RISK BASED MAINTENANCE APPROACH FOR WATER TREATMENT PLANTS

By

RASHA MAOWAD AHMED ABD EL MAKSOUD

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
In
STRUCTURAL ENGINEERING

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Under the Supervision of
Prof. Dr. Mohamed Mahdy Marzouk

Professor of Construction Engineering and Management
Structural Engineering Department
Faculty of Engineering, Cairo University

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Approved by the Examining Committee

_____

Prof. Dr. Mohamed Mahdy Marzouk .....Thesis Main Advisor
Professor of Construction Engineering and Management – Structural Engineering Department - Cairo University

_____

Prof. Dr. Moheeb El-Said Ibrahim..... Internal Examiner
Professor of Construction Engineering and Management – Structural Engineering Department - Cairo University

_____

Prof. Dr. Maha Mostafa El Shafai…… External Examiner
Professor of Sanitary and Environmental Engineering at Housing and Building National Research Center

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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2018

Engineer: Rasha Moawad Ahmed Abd El Maksoud
Date of Birth: 6/5/1980
Nationality: Egyptian
E-mail: rashaahmed6580@gmail.com

Registration Date: 1/10/2010
Awarding Date: / / 2018
Degree: Doctor of philosophy
Department: Structural Engineering
Supervisors:
Prof. Dr. Mohamed Mahdy Marzouk
Examiners:
Prof. Dr. Mohamed Mahdy Marzouk (Thesis Main Advisor)
Prof. Dr. Moheeb El-Said Ibrahim (Internal Examiner)
Prof. Dr. Maha Mostafa El Shafai - Housing and Building National Research Center (External Examiner)

Title of Thesis: **A RISK BASED MAINTENANCE APPROACH FOR WATER TREATMENT PLANTS**

Key Words: Risk based maintenance – Fuzzy fault tree analysis – Laser scanning

Summary:

Water Treatment plants are deemed important fundamentals for human living and development. They receive considerable attention to ensure they have steady performance under a lot of conditions. There are many causes of failures that occur in water treatment plants. The most important of these, are the inefficiency of the plant in producing the quantities of water that have the required quality of water standard specifications. Therefore, it is important to develop methods that reduce errors which may have a negative impact on consumer health and the environment. This can be done by identifying the various dangerous events that may have an impact on the service, and the associated risks. This research aimed to present an approach which used in maintenance of WTP. For that this research passed on three main phases. First phase, the risk factors on WTP maintenance process are identified in the first phase through the use of expert opinions as well as previous research in the same field. This phase resulted in the presence of 20 risk factor with high impact on WTP maintenance process which lead to major 12 events for WTP failure. Second phase, analyses the reasons for water treatment plants failure based on the analysis of the reasons using Fault Tree Analysis. Qualitative analysis was used to achieve 33 basic events that lead to 12 minimal sets of fault tree analysis data representing the minimum plant failure probability. There is a great probability that 1 of the 12 minimal sets from the fault tree analysis will causes problems and failures in the fundamental operation of the facility. The research proposes a new method combining diverse experts with a range of theories to assess the probability of events in order to avoid the problem of lack of precision that will be faced when assessing the basic events. The data are used to determine the likelihood of a fault tree. Probabilities of the top event (TE) and the basic events (BEs) are calculated using Boolean relationships. The occurrence probability of TE is 15.6% per year. After ranking all risks, the research reveals that the failure of the electrical system is the most critical risk based on the probabilities of basic events, which has a high probability (0.037) with a high impact in the occurrence of failure. Third phase, providing a method for linking equipment maintenance information within water treatment plants with the point cloud which results from 3D laser scanning of the plant. The methodology automates the exchange of information for three-dimensional computer-aided design objects from 3D site laser scans .

Equipment information is clustered, according to maintenance intervals, into daily, weekly, monthly, and annually maintenance plans. The proposed method was applied on the Sixth of October Water Treatment Plant as a case study to illustrate the benefits of using laser scanning technology in facility management .

Finally, it is necessary to determine the tasks and dates of periodic maintenance plans, whether daily, weekly, monthly, and annually for WTP in order to enhancement the efficiency of the WTP operation. It has become necessary to use science and modern methods such as BIM and Laser scanning for linking all of information about these tasks and dates of periodic maintenance for all kind of infrastructure in order to work for long time with the same operational efficiency.

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DISCLAIMER

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

***Name**: Rasha Maowad Ahmed Abd El Maksoud* ***Date**:*

***Signature**:*

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ABSTRACT

Water Treatment plants are deemed important fundamentals for human living and development. They receive considerable attention to ensure they have steady performance under a lot of conditions. There are many causes of failures that occur in water treatment plants. The most important of these, are the inefficiency of the plant in producing the quantities of water that have the required quality of water standard specifications .

