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A New Methodology to Optimize Turnaround Maintenance (TAM) Scheduling for Gas Plants

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Abstract Time, cost and risk are the main elements that effect the operating margin of the oil and gas companies due to Turnaround Maintenance (TAM). Turnaround Maintenance (TAM) is a methodology for the total shutdown of plant facilities during a pre-defined period to execute inspection actions, replacement and repairs according to Scope of Work (SoW). This paper presents a new methodology for improving TAM scheduling of oil and gas plants. The methodology includes four stages: removing Non-critical Equipment (NE) from reactive maintenance to proactive maintenance, risk-based inspection of Critical Static Equipment (CSE), risk-based failure of Critical Rotating Equipment (CRE), and application of failure distributions. The results from improving TAM scheduling is associated with decreasing duration and increasing interval between TAM leading to improved availability, reliability, operation and maintenance costs and safety risks. The paper presents findings from the TAM model application. The methodology is fairly generic in its approach and can also be adapted for implementation in other oil and gas industries that operate under similar harsh conditions.

Keywords: Turnaround Maintenance (TAM) Scheduling, Risk Assessment, Fault Tree Analysis (FTA), Weibull Distribution, Gas Plants.

1. INTRODUCTION

TAM is the major maintenance activity of plant facilities for most oil, gas, and refinery plants. This activity is considered expensive in terms of costs and time resulting from plant downtime and the actual cost of the TAM. TAM of processing plants depends on several equipment pieces 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 various factors: economic aspects, geographical conditions, process configurations and external markets. Sahoo [1] stated that TAM is a philosophy of scheduling shutdown of the plant to minimize downtime and maximize efficiency of the plant. Milana et al. [2] and Aldairi et al. [3] reported that decreasing downtime of equipment leads to increased productivity and reliability of equipment. Thus, TAM can be defined as an entire shutdown of production in order to inspect and maintain the equipment (resulting in the inspection, disassembly and renewal) which affects operation process. Neikirk [4] and Duffuaa et al. [5] also defined TAM as a periodic shutdown of the plant facilities to implement inspections, maintenance, repairs, and replacements activities.

Gas plants consist of numerous pieces of equipment and complex processes that continuously operate under rigorous conditions. Therefore, these plants need to shut down every few years to inspect, maintain and to avoid accelerating damage due to erosion, corrosion, pressure, and fatigue that can result in generation of fire and blast, toxic material release and the environmental pollution. Shutdown can be divided into planned and unplanned shutdowns. Planned shutdown is TAM, in here as unplanned shutdown includes an expected and unexpected shutdown Elwefalli [6]. Levitt [7] and Utne et al. [8] stated that shutdown can be divided into planned and unforeseen shutdowns of process plant that consider are major maintenance activities in which require the biggest financial supports.

TAM strategy depends on cycle life of the TAM that includes four-phases. Fig. 1 shows the main phases of life cycle of TAM which can be classified as: planning, preparation, execution and termination. Duffuaa et al. [5], Duffuaa and Ben-Daya [9], Lenahan [10] and Levitt [7] discussed these phases. Brown [11] 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 [12] presented three other TAM phases: pre-turnaround, execution, and post-turnaround phase of TAM.

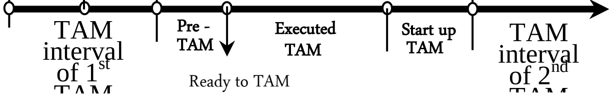

Fig.1. Life cycle of TAM

In order to improve TAM, Krings [13] and Williams [14] reported that successful TAM depends on planning in the long term to control budget, time and scheduling. Motylenski [15] presented several methods of successful practices that were applied in planning and execution phases for reducing cost and downtime of TAM. Ertl [16] identified the duration of TAM, cost of TAM and risk management as key factors for its success.

Tan and Kramer [17] stated that a typical refinery sometimes needs ten days every a year to conduct TAM activities 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] indicated 15 plants (petrochemical, refinery and natural gas) that carried out their TAM activities once every three years, and 8 plants executed their TAM activities once every five years. Lawrence [19] reported that all the processing plants such as refinery and petrochemical plants that run continuously under extreme conditions must be stopped every few years to achieve desired performance of TAM functions. Obiajunwa [20] also reported that a TAM interval of petrochemical and refinery plants were planned every two years, and TAM interval of the power plant was planned every four years. However, Obiajunwa [20] stated that the duration of TAM considers a very difficult to estimate due to complex operation process.

