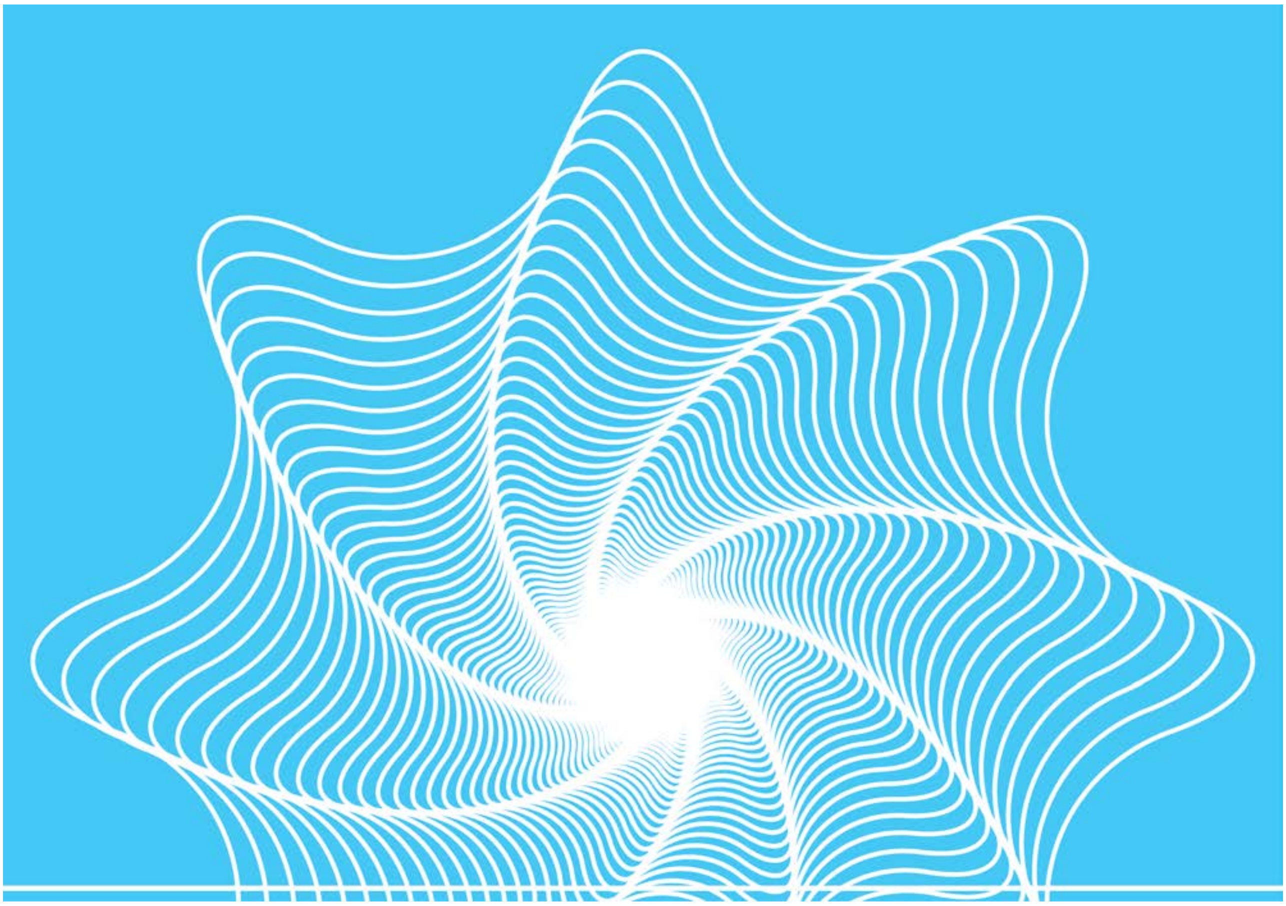
WHITEPAPER

MAROS

Managing the investments throughout the asset lifecycle



SAFER, SMARTER, GREENER

Date: September 2014

Prepared by DNV GL - Software

Table of contents

1 SUMMARY

Managing the expenditures of a process plant is a complex task. The overall investment is a combination of initial cost, namely capital expenditure or CapEx, with running cost, operational expenditure or OpEx.

The CapEx is typically based on construction investments, purchasing material and equipment packages – as one could conceive, these figures can easily range from the few hundred millions to few billions dollars. The OpEx is typically calculated based on maintenance costs, utilities (power, water and gas) supply and workforce etc. Taking into account that a great part of the maintenance expenditures are based on failures (the other part is based on inspections and planned maintenance) and failures occur randomly, this variable becomes quite hard to estimate.