Therefore, it is important to develop methods that reduce errors which may have a negative impact on consumer health and the environment. This can be done by identifying the various dangerous events that may have an impact on the service, and the associated risks. This research aimed to present an approach which used in maintenance of WTP. For that this research passed on three main phases as following:

First phase: the risk factors on WTP maintenance process were identified. Through the use of expert opinions as well as previous research in the same field. This phase resulted in the presence of 20 risk factor with high impact on WTP maintenance process which lead to major 12 events for WTP failure.

Second phase: analyses the reasons for water treatment plants failure based on the analysis of the reasons using Fault Tree Analysis. Qualitative analysis was used to achieve 33 basic events that lead to 12 minimal sets of fault tree analysis data representing the minimum plant failure probability. There is a great probability that 1 of the 12 minimal sets from the fault tree analysis will causes problems and failures in the fundamental operation of the facility. The research proposes a new method combining diverse experts with a range of theories to assess the probability of events in order to avoid the problem of lack of precision that will be faced when assessing the basic events. The data are used to determine the likelihood of a fault tree. Probabilities of the top event (TE) and the basic events (BEs) are calculated using Boolean relationships. The occurrence probability of TE is 15.6% per year. After ranking all risks, the research reveals that the failure of the electrical system is the most critical risk based on the probabilities of basic events, which has a high probability (0.037) with a high impact in the occurrence of failure .

Third phase: providing a method for linking equipment maintenance information within water treatment plants with the point cloud which results from 3D laser scanning of the plant. The methodology automates the exchange of information for three-dimensional computer-aided design objects from 3D site laser scans .

Equipment information is clustered, according to maintenance intervals, into daily, weekly, monthly, and annually maintenance plans. The proposed method was applied on the Sixth of October Water Treatment Plant as a case study to illustrate the benefits of using laser scanning technology in facility management.

Finally, it is necessary to determine the tasks and dates of periodic maintenance plans, whether daily, weekly, monthly, and annually for WTP in order to enhancement the efficiency of the WTP operation. It has become necessary to use science and modern methods such as BIM and Laser scanning for linking all of information about these tasks and dates of periodic maintenance for all kind of infrastructure in order to work for long time with the same operational efficiency.

Chapter 1: Introduction

1.1 General

A normal water feeding system is made out of water head, raw water transmission funnels, water treatment plants, and water circulation systems. These segments and subsystems give greatest chance for the normal and human-related impacts in light of the fact that most of those are spatially available and different. As for that, analysts have perceived the potential powerless zones in the midst of the way toward conveying water from the sources to the customers as: 1) sources of water (e.g., river, reservoir, and wells); 2) water treatment plants that are specialized in purifying water from impurities and connecting them to domestic consumption and different uses; 3) water distribution pipelines that deliver clean water to homes, commercial establishments, and industries; 4) storages (tanks); and 5) different facilities (transmission pipes, channels, pumps, valves, and so on.). These weak points are the focus of risks assessment.

Being a champion among the most basic essentials for human living and advancement, water treatment plants have become amazing thought relating to their execution under shifted conditions. Water treatment plants are generally designed, developed, operated, and oversaw in an open environment, thusly they are unavoidably presented to differed unverifiable threats/hazards. As a result of the necessities of system safety and dependability, risk assessment has been seen as a valuable instrument to distinguish threats, investigations risks, and select alleviation measures for water treatment plants.

Risk demonstrates the potential harm or loss of a benefit or a trade off in the function of an engineering system. Asset assessment of a water treatment plant is normally imparted as a procedure of distinguishing threats/hazards, separating sensitiveness of segments, framework, assessing risks of segments and system. A risk assessment should be seen as convincing and extensive if this procedure was coordinated completely.

Building information modeling (BIM) is the way toward making and administering information of manufactured facilities and assets in the midst of their life cycle. By using BIM models in design and execution phases of advantages and exchanging the data to the accompanying periods of the existence cycle, the total costs of benefit administration in its maintenance and operation phases can be extraordinarily lessened.

1.2 Research Motivation

Water is the basis of life and we use it in our daily activities life such as residential, service and industrial activities. The amount of productive water in Egypt in 2017 about 25.3 million m^3/day, meaning that per capita 298 lit/ day and our water sources for the plants divided as follows [1]:

- 89% surface water (Nile water).
- 10.74% groundwater.
- 0.26% desalination.

Due to population growth and urban development in Egypt from 2005 to 2017 as shown in Table 1.1 and the most import current challenge which is faced by the Arab

Republic of Egypt shortage in the amount of Nile water (surface water). Therefore, it has become necessary to preserve the water drops from the source to the consumer. For this reason, the process of the operation and maintenance of potable water is the most important way to preserve the quantity and quality of water and reduce the losses.

