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A New Methodology for Improving TAM Scheduling of Oil and Gas Plants

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Abstract - **Turnaround Maintenance (TAM) is a methodology for overall shut-down of plant facilities during a pre-defined period to execute inspection actions, replacement and repairs according to Scope of Work (CWo). This paper presents a new methodology for improving TAM scheduling of oil and gas plants. The methodology includes four stages: removing non-critical equipment from TAM list CWo to routine maintenance plan, risk based inspection of Critical Static Equipment (CSE), risk based failure of Critical Rotating Equipment (CRE), and application of probability distributions. The results from improving TAM scheduling is associated with decreasing duration and increasing interval of TAM leading to improved availability, reliability, operation and maintenance costs and safety risks. The paper presents initial findings from the TAM model application. This methodology is fairly generic in its approach and can also be adapted for implementation in other oil and gas industries.**

Index Terms - **Turnaround Maintenance (TAM) Scheduling, Risk Assessment, Fault Tree Analysis (FTA), Weibull Distribution, and Oil and Gas industry.**

ACRONYMS

CRE	Critical Rotating Equipment.
CSE	Critical Static Equipment.
CWo	Scope of Work
FTA	Fault Tree Analysis
MTBF	Mean Time between Failures
MTTR	Mean Time to Repair.
RBF	Risk Based Failure
RBI	Risk Based Inspection
TAM	Turnaround Maintenance

NOTATIONS

β, $\boldsymbol{\eta}$	Shape and Scale parameters.
h(t)	Hazard Rate.
R(t)	Reliability Function with time (t).

I. INTRODUCTION

TAM is a philosophy for the total shutdown of plant facilities for a certain time to carry out maintenance activities associated with inspection, replacement and repair according to CWo. TAM of oil and gas plants consists of several types of equipment and complex systems that operate under continuous harsh conditions of high pressures and fluctuating temperatures. It has been implemented differently from company to company due to variable factors: economic aspects, geographical conditions, process configurations and external markets. Sahoo [1] indicated that the philosophy of TAM is to have a scheduled shutdown of the plant to minimize downtime and maximize efficiency of the plant. Milana et al [2] have stated that decreasing downtime of equipment leads to increasing productivity and improving reliability of equipment. Thus, TAM can be defined as an entire shutdown of plant facilities in order to maintain the equipment (resulting in the inspection, disassembly and renewal). Neikirk [3] and Duffuaa et al [4] also defined TAM as a periodic shutdown of the plant to conduct modifications, inspections, repairs and replacements.

Oil and gas plants consist of several pieces of equipment and complex processes that continuously operate under rigorous conditions. Therefore, those plants require shutdown every few years for inspection and maintenance to avoid consequences of failure resulting from the system aging, corrosion, pressure, and fatigue that can result in generation of fire and blast, toxic material release and the environmental pollution. Plant shutdown is one of the maintenance strategies used in industrial plants. This can be divided into planned shutdowns which includes TAM, and unforeseen shutdown which is classified into plannable and unplannable shutdown. Levitt [5] and Utne et al [6] stated that planned and unforeseen shutdowns of process plant are major maintenance activities which required the biggest financial supports.

In order to improve TAM, Krings [7], Oliver [8], Mclay [9], and Williams [10] stated that successful TAM depended on planning in the long term to control budget, time and scheduling. Motylenski [11] presented several methods of successful practices that were applied in planning and execution phases for reducing cost and downtime of TAM. Ertl [12] identified the duration of TAM, cost of TAM and risk management as key factors for its success.

Fig 1 shows the main phases of cycle life of TAM, which can be classified as: planning, preparation, execution and termination. Duffuaa et al [4], Duffuaa and Ben-Daya [13], Lenahan [14] and Levitt [5] discussed these phases. However, focused on the execution phase of TAM from management perspective. Brown [15] focused on the planning and executing phases of TAM. Therefore, these studies did not cover the important aspects associated with the interval of TAM in order to improve reliability and availability of a plant. Hadidi and Khater [16] presented three other TAM phases: pre-turnaround, execution, and post-turnaround phase of TAM.