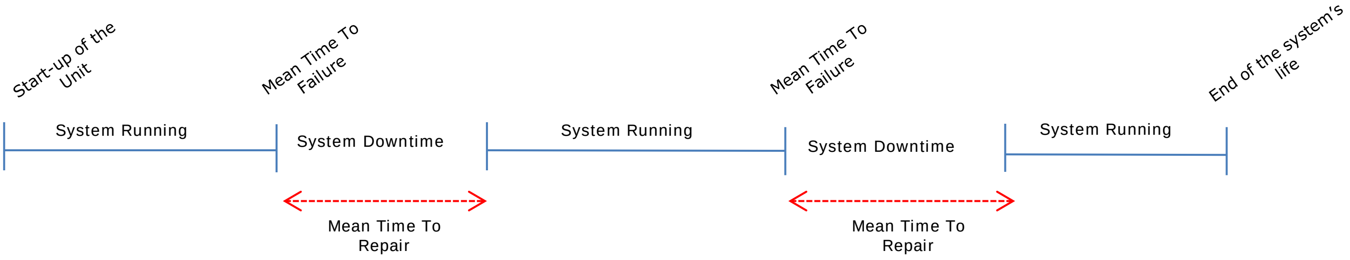
CapEx and OpEx are directed connected and finding the balance is essential. Consider an oil export system where we have one pump available. If this pump fails, the system cannot perform its function which is to export oil. What should we suggest? Purchase another pump and design the system in redundancy. This will directly impact on the CapEx – purchasing another pump – but also on the OpEx. By adding another pump, the potential number of failures of your system has been doubled and maintenance expenditure might have been doubled as well. The probability of having both pumps down at the same time is quite small, ensuring product delivery, but what about the extra cost from the additional pump?

RAM analysis can be used to precisely estimate these expenditures and combine that with the incoming revenue from product delivery to give an overall financial picture. This gives the analyst a powerful tool to optimise design configuration and maintenance strategies. It also helps to find the balance between CapEx and OpEx and what changes will be effective by ranking the options with higher return on investment.

This paper presents the importance of RAM analysis to manage the lifecycle cost of a project. In addition, a case study presenting the benefits is introduced.

2 IMPORTANCE OF RAM ANALYSIS

RAM analysis is typically used to predict the performance of process systems and to provide a basis for the optimization of such systems. The nature of a RAM analysis will vary according to the purpose of the study and the scope of work. However, in the majority of cases, the RAM analysis is used to predict system availability and identify ways to improve system availability by considering both equipment failures and maintenance factors. The events step, commonly, should follow the timeline below:



In the oil and gas industry, RAM analysis is used to forecast the production efficiency of oil and gas fields taking into account system configuration, different maintenance strategies and, specifically for this industry, operational bottlenecks. By adding the operability factor, we extend the traditional approach allowing analysts to combine a powerful and proven methodology with their expertise on the system operational behaviour, supporting the effective development and operation of any asset.

The benefits of running RAM analysis:

- Optimise design configuration, maintenance strategy and operational procedures
- Reducing maintenance and sparing costs while maintaining and/or increasing production levels.
- Rank capital investment opportunities and support the decision-making process based on revenue
- A decrease in the duration of unplanned and planned outages.
- Alignment of maintenance resources based on the criticality of equipment to production revenue.
- Accurate forecasts of equipment lifecycle costs that reflect equipment age, lifecycle, and maintenance effectiveness.
- Definition of reliability levels for specific systems. Models can be used to estimate frequency of failures for a certain system and equipment which can then be benchmarked with the expectation. If the predicted reliability levels are not as expected, changes to design and equipment selection can be performed to increase the reliability
- **Life Cycle Cost (LCC) Analyses**. Life cycle cost analyses are used to determine the overall cost of the oil and gas asset during its entire life. RAM analysis is used to estimate the frequency of failures and, therefore, estimated maintenance cost.

In conclusion, RAM analysis can used to support the decision making process regarding design configuration, maintenance strategy and operational policy.

2.1 Flow network

The ability to incorporate a flow network to the analysis extends its capabilities and addresses scenarios that cannot be typically handle using generic RAM analysis.

