RELIABILITY STUDY OF AN LNG COMPLEX

ETUDE DE FIABILITE D'UN COMPLEXE DE GNL

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ABSTRACT

One of the most effective ways to improve the profitability of an LNG plant is to improve its reliability/availability/maintainability in order to increase efficiency and production while reducing maintenance and improving equipment life. To achieve this, many companies are performing reliability studies of their plants with the intent of quantifying their existing performance and identify improvements which will result in debottlenecking activities and/or instauration of preventive maintenance programs.

This paper presents a typical example of an LNG plant reliability, availability and maintainability study done for the Qatar Liquefied Natural Gas Co. Ltd. in the State of Qatar. It includes:

- Production profile throughout the life of the plant
- Contribution of the different systems to overall losses, broken down to different levels of details i.e. losses associated to offshore and onshore facilities, LNG trains, refrigeration systems within a train, equipment within a refrigeration system, utility systems, etc.
- Parametric sensitivity studies showing effects that uncertainties in certain failure rate data have on production.

The model containing over 3,000 equipment and instrumentation items predicts the performance of the complex through application of an event driven algorithm, which creates life-cycle scenarios of the system under investigation. Failure and repair information data used within the model was extracted from established generic data sources or from historical maintenance records provided by the Company. In addition main planned shutdown activities were included to provide a realistic representation of actual facility performance.

RESUME

Une des façons les plus efficaces d'améliorer la rentabilité d'une usine de liquéfaction de gaz naturel est d'en améliorer la disponibilité et la maintenabilité. Ceci permet, en effet, d'accroître le débit de production annuel en réduisant les coûts de maintenance tout en améliorant la durée de vie des équipements. Pour ce faire, beaucoup de sociétés entreprennent des études de disponibilité de leurs usines dans le but d'en quantifier les performances et d'identifier les améliorations à apporter suite à des études de dégoulottage et de mise en place de programmes de maintenance appropriés.

Ce papier présente de façon générique les résultats d'une telle étude relative au complexe GNL de Qatargas.

Le modèle utilisé pour cette étude:

- Prend en compte le Profil de production sur la durée de vie de l'usine.
- Est basé sur la décomposition du complexe GNL en différents systèmes en regardant comment chacun d'entre eux contribue aux pertes globales de production, puis sur une découpe plus fine en plusieurs autres niveaux permettant d'allouer ces pertes en partie aux installations offshore, en partie aux installations onshore incluant les trains de liquéfaction proprement dits et leur système de réfrigération/liquéfaction avec leurs équipements correspondants, en partie aux utilités, etc…
- Permet de faire des études paramétriques de sensibilité du type « qu'est-ce-qu'il se passerait si ? » qui envisagent des scénarios incluant des effets de redondance d'équipements, des changements de taux de défaillance ainsi que des interconnections entre les trains.

Plus de 3 000 items d'équipements et d'instrumentation ont été pris en compte pour prédire les performances d'un tel complexe en simulant des scénarios de défaillance, de réparation et d'arrêts programmés sur la durée de vie de l'usine.

Dans cette étude, certaines données utilisées comme les temps de réparation et le planning des arrêts programmés ont été fournies par Qatargas. Celles qui n'étaient pas disponibles ont été tirées des bases de données reconnues par la profession.

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INTRODUCTION

For any plant or operating system, it is desirable to have available both the past and present performance information of the system. Analysis of this information can be used to predict future operations in order for the plant to more closely achieve an optimal performance.

Today, with the ever-expanding capabilities of the Distributed Control Systems (DCS) and computer systems, a historical database on each piece of equipment and instrument can be maintained. For these items, the database would track the mean time to failure (MTTF), the mean time to repair (MTTR), and their effects on production. As stated above, through a study of such data, modifications to the facility's future operations, maintenance and replacement programs can be made to improve its performance.