Table 1.1: WTP and distribution networks development in Egypt [1]

Statement	2005	2017
No of Population Served	53 million person	94 million person
The design capacity of the Water Treatment Plants (WTP)	20 million m3/day	34 million m3/day
Amount of productive water (Average annual)	13.5 million m3/day (4.6 Billion m3/year)	25.3 million m3/day (9.23 Billion m3/year)
No on Water Treatment Plants (WTP)	▪ 112 Large Surface water station ▪ 339 Small Surface water station ▪ 112 Ground water station ▪ 15 desalination station Total no of station: 1005 station	▪ 227 Large Surface water station ▪ 830 Small Surface water station ▪ 1610 Ground water station ▪ 40 desalination station Total no of station: 2715 station
Lengths of distribution networks	74000 km	160000 km

1.3 Research Objective

The main objective of this research is to create efficient structure and strategy for Water Treatment Plants (WTP) risk assessment in Egypt and provide a maintenance strategy for their critical parts. Additional objective includes implementing a tool to simplify the process of getting feedback on maintenance process for the critical parts. This is achieved by exploiting the risk analysis processes taking into consideration the characteristics of water treatment plant, various leveled structure analysis, fuzzy sets-based quantitative strategies, laser scanning and linking the data about maintenance by high density point cloud (HDPC).

To achieve above listed main objective, the following sub-objectives are carried out:

1. Collecting all risk factors which have high impact on maintenance process and the most critical events will occur based on its.
2. The use of fuzzy logic in risk assessment process. By using fault tree analysis (FTA) to get the probability of water treatment plant failure (Top Event) and the most critical event with high impact on top event.
3. Constructing a maintenance model. By using 3D laser scanning and linking the data about maintenance process by high density point cloud (HDPC).

1.4 Research Methodology

The research methodology framework shown in Figure 1.1 presents three consequence phases. The framework starts with an initial first phase that deals with identification of the most critical risk factors have high impact on WTP maintenance process. Through the use of expert opinions as well as previous research in the same field. Second phase, analyses the reasons for water treatment plants failure based on the analysis of the reasons using Fault Tree Analysis. Qualitative analysis was used to get the water treatment plant failure. Third phase, providing a method for linking equipment maintenance information within water treatment plants with the point cloud which results from 3D laser scanning of the plant. The methodology automates the exchange of information for three-dimensional computer-aided design objects from 3D site laser scans.

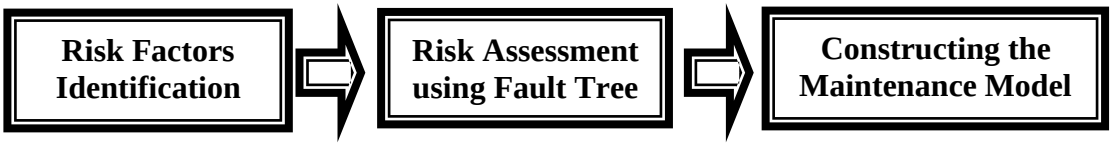

Figure 1.1: Methodology Framework

1.5 Thesis Organization

The structure of this thesis is portrayed in Figure 1.2 and brief discussed in the following:

Chapter 1 presents a general introduction to the research and its motivation, Also, the research objectives and the methodology presents in details .Finally, the organization of the research is discussed.

Chapter 2 reviews literature related to risk assessment techniques and strategies managing multifaceted nature and vulnerability in water treatment plant. As indicated by the audits, the limitations associated with previous methods are highlighted as well as possible resolutions to overcome these limitations. Then, the use BIM technique and how it can be used as efficient tool in asset management and maintenance. Also, presents the process of WTP operation.

Chapter 3 presents a rundown that contains the most critical risk factors of WTP maintenance by utilizing statistical analysis as per the level of significance of each factor. It illustrates the process of weights determination and positioning the factors, with a goal to build up a WTP maintenance need list model.

Chapter 4 intends to create reasonable structures for risk assessment and fault tree analysis of WTP. It reviews the methods to quantitatively assess the various leveled systems of risk assessment by utilizing fuzzy fault tree analysis. In fuzzy fault tree analysis method, the probability of top event and essentialness measures of contributing elements. Outcomes of this investigation are valuable to sort out the segments and hazards for specific risks and help risk investigators to decide.

Chapter 5 presents the developments made in a model dedicated for maintenance of WTP by utilizing BIM technique, additionally; it portrays the general use of the proposed model for maintenance design of WTP ventures, by connecting the maintenance information with the high-density point cloud (HDPC).