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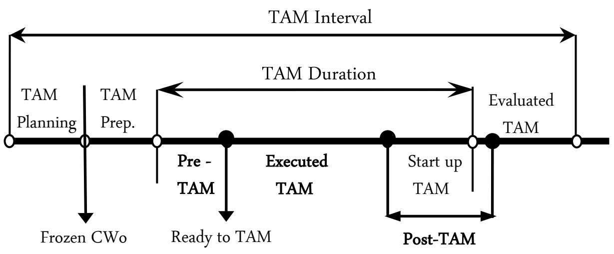

Fig.1. Cycle Life of TAM

Tan and Kramer [17] stated that a typical refinery sometimes needed ten days per a year of shutdown with an estimated loss between $20,000 and $30,000 per hour due to the plant being offline. Halib et al [18] discussed some of the organizational aspects of TAM management for the Malaysian petrochemical companies. They found that the average of the planning duration of TAM was 15 months for some oil companies (1.5 months as a minimum and 36 months as a maximum of planning duration for some oil companies). Halib et al [18] identified 15 of petrochemical companies, refineries and natural gas plants that carried out their TAM activities once every three years, and 8 companies executed their TAM activities once every five years. Lawrence [19] reported that all the processing plants such as refinery and petrochemical plants that operate continuously and under extreme conditions must be shutdown every few years to achieve TAM functions. Obiajunwa [20] also reported that a TAM interval of petrochemical and refinery plants was planned every two years, and TAM interval of the power plant was planned every four years. However, Obiajunwa [20] stated that duration of TAM was a very difficult to estimate.

Dyke [21] suggested many steps for improving TAM performances of refinery process using industry best practice model and specialist expertise that enabled consistent management, planning and execution of TAM as well as the use of benchmarking technique to measure performance of TAM that included duration and interval of each major process units. Krishnasamy et al [22] proposed a risk – based maintenance (RBM) strategy of a power plant that aims for developing optimization of inspection and maintenance program by integrating a reliability approach with a risk assessment strategy. Lenahan [23] identified critical activities in an attempt to prolong TAM interval of static equipment from two years to four years. This study resulted in a positive rise in the production. Elfeituri and Elemnifi [24] described moving redundant equipment from turnaround scope of work to routine maintenance in order for increasing interval and decreasing duration of refinery plant TAM using risk based inspection application. Ghosh and Rao [25] proposed optimization of the maintenance intervals using the reliability based on cost/benefit ratio. Rusin and Wojaczek [26] presented optimizing maintenance intervals of power machines by taking the risk into account. Emiris [27] highlighted the challenges encountered in development of TAM using project management office (PMO) based on high cost, short duration, risk, and scope of work according to the standards recommended by the Project Management Institute.

Obiajunwa [28] suggested determining the factors affecting TAM implementation failures and develop a framework to guide plants against failures. Obiajunwa [20] also established a best practice framework to manage a CWo in terms of cost, work pattern, duration, and human and materials resources due to fluctuation and changes of CWo during execution of TAM. The study concluded that the framework would become best practice guide for six multinational process plants in the UK. However, Duffuaa and Ben Daya [13] suggested a structured approach and guideline for all phases of TAM management (initiation, planning, execution and termination phases) of the petrochemical plants. This would then enable it to become a comprehensive manual to help planners and engineers in the CWo activities and make conducting of TAM more cost effective, consistent and efficient.

Khan and Haddara [29] proposed a quantitative methodology for risk based maintenance, which consists of risk estimation module, risk evaluation module, and maintenance planning module by integrating Weibull Distribution with safety and environmental consequences and to use it as a decision tool for P.M planning. Hameed and Khan [30] also proposed a framework to estimate the risk-based shutdown interval to extend intervals between shutdowns for oil and gas plants. This study focused on static equipment associated with heat exchangers to estimate interval of TAM from the risk perspective.

There are only a few studies that are associated with improving TAM scheduling of oil and gas plants. Therefore, most cited studies have focused on estimating interval of shutdown for individual equipment without interest in the improvement of duration of TAM. In addition, some studies have not taken applications of reliability models into consideration, especially for oil and gas plants maintenance that involve high risk and serious consequences due to undesirable failures. This study will present a new methodology for improving TAM scheduling associated with decreasing duration and increasing interval of TAM by removing non-critical equipment (NCE) from TAM list, Risk Based Inspection (RBI), Risk Based Failure (RBF), and applications of reliability approach in order to improve the availability and reliability of the oil and gas plants.