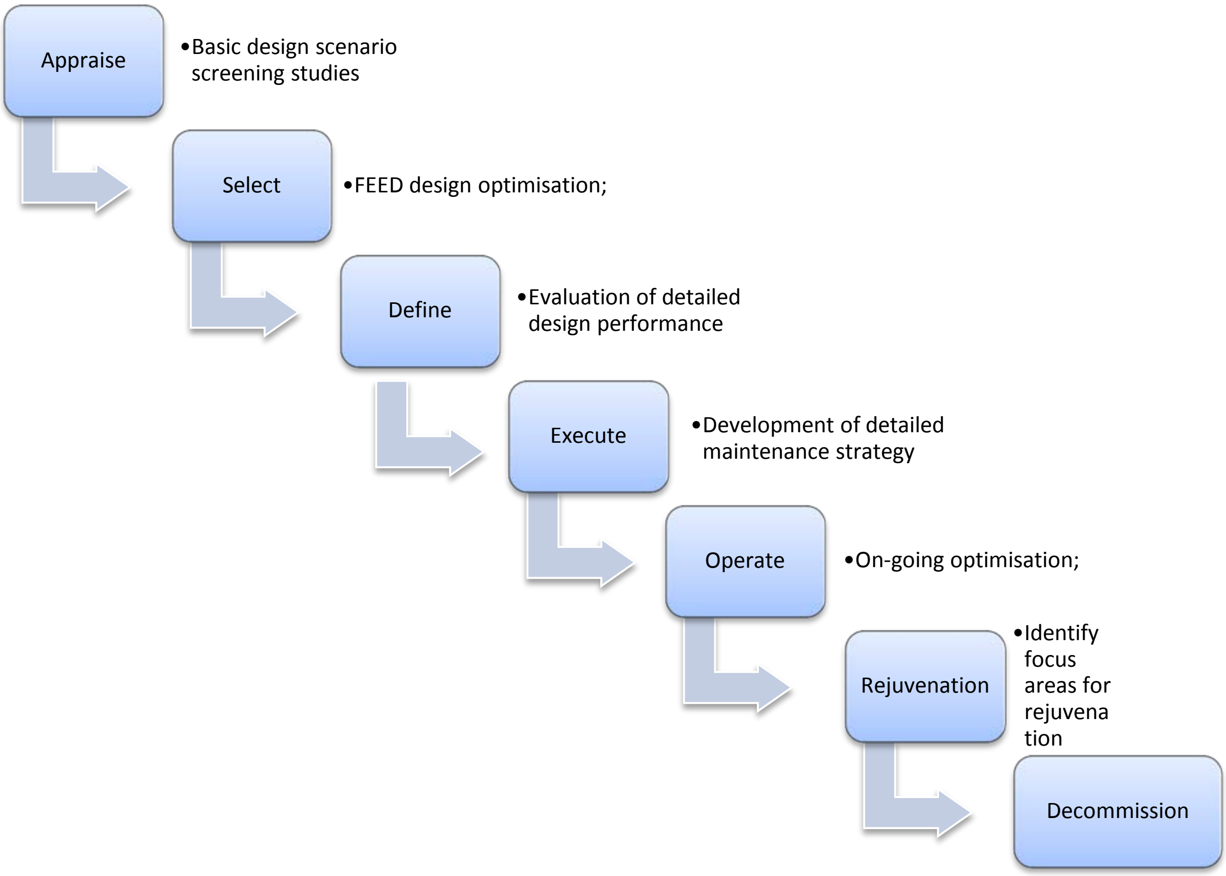
Generic RAM analysis focus on estimating the time which a system is not available – for the oil and gas industry, this is not enough. By adding a flow network and integrating production rates to the system, the methodology can account for degraded states and typical operations such as logistics operations, boosting mechanism a flaring operations (where failures in the gas related equipment are by-passed by burning the gas). Therefore, the final result is an estimation of the produced volume i.e. 100 bbls of oil is likely to be produced over each day.

This is particularly important for the upstream industry, where the analysis can be extended to account for reservoir data – production rates for the individual product streams, oil, gas and water – to estimate what is the potential production for a particular oil field or a single well. Hence, rather than just providing rudimentary uptime vs. downtime information, production efficiency keeps track of how much production losses are throughout the system life, and quantifies the efficiency by dividing the actual production by the potential production. Combined with time varying flow from multiple sources, this result becomes a very powerful metric.

Aligning this powerful approach with financial calculations takes the methodology to another level. If one can estimate the product price and define a discount rate, the Net Present Value (NPV) can be calculated. The NPV is detailed later on this document.

2.2 Supporting the project lifecycle

The analysis can be used throughout the project lifecycle to support the decisions that have to be made at each of the various stages:



The next session details what are the benefits for each stage.

2.2.1 Conceptual Design

The Conceptual Design is a preliminary stage where a description of the proposed system in terms of a set of integrated ideas and concepts are made. The result is the generation of many design concepts which are supported to evaluate the feasibility of each conceptual alternative. RAM analysis allows quick screening of various development options to assess suitability, from a functional and commercial perspective, of the proposed designs.

2.2.2 Front End Engineering Design stage

Once a number of options have been selected, a more detailed analysis can be carried out to choose major equipment configuration. At this stage, the most important decisions in regards to concept and plans for the project are made. From a RAM analysis point of view, the FEED stage is where the application of the analysis becomes the most effective – changes can be easily incorporated to the project as we still are at the planning stage.

From an investment perspective, this is the stage where potential savings are the biggest. Unnecessary redundancies can be eliminated; critical points of the system can be evaluated

2.2.3 Detailed engineering

The Front End Engineering Design (FEED) stage leads to the creation of primary design documents such as process flow diagrams (PFDs), Process & Instrumentation Diagrams (P&IDs), equipment lists and equipment datasheets. Once the FEED has been finalised, a much more detailed design for the system is specified. At this stage, the questions are much more specific.

RAM analysis ensures that the system design meets your required performance targets.

From an investment perspective, equipment can be selected from a number of vendors and a combination of reliability and cost can be incorporated to the system finding the optimum balance.

2.2.4 Execute

By identifying the critical elements and the bottlenecks in the system, the results from an RAM study can be used to feed in to other methodologies, such as Risk Based Inspection (RBI) and Reliability Centred Maintenance (RCM). Subsequently, the output from the RBI and RCM process can then be fed back into the model to provide a final picture of system performance.

2.2.5 Operational Stage

During the Operational phase, it is not very cost-effective to make decisions in regards to the design. However, RAM analysis can also be used to assess impact of planned modifications. The most common evaluation carried out during the Operational stage is related to the maintenance philosophy which, basically, refers to number of spares, re-stock time and available personnel. There is always a trade-off between the costs of lost production versus the cost of maintenance.

Additionally, a performance trend can be created based on the output of ongoing updates to the analysis. This might represent additional performance if areas of concern are being addressed directly.

2.2.6 Rejuvenate

For mature systems, as we keep asking more of our ageing assets, RAM analysis allows you to find potential areas for rejuvenation or facilities life extension. Many sensitivity cases can be applied to a mature system model, which will indicate to various rejuvenation options and the potential gains quantified.

