

The contribution of maintenance to improve the operational performance of an industrial process

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Abstract

In the petroleum industry, equipments must be maintained properly to meet the adequate reliability standards in order to achieve the desired business goals in terms of productivity, safety and environmental protection. This article offers a new approach focused on risk analysis to select a better maintenance strategy. The proposed approach consists of three stages. In the first step, we identify the accident scenarios that could lead to the loss of production and damage to the environment. In the second step, we estimate the frequency of occurrence of these scenarios. In the third step, we calculate the economic losses and environmental taxes. Finally, an appropriate maintenance strategy is proposed, taking into account the evaluation results obtained by the previous steps. A case study illustrates the proposed approach and shows that the latter constitutes an important decision support tool to improve the existing maintenance strategy to comply with regulations and standards in term of productivity, reduction of costs and environmental protection.

Keywords

Maintenance strategy, industrial process, environmental protection, risk based maintenance, importance analysis.

1. Introduction

The role of the oil sector in the national economy is essential. However, when oil installations fail, the consequences can be dramatic. They can cause serious economic losses, affect the population and cause serious damage to the environment.

In fact, Algeria has experienced in recent years a series of painful events affecting the majority of cities and which have revealed the extent of the problem of risks related to the hydrocarbon sector, such as: the explosion of the petrochemical complex of Skikda in January 2004 which caused 23 deaths and 74 injured, the Nezla well accident in September 2006 at the drilling platform in Gassi Touil (Hassi Messaoud) which caused 09 deaths and 78 people were injured and Loss of the drilling rig costing 4 million dollars and two bursts followed by fires on the gas pipeline in Relizane in August 2008 which caused injuries and material damage to local populations.

The efficient operation of these installations depends on the proper functioning of the maintenance management system which ensures the optimum availability of the installations, reduces the direct costs of intervention and the indirect costs incurred and ensures better safety of people, equipment and the environment and finally the achievement of the desired business objectives (Karsak, 2001), (Zhao *et al*, 2020), (Hammati *et al*, 2018).

From the 1990's, Risk Based Maintenance (RBM) received an increasing attention from researchers (Wang *et al*, 2012; Khan and Haddara, 2003; Selvikand Aven, 2011; Fereshthet *et al*, 2014; Chandima Ratnayake and Katarzyna^{a, b}, 2017; Lopes and Figueiredo, 2020). Khan and Haddara (Khan and Haddara, 2003) proposed a comprehensive framework for Risk Based Maintenance strategy, in which the probability of the accidental event was determined using Fault Tree Analysis (FTA) and the consequences involved the estimation of system performance loss, financial loss, loss of human health and environmental and / or ecological loss.

Arunraj and Maiti (2007) reviewed research on RBM using several qualitative / quantitative risk analysis tools such as Fault Trees, Event Trees, HAZared and OPerability study (HAZOP), Failure Mode, Effects and Criticality Analysis (FMECA), etc.

The present work falls within this perspective and consists in proposing an analytical approach that aims to show the interest and the contribution of a good maintenance strategy in improving the operational performance of industrial processes and this for a better control of industrial risks and their environmental impacts.

To illustrate the proposed approach and show the contribution of maintenance in improving productivity, reducing costs and downtime and protecting the environment, it was applied on gas recovery plant (RGTE-In-Amenas Algeria). The obtained results show the appropriateness of this approach for choosing an adequate maintenance strategy.

2. Risk-based maintenance methodology

Maintenance management based on risk analysis allows the continuous and controlled improvement of processes with an optimal use of the available resources and the detection of the critical operations or activities in these processes.

The proposed approach in this work consists of (Figure 1):

- The first step consists of defining the objectives and the operational requirements of the system or process to be studied, and the collection of information on the structure and operation of the system, through a technical and functional analysis;
- Apply a method to identify accident scenarios relating to the failure of critical functions and / or components that may lead to loss of production and damage to the environment;
- estimate the frequency of occurrence of these scenarios;
- Calculate the economic losses and environmental taxes which can be generated in case of occurrence of these scenarios;
- Calculate the criticality of equipment;
- Finally, propose an appropriate maintenance strategy taking into account the evaluation results obtained by the previous steps.