II. METHODOLOGY OF TAM SCHEDULING

Fig 2 illustrates the new methodology for improving TAM scheduling that is associated with decreasing duration and increasing interval of TAM of oil and gas plant. This study has been designed to bridge the existing gap in the literature review and field of experience in order to provide an improved methodology that can be implemented in oil and gas plants. The new methodology can be broken down into four stages, as shown in Fig 2.

Stage I. Removing Non-critical Equipment (NCE) from TAM list to Routine Maintenance.

- The first process commences with identifying the layout of plant that is being studied.
- Separate Static Equipment (SE) and Rotating Equipment (RE), as shown in Table I.

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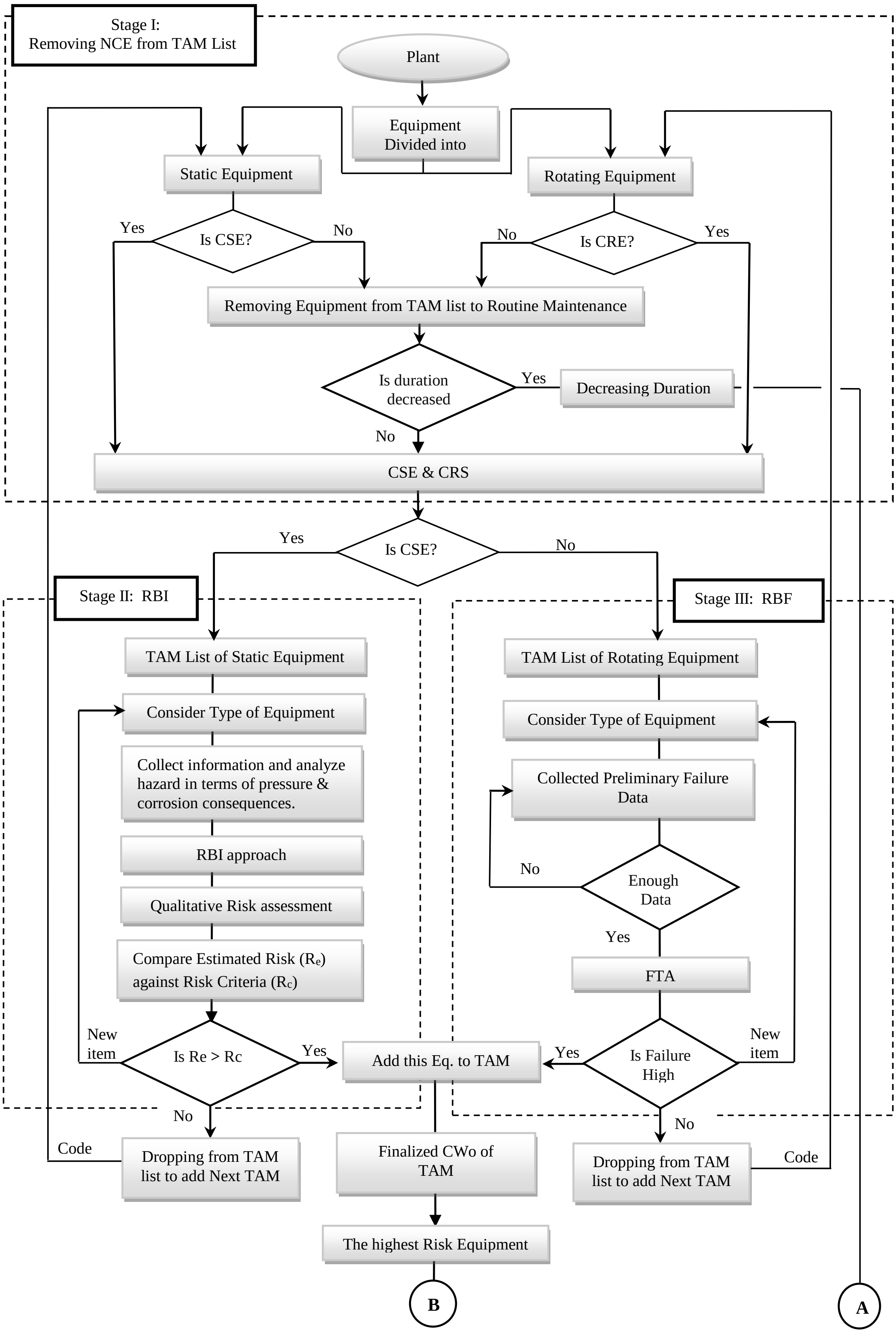
Stage I:
Removing NCE from TAM List
Plant
Equipment
Divided into
Static Equipment
Rotating Equipment
Yes
Is CSE?
No
No
Is CRE?
Yes
Removing Equipment from TAM list to Routine Maintenance
Is duration decreased
Yes
Decreasing Duration
No
CSE & CRS
Yes
Is CSE?
No
Stage II: RBI
Stage III: RBF
TAM List of Static Equipment
Consider Type of Equipment
Collect information and analyze hazard in terms of pressure & corrosion consequences.
RBI approach
Qualitative Risk assessment
Compare Estimated Risk (Re) against Risk Criteria (Rc)
New item
Is Re > Rc
Yes
No
Code
Dropping from TAM list to add Next TAM
TAM List of Rotating Equipment
Consider Type of Equipment
Collected Preliminary Failure Data
No
Enough Data
Yes
FTA
Yes
Is Failure High
New item
No
Add this Eq. to TAM
Finalized CWo of TAM
The highest Risk Equipment
Dropping from TAM list to add Next TAM
Code
B
A