2.2.7 Decommission

Sometimes, due the high number of variables in an oil and gas development, it is not easy to identify at where the operational expenditure exceeds the revenue, making the system no longer economically viable. By modelling all the dynamic behaviours of a system, RAM analysis helps you to evaluate decommissioning strategies viability.

3 CAPITAL EXPENDITURE AND OPERATIONAL EXPENDITURE

When discussing financial analysis in the oil and gas industry, the first thing that comes to everyone's mind is the overall investment to build a process plant – the Capital Expenditure (CapEx). Why is that? CapEx has indeed a massive contribution to the investment in an oil and gas asset and, as this investment is normally done in the first few years, one could feel like this is the largest investment in the asset.

To give us some perspective regarding sums of money, when referring to capex in the oil and gas industry, figures can easily cross the barrier of a few billions of dollars. For instance, taking the last capex budget report from Barclay's (NYSE:BCS) latest report on CAPEX budgets, the energy industry is expected to invest around $723 billion on exploration and production (E&P) efforts in 2014. This represents almost 6.1% increase comparing to 2013's total CAPEX spending and will, for the first time, cross the $700 billion-mark.

Of course, optimising the use of this investment is of vital importance to ensure the asset profitability. From a product delivery point of view, in an ideal world, we should have redundancy in every possible system. However, that is not feasible financially. Therefore, the design engineer has to optimise the number of redundancies presented in the system and reduce the cost but ensuring the targeted level of reliability and availability.

Another particularly important factor is the OpEx. The OpEx could be potentially larger than CapEx. When calculating the running cost of a process plant, we should be considering maintenance costs and utilities (power, water and gas) supply and so on. Now considering that we are calculating these expenses over the venture's life and the life span of a process plant can be around 15-20 years, OpEx is often a much larger number than CapEx.

CapEx is normally a known variable – the investment on purchasing equipment items, constructing the facilities. The challenging area is the estimate of the OpEx - this is variable as failures occur randomly. The OpEx is based on the fact that certain failures might require a number of maintenance resources such as spare parts as well as the manpower. Utilities such as power, gas and water supply will also depend on the system availability – if the system is not available, there will be interruption of gas supply, for example.

4 METHODS OF ESTIMATING EXPENDITURE

There are two techniques to estimate the financial aspects an oil and gas asset: the traditional approach using static calculation or dynamic simulation techniques - both of them present benefits.

Static calculation uses constant consumption rates of maintenance resources (spares) and utilities to determine operating costs for assets in the oil and gas development. It produces a general picture of the cost through the asset's life - it presents a simple solution which can be used as a starting point.

The use of dynamic simulation techniques allows estimations taking account of continuous changes in the state of the system over its expected life. Account is taken of equipment functionality, different component failure modes and consequences, logical events, operating and maintenance philosophies, availability of services and personnel, status of buffer storages. Clearly, any attempt to calculate the expenses with this degree of complexity by deterministic methods (i.e. static calculation) is virtually impossible.

Estimating the overall expenditure is a straight summation of the different expenditures and can be summarised as:

$$\text{Total expenditures} = (\text{Capital expenditure}) + (\text{Operational Expenditure})$$

As aforementioned, CapEx is normally known and it is a fixed value. The variable hard to estimate is the OpEx which is normally based on failures/availability of utilities.

For the static calculation, one would assume a constant failure rate for a number of systems and a constant repair time (downtime) for each one of these systems. This would allow a simple estimation of the OpEx.

When using dynamic simulation techniques, changes such as potential reservoir data, frequency of failures, availability of utilities, availability of maintenance resources, variation of repair times, seasonal demands and weather impact on performing repairs. This approach also allows the analyst to account for variations on the value of money over the predicted years – discount rates, interest, etc.

Another important point concerning the oil and gas industry refers to product delivery contracts. Typically, oil and gas operators have contracts on product delivery to meet. Dynamic simulation enables the methodology to track the number of contracts which were lost when production targets were not met. Lost contracts could then be assigned to a fine and the overall cost of losing these contracts can be quantified.

The financial calculation can be extended to incorporate product pricing which enables estimation of the revenue produced. With the revenue the Net Present Value can be calculated. Net present Value (NPV) is a financial figure that allows comparisons between different projects by using all the cash flows from the project and adjusting them to their present values by applying the appropriate discount factor. The projects then become directly comparable. Should the present value of the capital inflows exceed those of the outflows after the selected discount rate has been applied, the project is showing a positive cash flow return and the greater the value the better. However, if the NPV is negative the returns from the project are less than the outflows and attempts should be made to minimise the NPV.

There are two options when calculating the NPV– negative NPV or the Standard NPV. The negative NPV accounts for the potential loss of revenue whereas the standard NPV details the profit.

The NPV calculation should account for:

- Annual Discount Rate: An annual discount rate in percentage form must be ascertained. This will relate the worth in financial terms, of a future sum to its present value.
- Capital Expenditure: The initial capital expense outlaid at the beginning of the project and any other expenses incurred during the lifetime of the project.
- Operating Expenditure: This factor consists of the cost in day rates of the resources used, as well as any mobilisation/de-mobilisation costs incurred from their use.
- Product Price: Product pricing which represents the income when calculating the NPV. When defining the product pricing, the analyst must stipulate an initial price per unit, in the given currency (e.g. US$120/bbl.), and any changes occurring in this price over a specific period of time.