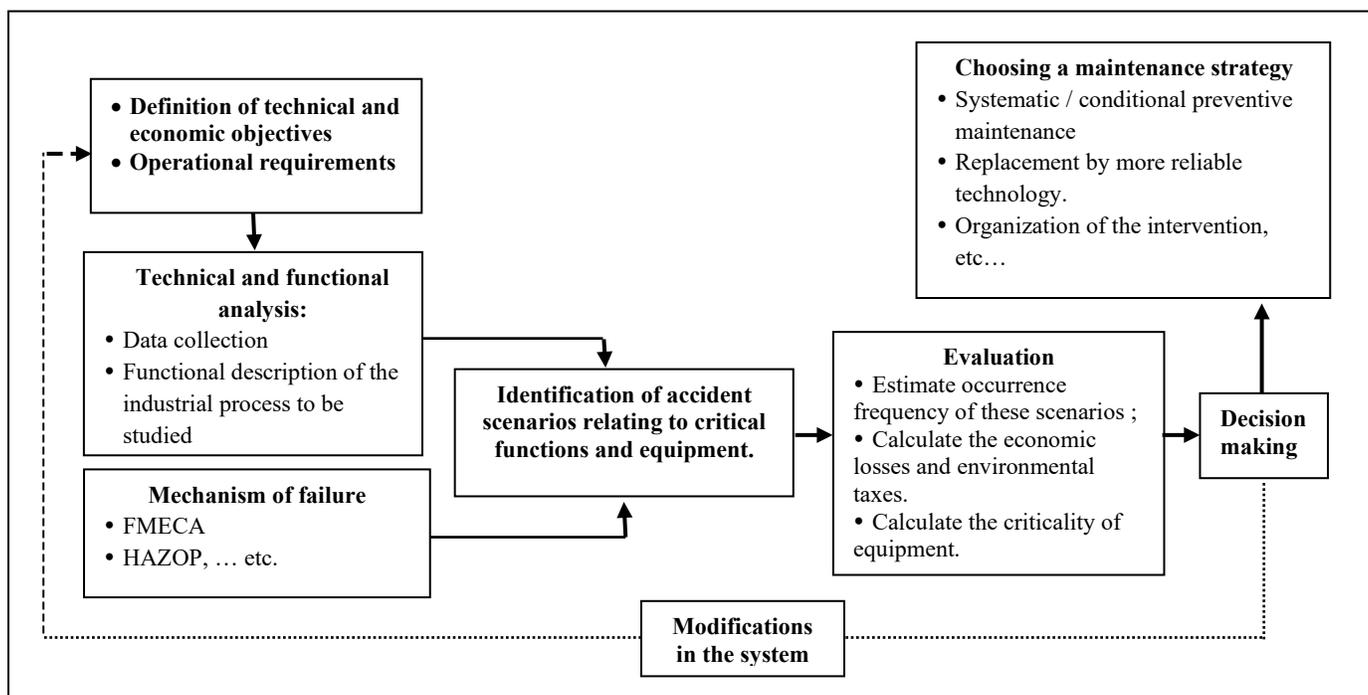


Figure 1. Maintenance management based on risk analysis.

3. Case Study

In order to validate our approach and show the contribution of maintenance in improving the operational performance of an industrial process, it was applied on gas recovery plant (RGTE-In-Amenas Algeria), which was created as part of an environmental protection project and for the reliable exploitation of Hydrocarbon processing facilities (Rudall Blanchard Associates, 2005).

The Objective of this application is to show that an adequate and well established maintenance strategy of a production system doesn't only improve the production and safety, but also contributes to environmental protection.

The RGTE Unit (*Récupération des Gaz Torchés du champ d'Edjelet*) is chosen as a case study, which aims to recover, compress, dehydrate and transport the gases usually flared at the ten (10) crude oil separation centers of the Edjelet field. The recovered gases will be used as *gas-lift* to be injected into oil wells which need activation (by gas-lift) in order to increase the production of crude oil or in certain cases to ensure the stable flow rate in the wells. In addition to the above objectives, the RGTE unit contributes in the reduction of the environmental pollution caused by flaring to comply with the terms of the **GGFR** (Global Gas Flaring Reduction Initiative) to which Algeria is part of it.

The analysis using HAZOP method reveals that the studied process may present several disturbances or deviation of operational parameters such as: drift of gas flow at the inlet and outlet of the blower section, compressor suction and discharge pressure deviation (11-K-001), temperature deviation at the level of the air coolers and the deviation in the liquid level in the separation tank 11-B-001... etc.

To deal with these deviations, the process is equipped with several regulation systems and an emergency shutdown system which, in case of activation, it ensures the automatic and total shutdown of the section to minimize the risk of damage (Figure 2).

In the case of deviation as an example "High liquid level" in the separation tank 11-B-001, the causes are the poor separation of the crude at the level of the upstream separators C7, C8, C9 and C10 or the malfunction of valve 11-LV-001.