There are many steps to improve the 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. Lenahan (2006) identified critical activities of processing plant associated with static equipment pieces in order to extend shutdown interval from 2 years to 4 years. This study led to a positive increased the production. Elfeituri and Elemnifi [22] described removing redundant equipment from TAM activity to routine maintenance in order to decrease the duration and increase interval of TAM of a refinery plant using RBI approach. Ghosh and Rao [23] presented optimizing maintenance intervals using the reliability based on cost/benefit ratio. Emiris [24] 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 [20] determined the factors affecting of TAM implementation and developed a framework to guide plants against failures in which accompany TAM. Obiajunwa [20] also established a best practice framework to manage a SoW in terms of cost, work pattern, duration, and human and materials resources due to fluctuation and changes of SoW during execution phase 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 [9] suggested a structured approach and guideline for 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 support planners and engineers in the SoW activities and make conducting of TAM more cost-effective and efficient.

There are other studies proposed a risk – based maintenance (RBM) strategy to optimize inspection and maintenance program by integrating a reliability approach with a risk assessment strategy. The methodology of Risk-Based Maintenance (RBM) comprises of risk estimation, risk evaluation, and maintenance planning module by integrating Weibull distribution to safety and environmental consequences, and to use it as a decision tool in order for planning of preventive maintenance. Hameed and Khan [25] proposed a framework to identify shutdown interval using the risk-based shutdown interval in order to prolong intervals between TAM periods of processing plants. However, This study focused on heat exchangers to identify interval of TAM from the risk perspective.

A few studies are associated with improving TAM scheduling of processing plants. Therefore, most cited studies focused on estimating interval of shutdown of individual equipment without achieving any improvements for duration of TAM. Moreover, some studies have not taken applications of reliability models into account, especially for oil and gas plants maintenance that involve high risk and serious consequences due to undesirable failures. However, this study will present a new methodology for improving TAM scheduling associated with decreasing duration and increasing interval of TAM by moving Non-Critical Equipment (NCE) from TAM to proactive maintenance, applying Risk-Based Inspection (RBI), applying Risk-Based Failure (RBF), and applications of failure distributions in order to improve a desired performance of the availability, maintainability and reliability of the processing plants.

2. TAM Scheduling Methodology

Fig. 2, 3 and 4 show the new methodology to improve the TAM scheduling that are associated with decreasing duration and increasing interval of TAM of oil and gas plant. This paper has designed to close the existing gap in the literature review and field of experience in order to provide an improved methodology that can be implemented in gas plants. The new methodology is divided into four stages.

2.1. *Stage one: Removing (NCE) from TAM list to Routine Maintenance*

The Stage one of the TAM model aims to remove specific pieces of equipment from reactive to proactive maintenance. The main philosophy of Stage one is the determination of downtime associated with the TAM duration. This stage includes:

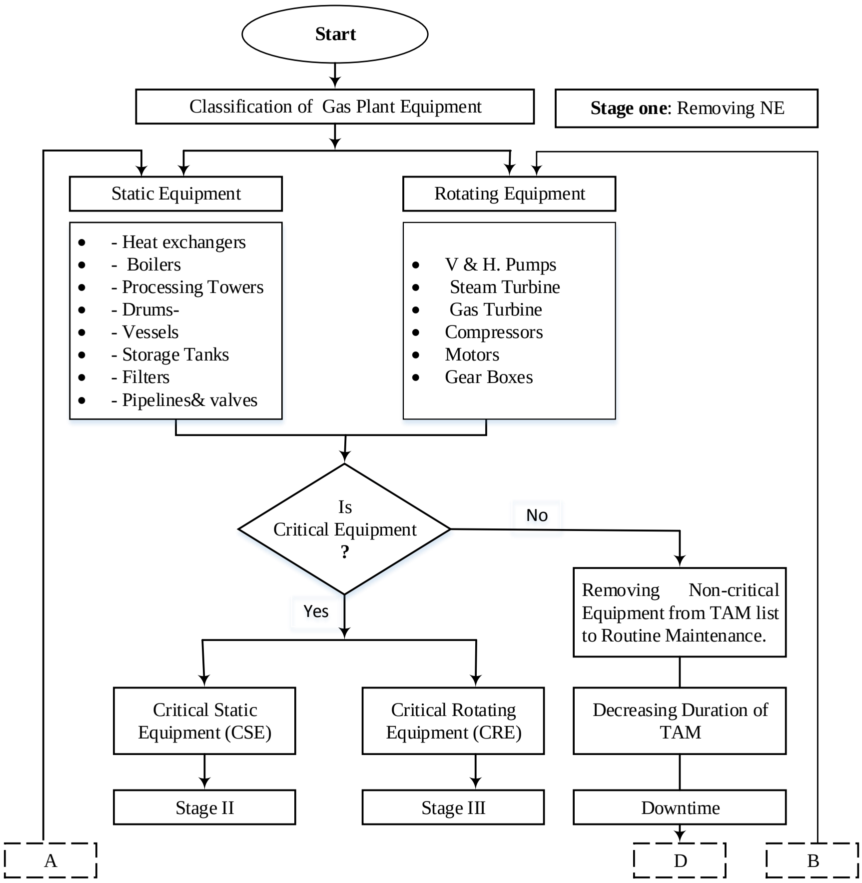

Fig. 2. Stage one of the new methodology for removing NCE (based on Elwerfalli, et al. [6])

- Separation of Static Equipment (SE) and Rotating Equipment (RE), as given in Fig .2.
- Classification of static equipment into Critical Static Equipment (CSE) and Non-critical Static Equipment (NSE), and then categorization Rotating Equipment into Critical Rotating Equipment (CRE) and Non-critical Rotating Equipment (NRE).
- The Stage one is characterized by the application of techniques to remove NSE and NRE from TAM activity to maintain as a part of routine maintenance plan, as illustrated in Fig .2.

This stage involves a precise description of each static and rotating equipment for moving NSE to proactive maintenance that can be inspected and maintained without the need to total shutdown of the plant; furthermore, removing redundant rotating equipment pieces from SoW of TAM to combine as part of proactive 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 SoW in order to inspect and maintain 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).

2.2. *Stage two: Risk-Based Inspection (RBI)*

Most oil and gas plant designed based on the RBI to reduce consequences of risk. Therefore, risk based approach has played an important role in decision-making process for optimizing maintenance strategy. 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.

RBI is approach that use to evaluate the PoF and CoF of each equipment and develops inspection approaches that can effectively reduce risks that affect the gas plant technology in terms of the corrosion phenomenon, burst pressure and fluctuating temperatures. To achieve this, the proposed RBI determines estimated risk (R_e) and compares this against risk criteria (R_c) in order to identify the highest risk of static equipment according to probability and consequences of failure resulting from failure causes and their impacts, as given in Fig .3.

This cycle is continued for each equipment of the plant. The result of risk assessment is identified for the equipment which has the highest risks and the largest consequences on the plant/company and environment issues, should be added to the current TAM, to be considered in Stage four.

A risk assessment matrix (5x5) is created which includes two categories: Probability of Failure (PoF) and Consequences of Failure (CoF). It is proposed to rank and assess risk of CSE which cannot be inspected and maintained during normal operation of the plant. This CSE includes several horizontal and vertical vessels, heat exchangers, safety valves and pipelines, which can be arranged in series, parallel or both series/parallel configurations.

2.3. *Stage three: Risk-Based Failure (RBF)*

The Stage three 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 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:

2.3.1. *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).

2.3.2. *Fault Tree (FT) Construction*

FT construction may be a complicated process and needs time, especially oil and gas equipment pieces that consist of many 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.

2.3.3. *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, 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.

