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Probabilistic Approach to Reduce Flaring Operations and Carbon Emission Based on RAM2S

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The world is facing a new reality when it comes to sustainability. All major oil and gas companies around the world are being pushed to operate their facilities, upstream, midstream or downstream, with the minimum amount of waste and hazardous emissions. The “green processes”, as the industry calls them, are not the exception anymore but the standard.
RAM analysis provides key parameters to guarantee a sustainable process. The equation is quite simple: more reliable processes use less feed products, reduce the size of storage and deliver the same amount of end-product.
A good example of how applying reliability methods can guarantee a sustainable process is carrying out a RAM study at an upstream asset. By replicating the design configuration and operational procedures of the platform in a virtual model, the analyst gets a complete picture of the performance including production rates of oil, gas and water, the critical systems and equipment leading to the major losses as well as the effectiveness of the maintenance strategy. Supplied with this information, optimisation and reduction of downtime can be easily performed by running sensitivities analysis. Finally, suggestions in regards to design configuration, different maintenance strategies and de-bottlenecking of the platform are defined considering implementation cost and return on investment (ROI). Traditional RAM analysis for the oil and gas industry should be able to cover all these scenarios (Calixto, 2016).
Many companies are evaluating the benefits of RAM analysis during the operational stage. One of possible application is to understand the environment impact of a specific design configuration or operational procedure.
DNV GL has developed a software tool that integrates Sustainability aspects into the traditional Reliability, Availability and Maintainability analysis. This approach, namely RAM2S (Alvarenga, 2009), helps to overcome the lack of quantitative numbers to support many potential engineering solutions to account and thus reduce or even avoid methane, CO2 or any GHG emissions. Superficial assessments might have been crucial to avoid sustainable and safer solutions being implement or further developed. This integrated approach, for instance, will allow natural gas industries to find more cost-effective alternatives to align even more their business towards global warming reality, overcoming or minimizing the inherent green-house gas emissions.
This paper presents a case study where RAM analysis is implemented to evaluate the impact of flaring operations to the environment and its impact on the asset performance.

1. Introduction

The world is facing a new reality when it comes to sustainability. All major oil and gas companies around the world are being pushed to operate their facilities, upstream, midstream or downstream, with the minimum amount of waste and hazardous emissions. The “green processes”, as the industry calls them, are not the exception anymore but the standard.
In this context, flaring operations act a major source of damaging gases for the environment such as methane and carbon dioxide (CO2). By using advanced analysis methods and optimising production, oil and gas companies can take steps to limit harmful flaring.

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Currently, five per cent of world annual gas production is being flared or vented. This is equivalent to about 110 to 140 billion cubic metres (bcm) of gas. It equates to the combined gas consumption of Central and South America in 2013.

This paper presents an extended approach to the traditional and very well-established RAM analysis methodology, integrating sustainability factors. This approach allows the analyst to align the decision-making process related to design configuration and maintenance strategy to gases emission targets. Challenges related to gases emission targets are particularly important for major oil and gas companies that are being pushed to operate their facilities with the minimum amount of waste and hazardous emissions. Many countries have very strict rules when it comes to the emission of hazardous gases to the environment. For instance, the Brazilian government restricts the amount of gas burned to be up to a certain percentile of the gas reserve. For Brazil, the issue becomes even more relevant as studies have shown that the concentration of carbon dioxide in the new offshore fields associated to the Pre-Salt zones is very high.

2. Case study – Offshore installation

The case study evaluates the performance of an offshore platform which produces oil, gas and water. The model is used to forecast 10 years of the system life. A base case will be developed to establish preliminary estimates of gas burned based upon failures in the Gas Processing systems.

To quantify the amount of gas burned during the lifecycle of an offshore facility, the first step is to defining all parameters required by a traditional RAM study such as: design configuration, reliability data, maintenance strategy and operational rules. RAM analysis inherently estimates the number of failures (Zio,2013) occurring in the gas related systems as well as the number of hours these systems are not operating. Consequently, the amount of gas by-passed to the flaring operations, caused by failure events, can then be quantified based on this production rates. These production rates are important as the amount of gas burned will differ if different systems fail. For example, the high-pressure gas tends to have a higher production rate when comparing to low-pressure gas – this means that failures in the system processing high-pressure gas will result on burning more gas when compared to failure in the low-pressure gas system. Many outputs can be derived using this method, examples of key environmental impact information are: amount of gas flared, Number of stops due to environmental restrictions and Gas production.

The model will also report the system productivity given constraints in the flaring operations and failures in other systems as well as identifying the relative importance of the various subsystems.