Among the consequences of this deviation is the destruction of compressor 11-K-001, shutdown of the blower section and gas flaring at the ten crude oil separation centers in the Edjelet field.

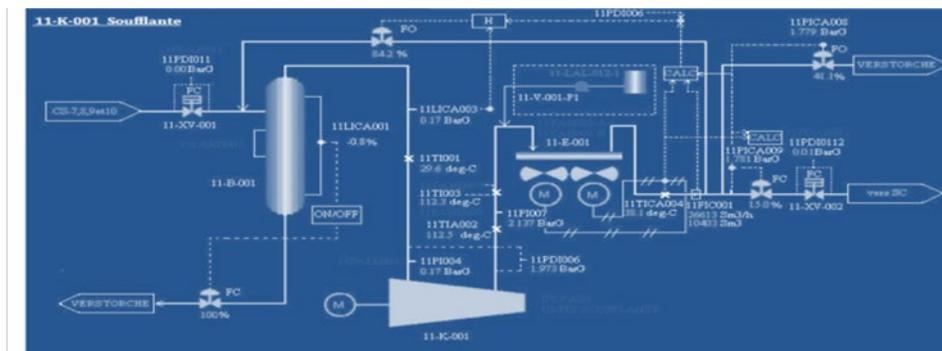


Figure 2. Blower unit diagram

3.1. Calculation of the initiating events frequencies and the probabilities of safety barriers failure

Various scenarios were established, two scenarios were selected resulting as consequences: the shutdown of blower section (destruction of compressor 11-K-001) and the flaring the entire quantity of gas, these scenarios are caused by the following initiating events:

- Failure of control loop Temperature-Pressure;
- Failure of control loop Level;

To prevent the occurrence of these consequences, the implemented safety barriers are:

- Alarm & operator;
- Emergency shutdown system ESD;
- Pressure relief Valve.

The ESD installed in the blower section is an SIS (safety instrumented system) functioning in low demand mode to ensure, in case of deviation, the total automatic shutdown of blower section. It consists of a set of input elements (transmitters, detectors) which monitor the evolution of physicochemical parameters representative of the behavior of the blower section process (temperature, pressure, level). If at least one of these parameters deviates beyond a set value and remains there, this deviation constitutes a demand or a solicitation, which is detected by the concerned sensor, this last send a signal to the logic solver unit which is a programmable logic controller of type Triconex Trident Controller (YOKOGAWA, 2003).

The used data to estimate the values of these parameters, namely the frequency of initiating events and the probabilities of failure on demand (PFD) of safety barriers, are taken from the literature (ICSI, 2009) and given in table (1).

Table 1: PFD and frequencies of the existents safety barriers (ICSI, 2009)

Element	PFD / Fr.
Alarm	1E-3
Pressure relief Valve	1E-2
Operator	1E-2
Control Loop	1E-1 per year

For the estimation of the PFD of ESD, the following simplified equations were used (IEC 61508-6, 2010). The PFD_{avg} of the SIS is deduced from the sum of the PFD_{avg} of the various subsystems that compose it and according to the architecture (KooN) of these last (Table 2).

Table 2 : Simplified PFD formulas

Architecture	Formula
1oo1	$PFD = \lambda_{DD} * MTTR + \lambda_{DU} (\frac{T1}{2} + MRT)$
KooN	$PFD = \lambda_N^{N-K+1} \prod_{i=1}^{N-K+1} [\lambda_{DU}^{ind} (\frac{T1}{2} + MRT) + \lambda_{DD}^{ind} MTTR] + \lambda_{DU}^{CCF} (\frac{T1}{2} + MRT) + \lambda_{DD}^{CCF} MTTR$.

Where:

λ_{DD} : Dangerous detected rate,

λ_{DU} : Dangerous undetected rate,
 MTTR: Mean Time to Repair,
 T_1 : time between two periodic tests,
 CCF: Common cause failure.

The used data to estimate the PFD of ESD system of the blower section are taken from the reference (SINTEF, 2005) and are grouped in Table (3).

Table 3: Data relating to the elements of the ESD system.

Element	λ_D (10E-6 per hour)	λ_{DU} (10E-6 per hour)	MTTR=MRT (hour)
Level Transmitter	1.4	0.6	10
Pressure Transmitter	0.8	0.3	10
Pressure Switch	2.3	2	10
Temperature Transmitter (detector)	0.7	0.3	10
Processing module (one card)	15	5	8
Isolation valve	3	2.1	10

For the characterization of common cause failures (CCF) we take (Touahar, 2015):

$\beta_{DD} = \beta_{DU} = 10\%$ for input elements (S) and final elements (FE);

$\beta_{DD} = \beta_{DU} = 1\%$ for the logical unit part (PLC).