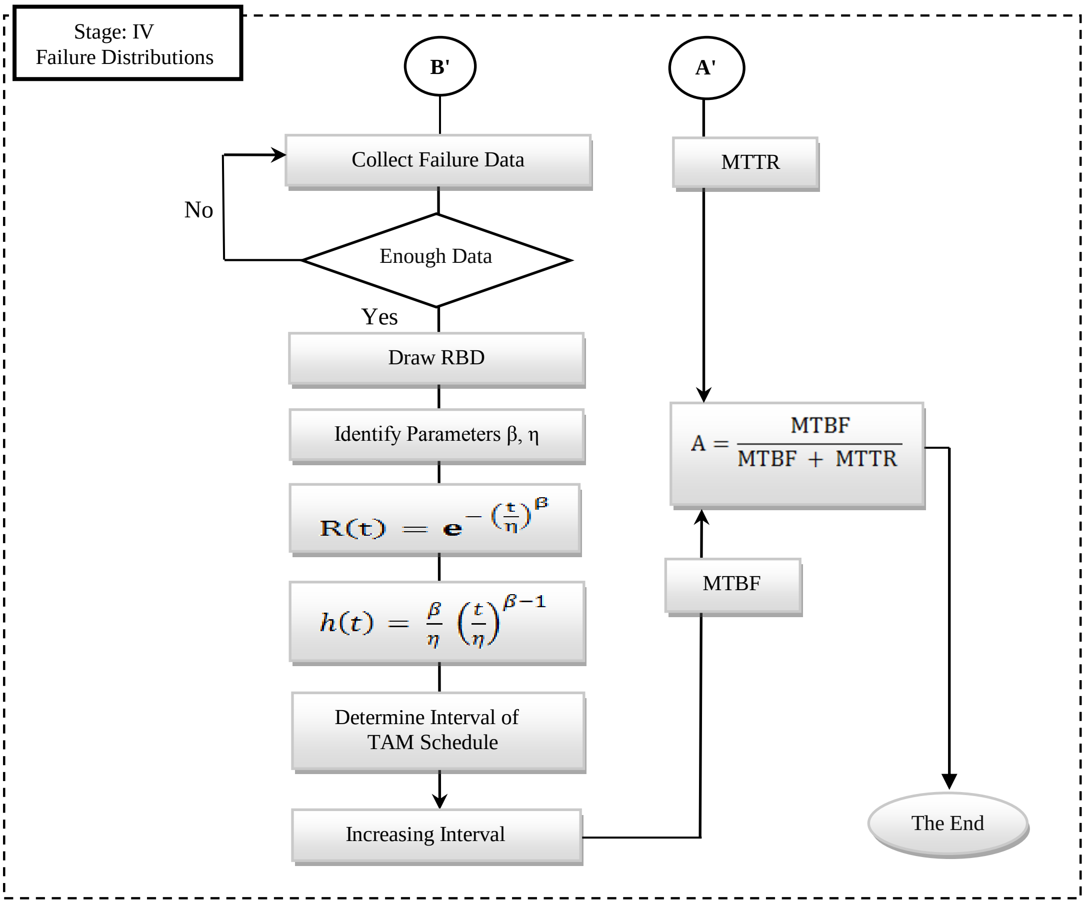

Fig. 2. Methodology for an Improved TAM Scheduling

TABLE I
Types of Selected Equipment in the Oil and Gas Plants

SE Code	SE Types	RE Code	SE Types
L36	Pipelines	PM20	Pumps (V & H)
D501	Vessels (Drums)	T03	Turbines
T301	Vessels (Tower)	C22	Air Compressors
E102	Heat Exchanger	CO10	Air Coolers
V203	Safety Valves	B402	Boilers
TK101	Tanks	M101	Motors
Total		Total	

- Classify SE into Critical Static Equipment (CSE) and Non-critical Static Equipment (NSE); also categorize Rotating Equipment (RE) into Critical Rotating Equipment (CRE) and non-Critical Rotating Equipment (NRE).
- Use taxonomy code (ID of equipment) according to records and documents authorized by company specification. These codes identify the type, design of equipment and the area the equipment belongs for identifying target equipment.
- Remove Non-critical Equipment from TAM to Routine Maintenance.

This Stage I contains a precise description of each static and rotating equipment for removing non-critical static and rotating equipment' that can be maintained and inspected without the need to shutdown the plant; furthermore, these redundant rotating equipment pieces are removed from CWo's of TAM to combine as part of routine maintenance plan in order to decrease duration and increase interval of TAM. To achieve this, the following, also needs to be considered: advice of static maintenance team, rotating maintenance team and operation team, failures and maintenance records and layout of the plant. However, there are some pieces of rotating equipment such as turbines and compressors that require long time period, specialized team and major maintenance activities for their maintenance, therefore these equipment need to be included into CWo for inspection and maintenance during the TAM duration. Consequently, these critical static equipment are moved to Stage II to apply the risk assessment approach and CRE are moved Stage III to apply the Fault Tree Analysis (FTA) technique. FTA can be defined as a logical network to analyze processes of engineering systems and translate the failure behavior of complex system into a structured logic diagram (called a Fault Tree) to identify specific causes that can lead to an undesired event (called the top event).