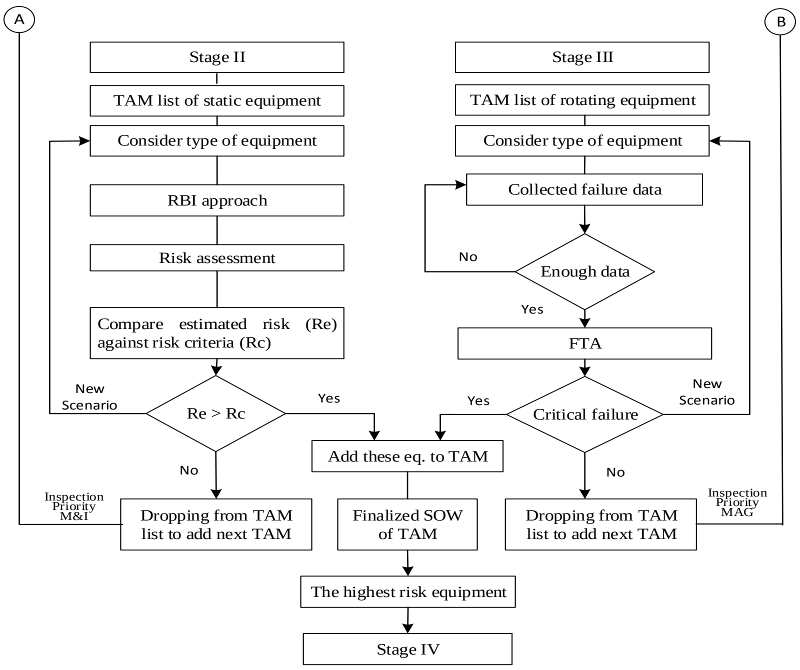

Fig. 3. Stage two and three of the new methodology for applying RBI and RBF (based on [6]).

2.4. *Stage four: Failure distributions*

Application of probability distributions to identify interval of TAM for each critical equipment resulting from Stage two and three associated with risk effects of static and rotating equipment on human, structure of plant and environment. The Weibull distribution can be utilized to identify the optimal interval of gas plants (uptime) as shown in Fig. 4 to avoid any unexpected shutdowns of the plant due to the indiscriminate estimation of TAM interval.

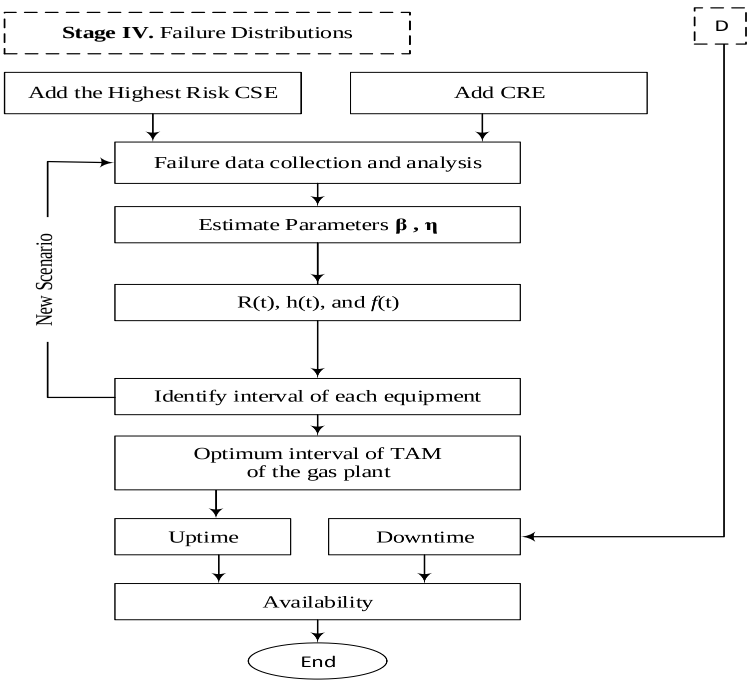

Fig. 4. Stage 4 of the new methodology for applying failure distributions. (based on [6]).

The application of the Weibull distribution can simulate the behavior of other distributions based on the values of the shape and scale parameters (β, $\boldsymbol{\eta}$), which are be estimated from failure data and derived reliability of the equipment involved in the system. The reliability R(t), Hazard Rate h(t), and Probability density function *f*(t) of equipment during time (t) following the Weibull distribution can be expressed as:

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

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

where,

β, η Shape and Scale parameters.
h(t) Hazard Rate.
R(t) Reliability Function with time (t).
f(t) Probability density function [R(t).h(t)]

3. The Application of TAM Scheduling to a Gas Plant

The above methodology is applied to facilities and units of a 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 lead 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 the TAM.