A "base case" model of the system will be developed and used as a yardstick for comparing changes in design configuration, operating policy, maintenance policy etc. Sensitivity cases are run to improve and optimise the system performance with focus on flaring operations. Three scenarios are tested:

1. Minimum and Maximum case to benchmarking improvements to the base case
2. An optimised spare management strategy for the compressors
3. Replacement strategy for compressor component

One key aspect of this base case model is the flaring limits. The flaring limits are typically related to structural problems (e.g. flare stack cannot take radiation for more than 12 hours) or an environmental limit (e.g. regulatory rules which state the platform can only burn 1% of its gas production). This restriction is either a limit based on: Volume, percentage of production and time. All flaring limits refer to an accounting period which is the time within which the limits must be adhered to. If these limits are breached within any accounting period, then production will be affected. This case study will incorporate a limit of 2% of the gas production can be burned per month.

3. Results

Upon completion of the modelling process, the model can be run and results assessed. The first result is the measure to the platform's ability to export oil, the primary product which is called production efficiency. This relates to total volume produced at the export system to that which would have produced had all equipment run without failures throughout the system life.

The production efficiency for oil is 95.37% with 1.09% of standard deviation. The standard deviation is large for this model – this means the production efficiency is varying between 94.2% and 96.5%.

A criticality analysis is also produced as part of the results. This analysis is used to rank the events responsible for highest production loss. From the Subsystem criticality, the most critical system is the "Planned Maintenance" which is responsible for 45.9% of the production losses. "Gas injection system" is the second in terms of criticality, responsible for 28.6% of the losses.

Information in the criticality graph can be drilled-down to access different levels of the detail. At the subsystem level, the highest level in the model, the combination of production loss coming from different equipment items is displayed. By drilling into Gas Injection system, one can see the top contributors within this system are the 1st and 2nd stage injection gas compressor, as shown in Figure 1:

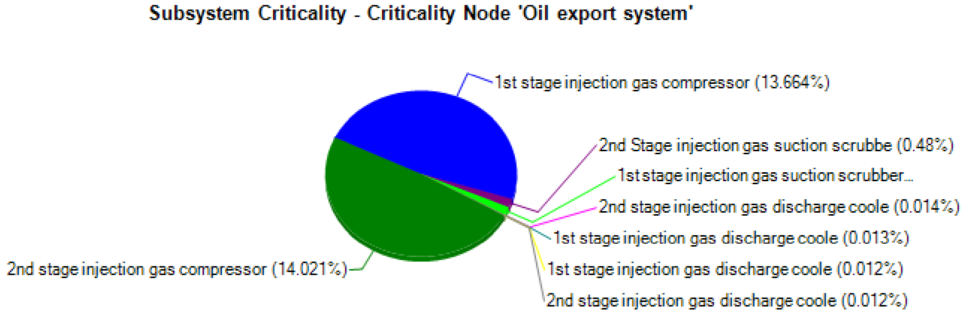

Figure 1: Main contributors to the production loss under the Gas Injection system

This criticality analysis also includes delays related to maintenance resource logistics – this means that delays related to the unavailability of spare parts is also shown here. Further investigation to the maintenance resource analysis shows that on average four maintenance jobs are delayed because of the lack of spare parts.

It is important to note that the criticality analysis is tracking production for the oil and when flaring operations take place, the oil production continues until the flaring limit is breached. This means the criticality analysis will consider the fact the system can by-pass failures in the compression system up to a point, reducing the contribution of criticality. The criticality analysis could be calculated based on the system ability to produce gas; this scenario would include all failures from the compression system to the criticality analysis. Furthermore, this set of results could be identified as the main reasons why the flare is needed. Comparing the two results, one can see an increase on the criticality for the gas related systems – Gas Injection system and Flash gas system. This difference is also how production is gained because of the system's ability to perform flaring operations.

The base case shows an average of 4.3 shutdowns per year have been simulated due to flaring limits with an average number of flaring operations of 13.5 per year. This will be the main KPIs to measure flaring operations.

4. Performing a what-if scenario

One of the most powerful aspects of RAM analysis is the ability to simulate and inspect the behaviour of a complex system under some given hypotheses, called scenarios. The following section lists all sensitivity cases that were identified and evaluated:

4.1 Sensitivity case – Minimum and Maximum case

To support the process of benchmarking models, another two versions of the base case model is run: Case 1: No Limits to Flaring operations; Case 2: Base Case, and Case 3: Flaring operations are not allowed

Table 1 shows the main results for Case 1, Case 2 and Case 3.