The NPV (Khan, 1993) should have the cash flow discounted back to its present value or the current estimated product pricing (PP). The cash inflow and cash outflow are summed so the NPV is the summation of the terms:

$$Standard\ NPV = \left(\sum_{t=1}^{N}\left(\frac{PP}{(1+i)^t}\right)(yearly\ production)\right) - (Capital\ expenditure) - \left(\sum_{t=1}^{N}\left(\frac{PP}{(1+i)^t}\right)(Operational\ expenditure)\right)$$

$$Negative\ NPV = (-Capital\ expenditure) - \left(\sum_{t=1}^{N}\left(\frac{PP}{(1+i)^t}\right)(Operational\ expenditure)\right) - \left(\sum_{t=1}^{N}\left(\frac{PP}{(1+i)^t}\right)(yearly\ production\ loss)\right)$$

Where:

- t– reference year
- i – the discount rate
- PP – product price

5 CASE STUDY

An offshore oil production unit designed to operate in shallow waters is operated remotely through automated processes and without the presence of personnel. This type of platform requires a unique maintenance strategy which effectiveness can be heavily influenced by several parameters such as travel times, maintenance resources constrains, mobilization time and prioritisation of repair.

The model consists of an offshore unit with 4 oil wells and 1 water injection system. The expected flow of oil from each well is 12,000 bbls per day.

- All flows coming from the wells converge to the NUI platform passing through a water injection system.
- All wells have a similar system including valves and tubing. A planned inspection of the subsurface safety valve is carried out every 6 months.
- The NUI comprises of different systems such as separation system, seawater system, telecommunication system, and power generation unit.
- Every time there is a failure leading to complete shutdown, the NUI platform must be restarted manually.
- The maintenance crew flies by helicopter to repair failures. There is unscheduled maintenance to address production critical failures and a scheduled weekly maintenance visits to address non-critical failures.

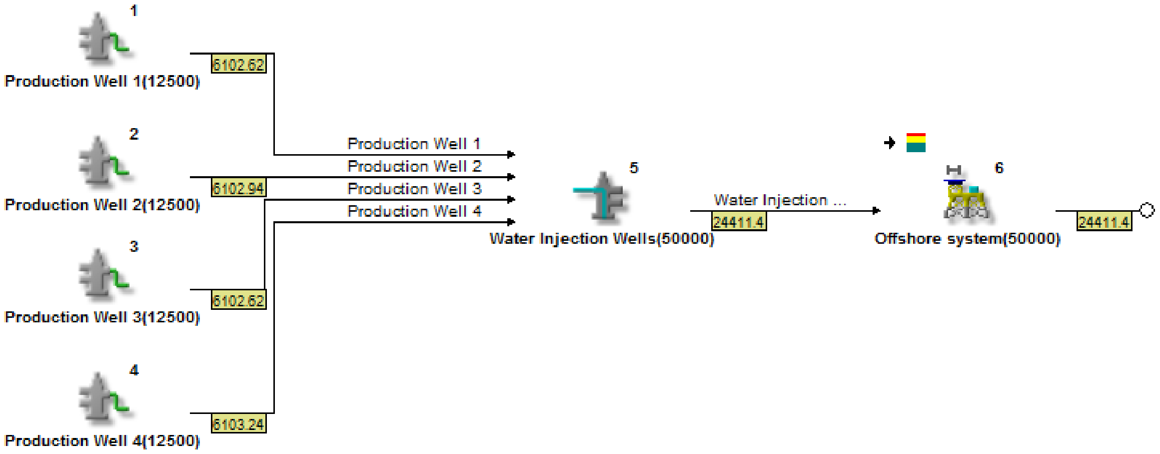


Figure 1: flow network

Each well has its own production profile – the overall production profile is shown in Figure 2:

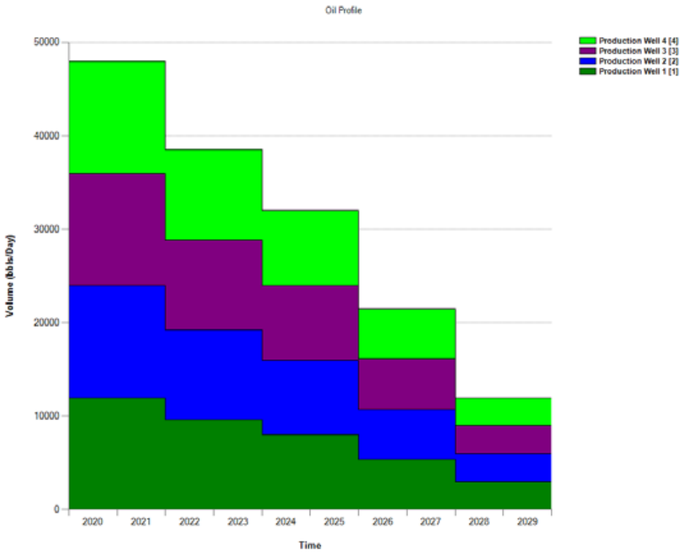


Figure 2: Production profile

5.1 Events

In oil and gas developments, events can be separated mainly into three categories: unscheduled, scheduled and conditional. These three basic events are defined below:

- Unscheduled events are unplanned and occur at random. However, their occurrence usually corresponds to a particular statistical distribution. Example: equipment failures
- Scheduled events where the occurrence is known. Example: routine inspection
- Conditional events that are initiated by the occurrence of other events via a Boolean logic expression. Example: warm-up of equipment in standby

Reliability Block Diagrams (RBDs) are used to outline the logical relationships between the different events. Each one of the blocks in a Reliability Block Diagram represents one “event” that can lead to production loss. RBDs are a logical representation of the system connection taking into account path of success of the system mission; in this case flow. If you have items in series, when one of them is in a failed state there is no way for the system to move forward. However, if you have items in parallel, it means that there more than one “success” path in the system.

On the specific case of this model, each one of the blocks represents an equipment item. Below the equipment level, the user must define failure modes – failure modes are different ways in which the equipment can fail.

An example of RBD is show below:

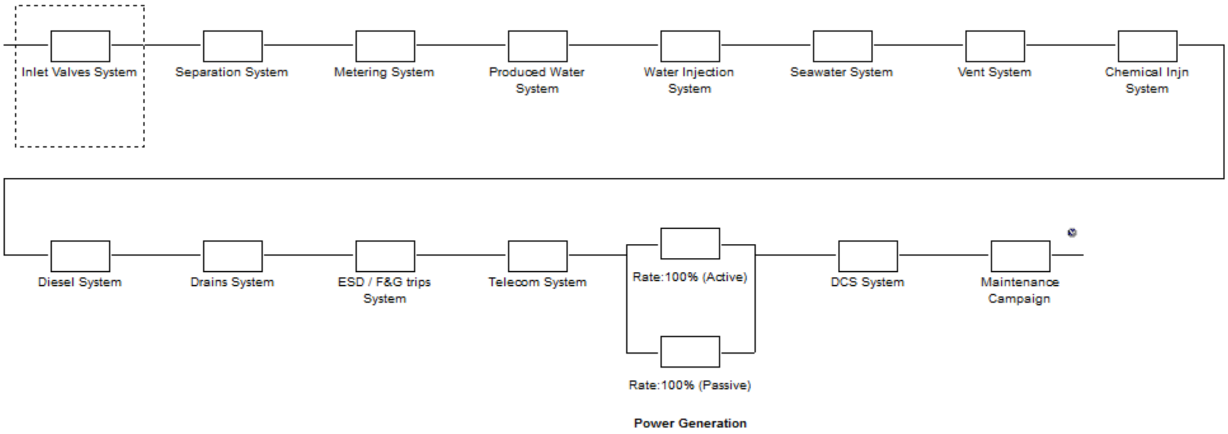


Figure 3: RBDs for Offshore plant

Each unit will comprise its own reliability data – for example, the data extracted from the seawater system is shown as follows:

Equipment	Type of failure	Impact at failure	Impact at repair	Failure type	MTTF	*Repair Type*	Min (hours)	Max (hours)
Seawater Filter	Critical	100%	100%	Exponential	3.03	Rectangular	2	8
	Degraded	50%	100%	Exponential	3.03	Rectangular	2	8
	Incipient	0%	100%	Exponential	2.941	Rectangular	2	8
Lift Pump	Critical	100%	100%	Exponential	10	Rectangular	72	96
Caisson Lift Pump	Critical	100%	100%	Weibull (no delay)	0.5	Rectangular	72	96

5.2 Maintenance Resources Logistics

An extensive number of maintenance resources must be accounted for when performing a RAM study. It is important to understand how these logistics manifest themselves in the simulation. Consider a generic event, a failure or a planned shutdown. In real life, this failure will start being repaired with a certain delay time corresponding to the time required to diagnose the problem and organize the repair resources to carry out necessary repairs. Once all resources are on the job location, the actual repair procedure can commence. The repair action itself may impact the production in another manner.

Modelling maintenance logistics involves determining the 'repair delay' portion of the above sequence. This is achieved by defining the location, quantity and constraints of the various resources involved in the repair process. Simulation is then carried out to determine each repair delay depending upon the foregoing and the workload at the instant of the failure. It is not simply a case of specifying a repair delay per task.

This model presents a great level of detail regarding maintenance strategy – remember this platform is unmanned so it is requires special type of maintenance strategy.

Considerations for the case study follows:

- Failures are separated into incipient and critical. Critical failures require immediate attention whereas non-critical (incipient) might wait until the next planned maintenance or next critical failure
- There is a weekly inspection of the platform supported by a helicopter
- There is an unscheduled helicopter which is required to perform critical failures that need immediate attention
- A number of maintenance resources are required to perform repairs i.e. Rig day rate and diver support vessel

5.3 Financial data

The platform is assumed to be operational and, therefore, the initial CapEx has been already recovered. For simplicity, the case study assumes that only the OpEx is of concern in addition to the CapEx for the different design options.

Cost data is provided for:

- Scheduled helicopter visit $12,000.
- Unscheduled helicopter visit $15,000.
- Rig day rate: $60,000, diver support vessel day rate $45,000.
- Oil price: $20/bbl.
- Discount rate: 10%

6 RESULTS

The methodology presents amongst a number of results three main Key Performance Indicators:

- The overall system performance for the base case is 93.950% +/- 0.334 %
- The annual production graph shows losses throughout the life of the system.