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Stage II: Risk-Based Inspection (RBI)

Risk based approach has played an important role in decision-making process for optimizing maintenance strategy [31]. This stage is associated with applying RBI on the static equipment pieces for selecting the highest risk equipment pieces in order to add to TAM list, and drop equipment pieces that exhibit the lowest the risk from the TAM list. Therefore, equipment pieces that have the highest risk should be taken into account due to their major impact on humans, asset of company, environment, time and finances.

It is necessary to highlight each unit that may affect the functionality of the plant in terms of corrosion rate, pressure factor and fluctuating temperatures. To achieve this, the proposed RBI approach determines estimated risks and compares against risk criteria in order to select a higher static equipment risk according to consequences of failure resulting from failure causing factors mentioned earlier (and their impacts).

This cycle is continued for each of the equipment until the whole plant is analyzed. The result of qualitative risk assessment is identified for the equipment which has the highest risks and the largest consequences on the company and its environment.

A qualitative risk assessment matrix (5x5) consists of two categories: Probability of Failure (PoF) and Consequences of Failure (CoF). It is proposed to rank and assess risk of CSE, which cannot be maintained or inspected if the plant is running. This type of static equipment includes vessels, heat exchangers safety valves and pipelines, which can be arranged in series, parallel or both series/parallel configurations.