Table 1: Main results for benchmarking against sensitivities

Results	Case 1	Case 2	Case 3
Average efficiency	97.69%	95.37%	93.83%
Flared Volume - HP Gas (mmscf)	2381	647	-
Flared Volume - LP Gas (mmscf)	3847	1515	-

These models can be used as minimum and maximum case for the flaring operations – they show how much production the system is recovering because of flaring operations and how much production could be achieved if flaring was allowed for longer in specific scenarios.

If flaring operations were allowed all the time, the system would be producing 2.3% more comparing to the base case. This can be used to assess whether there are specific scenarios where continuing flaring operations might be allowed if it doesn't compromise safety/regulations. On the other hand, if more restrictions were added to flaring operations, production efficiency could be as low as 93.8% on average, close to 4% below the scenario where flaring operations are permitted all the time and 1.5% when compared to the

scenario where flaring operations are limited. This can be used to show the risk involved to not having the flare available – either because of process and regulatory.
These three results can be used to understand the trends in flaring operations, providing scientific support to decisions related to maintenance strategy for specific items, opportunistic maintenance and a replacement strategy/ranking for equipment items/systems.

4.2 Sensitivity case – Maintenance strategy

A new for the spare management is implemented to reduce the delay associated with maintenance resource logistics. The base case shows four repair job delays caused by the unavailability of spare compressors.
The new strategy evaluates a modification to the Restock level; instead of waiting until there are no spare parts in the warehouse, the centralised maintenance management system will order a new spare when one is used.
The results are displayed in Table 2:

Table 2: Main results for maintenance sensitivity

Results	Case 1	Case 2
Average efficiency	95.37%	96.53%

This sensitivity case shows an increase in efficiency of 1.2% when compared to the base case. However, this change has minor impact to flaring operations and the amount of burned gas. The number of shutdowns per annum is reduced from 4.4 to 4.2. This result indicates maintenance resource logistics have no impact over flaring operations, in this case. This can be explained by the fact that improving maintenance resourcing will impact the duration of the shut downs. However, the reduction in duration is not enough to reduce the number of times the flaring limits are breached.
There is another improvement to the model– the standard deviation went down from 1% to 0.4%. Reducing the standard deviation represents working with models that more predictable.

4.3 Sensitivity case – Replacement strategy for compressor component

Drilling into Gas Injection system criticality results, one can see the top contributors within this system are the 1st and 2nd stage injection gas compressor. Initially, these items are defined with a single failure mode which is used to describe all the potential failures that could occur. Looking at the original data gives the opportunity to identify the reliability data for a “component” level. The detailed component failure modes are described in Table 3:

Table 3: 1st and 2nd stage injection gas compressor failure modes

Failure Mode	MTTF (years) - Exponential	MTTR (hours) - Constant repair	Capacity Loss at Failure	Capacity Loss at Repair
Compressor driver	3	72	100	100
Degraded	0.9	12-24 hours (rectangular)	75	100
Overheating	9.5	12	100	100
Spurious trip	5	12	100	100
Vibration	9	12	100	100

It is important to note that the Compressor driver has also been defined using a Weibull distribution. This means that some ageing has been associated with the failure. The parameters for a Weibull distribution can be calculated using data fitting methods based on historical data. Furthermore, the new reliability data should be associated with the right maintenance resources. This requires the analyst to add another spare part for the spurious trip in addition to the compressor driver.
As expected, upon completion of the simulation with the new reliability data should present very similar results.
Within the contributors of the compressor failure modes, the compressor driver is the highest, contributing with 8.432% of the total of 13.686%, as shown in the following graph:

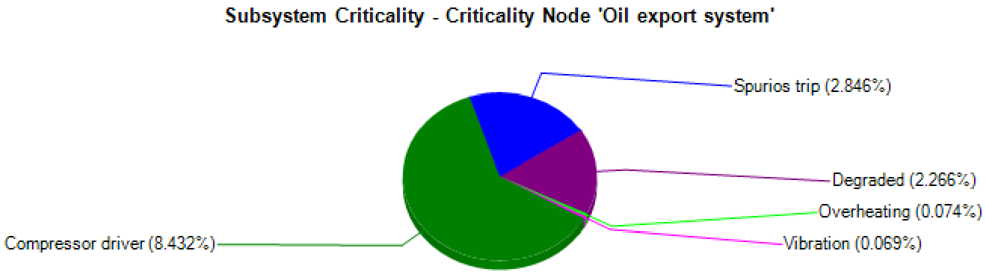

Figure 2: Main contributors for new replacement strategy for compressor component