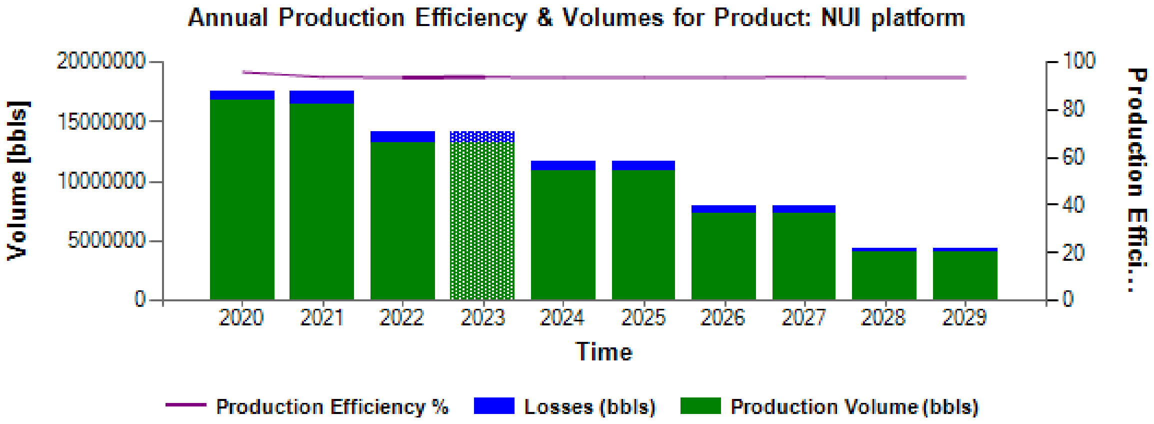


Figure 4: Annual production

- The criticality analysis highlight the most critical equipment items/system:

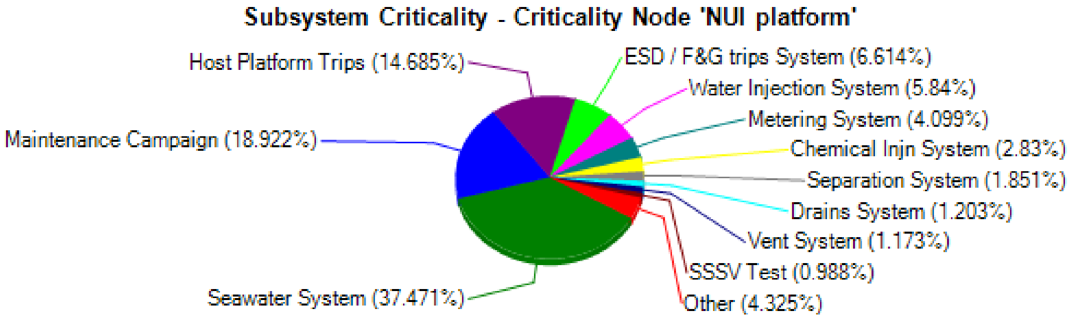


Figure 5: Subsystem criticality

Based on the subsystem criticality (Figure 5), the most critical system is the seawater system, which is responsible for 37.471% of the losses.

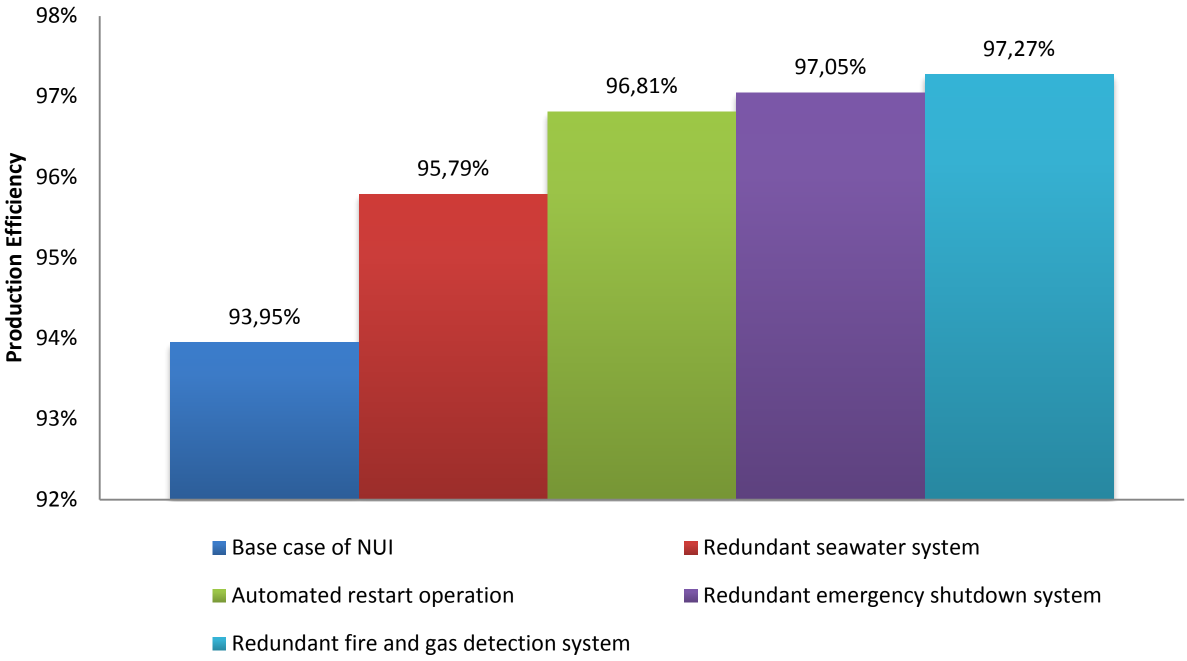
- The economic analysis gives the NPV of the project, and is summarized. In this case, there is a loss of $95.2 million throughout the life of the system.