4. Results

4.1. *Decreasing Duration of the TAM*

Removing these equipment pieces from TAM list can reduce the workload associated with efforts of maintenance team, hours of work, decreased downtime and increased uptime of the plant, minimized the cost of the TAM maintenance and inspection (to a level of less than $2 million during 21 shutdown days). Therefore, TAM activities of the gas plant can be carried out between 21 and 24 days, compared to TAM of the gas plant of SOC – 2006, 2008 and 2010. Execution of TAM duration during 24 days rather than 30 days leads to decreased costs spending on the maintenance and inspection to $2 million at most, and lost production that may exceed 100,000 per day.

4.2. *Increasing Interval of the TAM*

Based on equipment pieces that were extracted of the Stage one to be considered in the Stage two and three in order to identify equipment pieces that represent the highest risk in terms of inspection and failure, respectively, then apply Stage four to identify interval of TAM for these pieces that include 6 series configuration of heat exchangers, 2 HP drums, 2 processing columns, 26" - Steam Header Line, and 4 pieces of rotating equipment as shown in Table 1. This Table shows that 1020 days is considered as an optimum interval between the TAM periods in order to address any a high risk event which may cause an increasing probability and consequences of failure. Therefore, the plant should be totally shut down after 24500 operational hours to greatly reduce the TAM costs and avoid any threats that may be caused in the production losses, damage of company assets and the environment.

Table 1. Optimum interval of the TAM of the gas plant.

Equipment	Stage 1		Stage 2		Stage 3		Stage 4				TAM (day)
	In	Out	In	Out	In	Out	In	R(t)	h(t)	*f*(t)	
Heat Exch.	81	63	18	12			6	0.57	5E-5	3E-5	1020
HP Drums	36	4	32	30			2	0.45	5E-5	2E-5	3063
Columns	16	0	16	14			2	0.42	7E-5	3E-5	3129
Pipelines	91	56	35	2 Line			1	0.4	6E-5	2E-5	4729
Rotating	118	114			4						

Consequently, it is necessary to avoid such high risks, the plant availability should be kept under two elements: decreasing duration and increasing interval of the TAM as shown in Table 2 within allocated budget of TAM and risk criterion.

Table 2. Improving availability and cost of the gas plant.

Year	Duration (days) MTTR	Interval (days) MTTF	Availability	TAM Cost ($)	TAM Cost (%)
2002	30	365	0.9178	2.50 million	100%
2003	30	365	0.9178	2.45 million	98%
2004	30	365	0.9178	2.70 million	108%
2006	45	730	0.9384	3.00 million	120%
2008	30	730	0.9589	2.47 million	99%
2010 Current	30	730	0.9589	2.87 million	115%
Suggested	21-24	1020	0.977-0.9798	< 2 million	< 100%

The current availability of gas plant of year 2010 was 95.89%. However, with decreasing duration of TAM to 24 days, and increasing interval of TAM to 1020 days (rather than 730 days) demonstrated great improvements in availability of the plant, achieves to 97.7 - 97.98% availability rather than 95.89%, without any threat to the plant performance.

5. Conclusions and Future Work

This paper has presented a new methodology to improve TAM scheduling of the gas plants. The novelty of this methodology includes four stages:

- Identifying and removing Non-Critical Equipment (NCE) from reactive to proactive maintenance to decrease the TAM duration of the plant,
- Applying RBI on the CSE pieces,
- Applying RBF on the CSE pieces, and
- Applying probability distributions of CE.

The implementation of the new methodology in gas plant can result in minimizing downtime which is associated with duration of TAM, and maximizing uptime that is related to the 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 the processing plant and that is operated under extreme operating pressures, high corrosion rate, and other failures that can result in large financial losses.

The study also demonstrated that the static equipment is the most critical for the interval of the TAM of the gas plant, especially heat exchangers that represent the high risk items in terms of the production, plant assets, and environment issues.

The future work will highlight the validation of the TAM model in a real environment associated with oil and gas industries that operated under harsh conditions in order to ascertain the effectiveness of the new approach.

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