To mitigate the production loss coming from these items, it is possible to implement a maintenance strategy that replaces specific parts of a component based on a preventive activity. Replacing parts in a controlled environment leads to less shut down time e.g. waiting for the compressor driver to fail leads to 72 hours of repair, whereas replacing only takes 24 hours to replace the item. The next question is: how often should the compressor be replaced?
Three different replacement frequencies are tested: every 6 Months, every 1 Year and every 2 years. Table 4 displays Average efficiency results for all cases:

Table 4: Average efficiency results for all cases

Results	Case 1 (Base case)	Case 2	Case 3	Case 4
Average efficiency (delta)	95.37%	0.714	0.72	0.456
Average efficiency	95.37%	96.08%	96.09%	95.83%

Comparing the criticality results, it shows a great reduction on the criticality for the Gas Injection system.
Regarding the flaring operations, Table 5 shows the flaring results for all cases.

Table 5: Flaring results for all cases

Flare Name	Ops/Year	Duration (hours/year)	Volume (mmscf/year)	Shutdowns/Year	Downtime % production
Base case	13.5	152.14	216.28	4.357	2.36
6 months	15.761	161.04	237.61	4.022	1.638
1 year	13.661	148.28	204.2	3.721	1.639
2 year	13.694	149.74	208.44	3.845	1.903
3 year	13.697	149.66	209.84	3.901	2.066

The number of operations for the base case is 13.5 which is very similar to all cases. The exception is the case where replacement is performed every 6 months, which makes sense as the system is constantly being shut down to replace the part.
The cases that lead to better performance are related to replacement strategies performed every 6 months and 1 year. They also show very similar performance indicators (around 96% of performance) but the latter is showing a reduction on the amount of volume flared. Furthermore, the average number of shutdowns went down by 0.5 shutdowns per year. This represents an improvement to the base case. However, the number of shutdowns did not come down because the amount of time is being saved is not enough to avoid the flaring limits breach.
The new criticality chart now displays the Flash Gas System as the major contributor to production loss. Within this system the most critical items are the compressors. The same method applied before is used to define a maintenance strategy that replaces these compressors. To implement the same strategy, the planned maintenance activity duration must be doubled to account for the second set of compressors.
This reduces the flaring operations per year from 4.3 to 3, effectively reducing the amount of gas burned.
Another interesting result of this new detailed approach relates to the delays associated with maintenance spare parts. The job delays associated with the compressor maintenance logistics relates only with the compressor driver. The second spare part, responsible for replacing spurious failures, present 0 repair delays

associated with it. The compressor driver still shows around 4 job delays caused by the lack of spare parts available.
This means that the second sensitivity could be used to mitigate this specific bottleneck.

5. Conclusions

RAM analysis is a well-stablished methodology mainly used during the design optimisation stage of different industries. In the oil and gas industry, RAM analysis can be extended to include production rates which adds to the simulating capabilities and decision-making process.
One of the areas of application of this hybrid version of RAM analysis, namely RAM2S, is environmental analysis concerning flaring operations.
The ability to track failure in the compression system already incorporated to the traditional RAM analysis can be extended to calculate the amount of gas that would be burned in case of planned and unplanned shutdown.
The case study gives an example of the applicability of the analysis – the performance of an offshore oil and gas production platform is assessed for the period of 10 years. The main objective of this study is to assess amount of gas burned due to failures at the compression system.
After running the simulation, the production efficiency for oil is 95.37% with 1.09% of standard deviation. The standard deviation is large for this model – this means the production efficiency is varying between 94.2% and 96.5%. From the Subsystem criticality, the most critical system is “Gas injection system”, responsible for 28.6%.
All this information leads to three sensitivities which are used to investigate opportunities to reduce the emission by burning gas in addition to optimising the performance of the platform.
An optimised version of the model is generated by evaluating all the different sensitivities results. If the replacement strategies are implemented, the average efficiency could be increased by 0.7% and the number of shutdowns caused by flaring operations reduced from 4 to 3 per year.
Performance forecasting is a methodology based on RAM analysis specifically design to cover the oil and gas modelling needs. This methodology has been an important tool for design optimisation but there is a great shift in the market to start applying this method during the operational stage. However, the ever-changing state of an oil and gas production system poses several challenges to performance prediction studies. This is especially true for reservoir data where many variables have a transient behaviour (e.g. production rates) making it complex to predict. This method provides the tools to combine several variables into a complex system and make informed decisions.

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