Stage III: Risk-Based Failure (RBF)

This Stage III is related to identifying critical component/equipment and paths that cause failures of rotating equipment, which cannot be maintained or repaired during normal operations such as turbines and compressors. In addition, the highest risk equipment need to be identified that can hinder the plant performance in terms of operability, reliability and availability of the system and financial effects such as production losses and lost revenue due to unplanned shutdown. Therefore, in this stage, it is proposed that Risk Based Failure (RBF) using FTA as a deductive technique is applied to identify the causal relationships which can lead to a specified system failure mode in order to determine critical components and paths of each rotating equipment or a critical component that can be a considerable risk on the plant functional and its performance. This stage consists of three parts as follows:

A. Preliminary Data

This part is the most important in RBF approach for identifying equipment that can have a high impact on the plant performance. This stage also covers the collection of preliminary failure data: record of failure of each equipment and interviews with the maintenance and operation team. This will identify undesirable events and sub-events for system component interaction and provide the foundation for constructing a Fault Tree (FT).

B. Fault tree construction

FT construction may be a complicated process and needs time, especially oil and gas equipment that consist of several components/sub-events. The FT construction commences from the top (high level) event and thereafter in a descending order until the bottom (low level) basic events are covered; each of these events are connected by gates with identified failure logic until a complete FT is constructed.

C. Qualitative Fault Tree Analysis (FTA)

This part is dependent on the information that is collected by constructing the FT. The purpose of FT qualitative analysis is to determine minimal cut sets using MOCUS algorithm and Boolean algebra [32], which is the key aspect for identifying critical component's failure that can cause an unexpected system shutdown, lost production and revenue, and other losses to the system.

Stage IV: Failure distributions

This Stage IV is based on the outcome of Stages II & III that are associated with risk effects of static and rotating equipment on human, structure of plant and environment for TAM list. Therefore, statistical distributions are applied to determine optimum interval of TAM using MATLAB program that models the Weibull distribution behavior. The proposed Weibull distribution can simulate the behavior of other distributions based on the values of the shape and scale parameters (β, $\boldsymbol{\eta}$) that are estimated from the failure data and derived reliability of the equipment involved in the system. O'Connor and Kleyner [33] reported that reliability and hazard rate functions of equipment during time (t) following the Weibull distribution can be expressed as:

$$R(t) = \mathbf{e}^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad \text{-------------------- (1)}$$

$$h(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \quad \text{------------------- (2)}$$

III. THE APPLICATION OF TAM SCHEDULING TO A GAS PLANT

The above methodology is applied to facilities and units of oil and gas plant to minimize downtime and maximize uptime in order to achieve maximum availability of the plant and to reduce operation and maintenance costs and avoid all forms of risks resulting from loss of production in LNG, LPG, Naphtha and petrochemical products due to increasing shutdown time, and unforeseen shutdown. Applying this new methodology can also be led to more interest in on-line maintenance for equipment that can be maintained or repaired during normal operations in order to enhance decreasing duration of TAM.

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IV. Future Work

The future work will be focused on preparation of the TAM model for verification and validation in a real environment of the oil and gas plant and other processing plants that are operated continuously.

V. Conclusion

This paper has presented a new methodology for improving TAM scheduling in oil and gas plants. The novelty of this methodology includes four stages:

- Identifying and removing Non-Critical Equipment (NCE) from TAM activities to routine maintenance plan,
- Applying RBI on static equipment parts using risk assessment,
- Applying RBF on rotating equipment using FTA, and
- Applying probability distributions using Weibull distribution.

The implementation of the new methodology in oil and gas plant can result in minimizing downtime which is associated with duration of TAM, and maximizing uptime that is related to interval of TAM in order to improve availability and reliability of a plant. In addition to reducing costs of TAM, the new approach also takes into account the level of risk. Thus, this methodology can be implemented with equipment that cannot be maintained or inspected during normal operation of plant and that is operated under extreme operating pressures, high corrosion rate, and other failures that can result in large financial losses.

The future work will focus on the implementation of the TAM model in real industrial (oil and gas) environments in order to ascertain the effectiveness of the new approach.

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