
Figure 4.4: Pareto Analysis chart for the Azrakiya project WTP of equipment failure mode according to the frequency of failure	69
Figure 4.5: Pareto Analysis chart for the Azrakiya project WTP of equipment based on the downtime.....	70
Figure 4.6: Pareto Analysis chart for the Azrakya project WTP equipment to the failure modes based on failure probability.....	76
Figure 4.7: Pareto Analysis chart for failure modes of the equipment station (Policy proposed).....	84
Figure 4.8: Fish Bone Strategies & Cause and Effect Diagram	85
Figure 4.9: Hierarchical Decision Tree.....	87
Figure 4.10: Chart for the AHP of the Alternatives.....	97
Figure 4.11: Effect percentage ratio Criteria from the Validation Test.....	104
Appendix Figure L1: Pareto scheme for the AL- Cement project WTP of equipment according to the frequency of failure	124
Appendix Figure M1: Pareto scheme for the AL- Cement project WTP of equipment according to the times the downtime	125
Appendix Figure N1: Pareto Analysis chart for the AL- Cement project WTP of equipment failure mode according to the frequency of failure.....	125

Appendix Figure O1: Pareto Analysis chart for the AL- Cement project WTP of equipment according to the times the downtime	126
Appendix Figure R1: Pareto Analysis chart for the Cement project WTP of equipment to the of failure modes according failure probability.....	127
Appendix Figure L2: Pareto scheme for the AL- old project WTP of equipment according to the frequency of failure	134
Appendix Figure M2: Pareto scheme for the AL- old project WTP of equipment according to the times the downtime	134
Appendix Figure N2: Pareto Analysis chart for the AL- old project WTP of equipment failure mode according to the frequency of failure.....	135
Appendix Figure O2: Pareto Analysis chart for the AL- old project WTP of equipment according to the times the downtime	135
Appendix Figure R2: Pareto Analysis chart for the old project WTP of equipment to the of failure modes according failure probability.....	137
Appendix Figure L3 Pareto scheme for the new AL-shuhada project WTP of equipment according to the frequency of failure	145
Appendix Figure M3: Pareto scheme for the new AL-shuhada project WTP of equipment according to the times the downtime	145
Appendix Figure N3: Pareto Analysis chart for the AL-shuhada new project WTP of equipment failure mode according to the frequency of failure.....	146
Appendix Figure O3: Pareto Analysis chart for the AL-shuhada new project WTP of equipment according to the times the downtime	146
Appendix Figure R3: Pareto Analysis chart for the new AL-shuhada project WTP of equipment to the of failure modes according failure probability.....	148
Appendix Figure L4: Pareto scheme for the AL- tahade project WTP of equipment according to the frequency of failure	156
Appendix Figure M4: Pareto scheme for the AL- tahade project WTP of equipment according to the times the downtime	156
Appendix Figure N4: Pareto Analysis chart for the AL- tahade project WTP of equipment failure mode according to the frequency of failure.....	157
Appendix Figure O4: Pareto Analysis chart for the AL- tahade project WTP of equipment according to the times the downtime	157
Appendix Figure R4: Pareto Analysis chart for the new AL- tahade project WTP of equipment to the of failure modes according failure probability.....	159

LIST OF ABBREVIATIONS

TERM	SYMBOL	MEASRUING UNIT
Water treatment plants	WTP	---
maintenance systems	MS	---
Root Cause Analysis Technique	RCAT	---
Corrective Maintenance	CM	---
Emergency Maintenance	EM	---
Mean Time Between Failures	MTBF	Hour
Operation time	OT	Hour
Number of failures	NF	---
Mean Time To Repair	MTTR	Hour
Downtime	DT	Hour
Failure Rate.	λ	Hour ⁻¹
Repair Rate	μ	Hour ⁻¹
Total Failures	TFN	---
Number Failures Mechanism	FN _i	---
Percentage Failures Mechanism	P _i	---
Cumulative Percentage	CP	---
Fault Tree Analysis Techniques	FTAT	---
Multi-criteria Decision Making	MCDM	---
Failure rate for failure pattern (A).	FR , λ_A	---
Repair rate of failure pattern (A).	μ_A	---
The probability of failure of the pattern (A)	FP (A)	---
The probability of failure of the pattern (B)	FP (B)	---
Activities	A,B,C,D	---
The probability of the failure part (B ₁ , B ₂)	FP(B ₁ , B ₂)	---

The probability of the failure part (C)	FPC	---
Planned Maintenance	PM	---
Discovery	D	---
Probability of Occurrence	O	---
The risk priority number	RPN	---
Planning Corrective Maintenance	PCM	---
Severity	S	---
Analytic Hierarchy Process	AHP	---
Criteria	K	---
Total Productive Maintenance	TPM	---
eight pillars	EPS	---
performance efficiency	PE	---
quality rate	QR	---
through the effectiveness of total equipment	OEE	---
net equipment activities	NEE	---
Number of equipment or parts	N	---
the underlying root of the binary comparisons matrix	λ max	---
Number of comparative items	n	---
consistency index	CI	---
random index	RI	---
consistency ratio	CR	---
Preventive Maintenance	PM	---
Predictive maintenance	PrM	---

Root Cause Analysis Technology to Improve Maintenance Management of Equipment in Water Treatment Plants

**Prepared By
Hussein Abdullah Awad**

**Supervised By
Dr. Walid Emar**

ABSTRACT

The main objectives of this research are to identify the main challenges and success factors of operation and management of the water treatment system in Fallujah city Iraq; including analysis of the performance of the system; and to make recommendations on how the system can be improved and how lesions can be applied to similar type of systems in other areas in Iraq and Arab world.

The water treatment plant is one of the most important facilities in the country because of its great importance to serve the citizens, especially in the current circumstances in Iraq, which suffers from weakness and a bad management in the provision of services provided and available to people, so it became necessary to maintain water treatment plants that cost the national economy huge sums of money .

To clarify the contribution of the maintenance management to improving the performance of institutes and companies, especially those companies depending in their job on the watering systems, a case study is being conducted for the water treatment plant (WTP) in Fallujah city in Iraq. The case study company is important for the water treatment sector as it has an annual capacity to process and distribute 30 million cubic meters of drinking water for all people in Fallujah city.

This research work mainly refers to reducing sudden abandoned breakdown failures and enhancing the achievement of the current manufacturing capabilities of the water treatment plant. This could be achieved through the availability of the

application of good maintenance management just to improve the average time between failure and the average time between malfunctions of the vital components of the machine that require comprehensive maintenance techniques and skills.

This study research shows that the policy of selected maintenance consists of three methods: The first is to perform a planned and predictive maintenance for all types of equipment and units that are highly critical depending upon measurement and analysis in the sense that this maintenance requires predetermined and preset conditions. The second is to perform the so-called preventive and planned maintenance before the breakdown and failure of equipment occur even when machines or the systems are in complete functional mode. The third one is the corrective maintenance which is performed after the failure of the non-critical modes or units of each station occur.

It has been shown through the application of Pareto analysis in parallel with fault tree analysis for the frequency of failure occurrences and down times in the five projects at the Water treatment plants in Fallujah city that 10 equipment of a total number of 23 unit patterns in WTP are to be subjected to preventive and predictive maintenance .

Furthermore, Analytic Hierarchy Process (AHP) has been used to determine the weights of each unit in WTP and to determine priorities in maintenance operations for water treatment plant equipment and units. Finally, the recorded data and the final results were evaluated by conducting a verification test with a questionnaire in cooperation with experts concerned in this field.