Where β factor for quantification of CCF.

T_1 : The time between two periodic tests is equal to 1 year = 8760 h. (company data).

In this case:

$$PFD_{ESD} = \prod_{i=1}^{N=22} PFD_{Si} + PFD_{LS} + PFD_{FE} \quad (1)$$

$$PFD_{ESD} = 0.194E-2$$

3.2. Calculation of the lost and flared gas frequency

Figures (3) and (4) show the event trees relating to the two accident scenarios selected for this study.

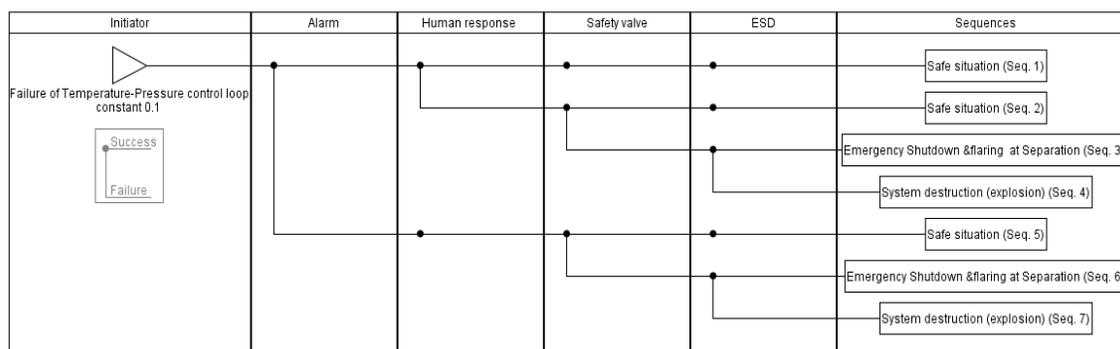


Figure 3.Event tree of Scenario 1.

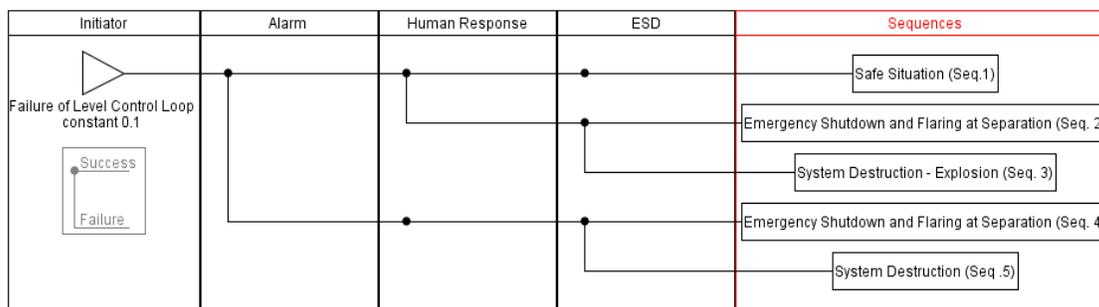


Figure 4.Event tree of Scenario 2.

- The flaring frequency for the first scenario:

$$Fr(\text{Flaring}) = Fr(\text{seq.03}) + Fr(\text{seq.06}) = 5, 48.1\text{E-3/year.}$$

- The flaring frequency for the second scenario:

$$Fr(\text{Flaring}) = Fr(\text{seq.02}) + Fr(\text{seq.04}) = 5, 4.1\text{E-1/year.}$$

3.3. Calculation of the lost and flared gas volume:

Each shutdown of the blower section will lead to the loss and flaring of a large quantity of gas at the separation centers, in addition to the decrease in gas-lift pressure at the outlet of the compressor section, which causes a decrease in the production of oil wells.

Although flaring is a safety measure, but it is a waste of a valuable energy resource that could have been used to support economic growth.

Flaring also has a significant environmental impact on climate change, as it represents an additional volume of CO₂ emissions, the main greenhouse gas.

To estimate the amount of gas flared during shutdown of the blower section, the following relationship is used:

$$V = Q_{act} * T \quad (2)$$

Where Q_{act} the current flow of associated gas and T is the downtime of the blower section.

The used data to estimate the gas flow at the inlet to the blower section and the gas volume of flared gas were taken from (Mitsubishi Heavy Industries, 2004).