7 SENSITIVITY ANALYSIS

Armed with the information regarding the subsystem criticality, the analyst can suggest changes to the design or maintenance strategy. This gives guidance on the mitigation effort on optimising the system. Once one suggestion has been tested, it can be accepted or not depending on the return on performance.

Four suggestions have been made to optimise the design of the modelled system:

- Redundant seawater system
- Automated restart operation
- Redundant emergency shutdown system
- Redundant fire and gas detection system

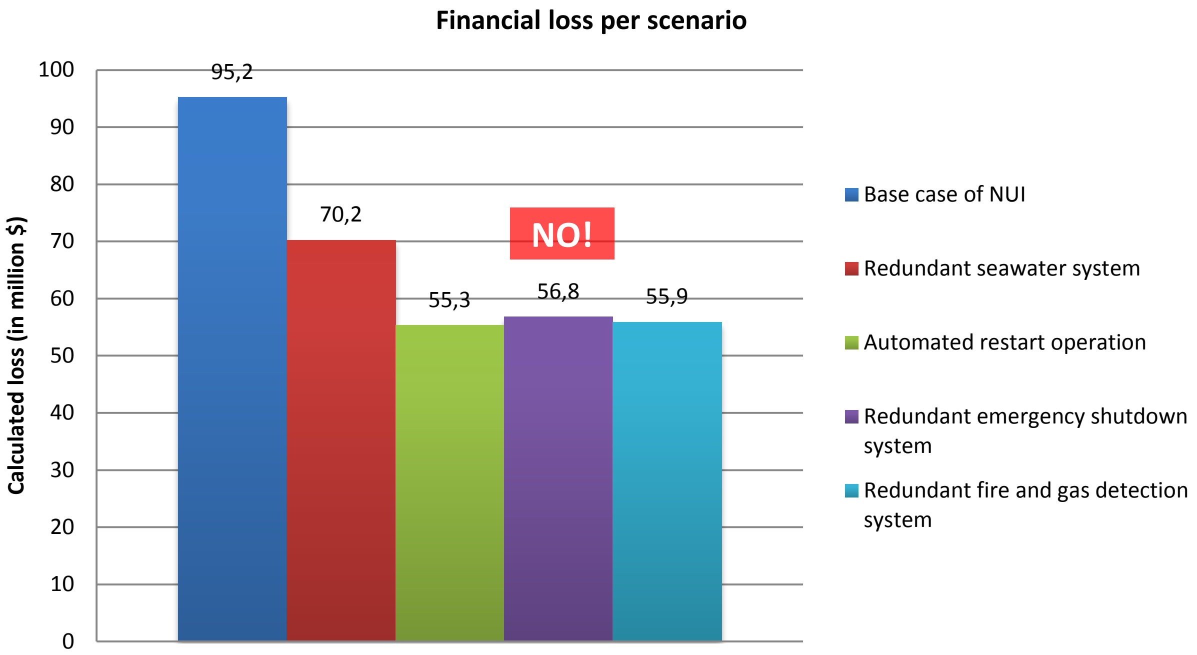


Evaluating only the production efficiency figure, one could conclude that all the suggestions should be accepted as all of them present an increase on performance.

However, when taking into account the capex required for each suggestion, the conclusion is slightly different. Assuming that each option requires a capex of:

- Redundant seawater system: $1.5M
- Automated restart operation: $1.0M
- Redundant emergency shutdown system: $5.0M
- Redundant fire and gas detection system: $2.5M

The return on investment for each case can then be calculated. The negative NPV shows the lost opportunity (financial losses) when operating the system.



This graph above shows that option 4, redundant emergency shutdown system, is not feasible. Basically, the capex to invest to implement this change is higher than the extra production coming from the increased availability of the system.

8 CONCLUSION

RAM analysis plays a key role when analysing optional combinations of design configuration, maintenance strategy and operational rules, in the oil and gas industry. Informed decisions can be made and uncertainty in regards to the production behaviour can be accurately predicted and therefore avoided or reduced.

A list of possible design options can be created from a base case. These options can then be ranked showing the effectiveness and financial benefits of each one of them:

Design option	Financial loss per scenario (million $)
Base case of NUI	95.2

Redundant seawater system	70.2
Automated restart operation	55.3
Redundant emergency shutdown system	56.8
Redundant fire and gas detection system	55.9

9 ABOUT THE AUTHOR

Victor Borges, RAM Product Manager at DNV GL Software, is a chemical engineer with years of experience performing Risk and Reliability analysis for assets in the oil and gas industry. He is responsible for DNV GL's world-leading simulation software packages Maros and Taro.