Table 4: Data relating to the conditions of the blower section feed gas

Parameter	value
standard flow rate of associated gas (Q_{st})	610500 SM ³ /day
the associated standard gas pressure(P_{st})	1.01325 bar
the current associated gas pressure(P_{act})	0.1 bar
the current associated gas temperature(T_{act})	55 C ⁰
the associated standard gas temperature(T_{st})	15 C ⁰
compressibility factor(Z)	19.84

The national authority ALNAFT (Official Journal, 2005) estimates the fee of flaring gas as: for every 1000 cubic Nm of flared gas corresponding to 2000 DZD (15.3 \$USD). Table 5 below shows the estimated results of the flared gas and the production loss and penalty costs for flaring for each shutdown of the blower section.

Table 5: Estimated quantities of flared gas, flaring penalty, production loss cost associated to the blower section.

Shutdown time (hour)	Flared gas volume (m3)	Flaring penalty (US Dollar)	Production loss cost (US Dollar/year). 4 Separation Complex	Total costs
12	18 483 501.2	28 490.88	55 450 503.6	55 478 994.48
24	36 967 002.4	569 771.08	110 901 007.2	111 470 778.3
14	21 564 084.7	3 323 366.46	64 692 254.1	68 015 620.56

3.4 Equipment criticality analysis

Among the used solutions to ensure maintenance strategic optimization; the critical analysis of technical equipment based on the importance measure analysis. The importance measures allow to:

- Identify the most critical components to system performance and measure the contribution of each component (or basic event or cut set) to system failure;
- Determine which components need to be upgraded as a priority to increase the reliability of the system and minimize its probability of failure;
- Establish fault diagnosis and choose an appropriate maintenance policy.

In this work, we adopted the calculation of the marginal importance measure (MIM) (Limnios, 1991) given by the equation:

$$MIM_i(t) = Q(1_i, q(t)) - Q(0_i, q(t)) \quad (3)$$

The determination of this measure makes it possible to identify components whose reliability needs to be improved as a priority to improve the overall system's performance.

The obtained results for scenarios 1 and 2 are given respectively in Tables 6 and 7.

Table 6: Marginal Importance Measure relating to the safety barriers of the blower section (scenario 1)

Time	MIM	Component
8760.0	0.0000000E+00	ESD
8760.0	9.9706194E-04	Safety valve
8760.0	9.9998808E-02	Alarm

Table 7: Marginal Importance Measure relating to the safety barriers of the blower section (scenario 2)

Time	MIM	Component
8760.0	0.000000E+00	ESD
8760.0	9.880794E-02	Alarm

The obtained MIM values were calculated for the critical consequences: Emergency Shutdown response and flaring at Separation.

3.4. Discussion

The flaring in the first scenario is less likely to occur than the second one; this is due to the existing of safety relief valve which reduces the intervention of the emergency shutdown system. The production loss and flaring frequency estimated to $0.548E-3$ per year.

For the second scenario where the failure of second safety barrier (human response) conducts directly to either the loss of production/ flaring or destruction of the system depending on ESD availability. The production loss and flaring occurrence frequency is about $0.54E-1$ per year which leads to higher costs related to flaring taxes and production loss.

It can be seen that the quantity of flared gas in each shutdown is considerable and the production loss and penalty costs are very high, which constitutes additional costs to the company. In this case improving the maintenance of the safety barriers which are the main cause of these consequences is essential. Therefore, selecting an adequate maintenance strategy ensuring the reduction of loss costs requires the classification of equipment (control loops and safety barriers) according to their criticality. The importance analysis allowed us to determine which equipment is most important in contributing to the occurrence of the critical consequence under study.

According to the obtained results of this analysis, the ESD has more importance in contributing to the occurrence of the critical consequence (Emergency Shutdown response and flaring at Separation), then the safety valve and finally the alarm for the first scenario. Likewise, the second scenario, the ESD contributes more to the occurrence of the critical consequence in relation to the alarm.

These results can be used for the optimal allocation of maintenance resources, which led to plan test and repair times, minimize expenses and thus reduce the frequency of occurrence of adverse events. The significance analysis is therefore a decision support tool.

4. Conclusion

The problem of decision-making on the planning of maintenance tasks remains at the heart of industrial concerns. Indeed, the impacts of poorly planned maintenance are not limited to production loss, but can also lead to risks to installations, the personnel safety and damage to the environment. For this reason, adopting an appropriate maintenance strategy is essential to prevent a technical failure and its propagation from leading to these effects.

This work based on risk analysis for the selection of a better maintenance strategy. The application of the proposed approach to an operational industrial process has shown an optimal allocation of maintenance resources by taking into account the results of the risk analysis. The proposed approach can help in decision making.

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