A study of a system's historical statistics is normally carried out by developing a reliability, availability, maintainability (RAM) model of the whole plant/complex. This model can be used to calculate a facility's overall unavailability and assist in identifying possible areas in which to increase the availability. A complete database may not be attainable in a short period of time. However, generic failure rate data is available from typical process plants and can be used to complement an existing database. To determine the effect that data uncertainty may have on the overall plant performance, sensitivity studies are made by perturbations of the failure rate database. Based on these results, a rational evaluation of a plant's operation is made with the aim to improve plant profitability (increase its efficiency and on-stream time) by reducing maintenance, improving equipment life and/or modifying sparing philosophy.

A unique example of a RAM study performed for an LNG complex (both upstream and downstream) is presented in this paper. The study encompasses the Qatar Liquefied Gas Co. Ltd. complex located in Ras Laffan Industrial City in the State of Qatar.

MODELLING OF THE QATARGAS LNG COMPLEX

The Qatargas LNG complex designed and built in the period between 1992-1998 is divided into the Upstream and the Downstream sections.

The Upstream consists of the offshore production facilities, the submarine pipeline and the onshore receiving facilities. The offshore facilities comprise the wellheads, three process/utilities production platforms, accommodations platform, flare structure and bridges/support platforms. The upstream onshore facilities consist of the slug-catcher, three condensate stabilization units, condensate storage and loading facilities.

The Downstream section consists of three LNG trains supported by utilities and offsites facilities.

The main purpose of the RAM study was to develop a model of the complete complex to assess the overall availability of the facilities, and to assist in understanding the contribution of the different units to the overall unavailability. From this study, different ways to improve the facility's availability could be proposed and tested using the model. The best of these options would then be proposed for implementation. The model would also be used to determine the effect that any changes of the facilities could have on its availability.

The simulation for the Qatargas LNG Facilities included the following units:

1) Offshore Wellhead Facilities
2) Three Offshore Production/Utility Platforms
3) Onshore Reception Facilities with Three Stabilization Units and the Condensate Storage and Loading system
4) Three LNG Production Trains
5) Onshore Utility Systems
6) LNG Storage and Loading System

For the purpose of the model the complex was divided in Offshore including the first two units mentioned above and the Onshore comprising the remaining units.

The QatarGas Facility's RAM model was built using the software package called MAROS (Maintainability, Availability, Reliability and Operability Simulation). The program predicts the performance of a system through application of an event driven algorithm that will create life-cycle scenarios of the system which include its reliability, maintainability and operating policies. Many life-cycles are used to generate a mean life-cycle which forms the basis of the model results. Statistical deviation is then employed to quantify potential variation from the mean.

The MAROS model uses information from the Reliability Block Diagram (RBD), a diagram built from the Process Flowsheets which consists of a set of blocks representing discrete steps in the process. Each block is connected via a series of nodes. For a success path to be found through a number of blocks in series, all have to be operating. If one block or process step is in a failed mode the path cannot be completed and the process is unsuccessful. If two or more blocks / processes are redundant (they are drawn in parallel), then more than one success path is allowed through that section. The model contains over 3,000 blocks, each one with failure and repair reliability data as well as capacity losses for the individual nodes. About 100 simulations are normally run to generate availability projections for a 20 years operating facility.

The RBD block number, reliability data source reference and equipment/instrument tag number are incorporated into each MAROS equipment specification database to ensure an effective audit trail.

Failure and repair data contained within the model are described by different distribution functions, i.e. exponential, normal, log normal, Weibull, triangular, rectangular, etc. Capacity losses at failure and repair are expressed as a percentage of the production rate at the affected unit.

In addition to the unscheduled failures, all major maintenance activities requiring equipment shutdown are included as scheduled events at the required frequency (in years) and duration (in hours).

Where complex interactions between elements of the model are required, conditional logic is used to ensure a good representation of the real world. The logic function is divided in two parts:

1) Identification of which events within the model, or combination of events, will initiate the conditional element.

2) Definition of the action which will occur when the conditional element is activated. This places a marker at the proper point within the model and quantifies the capacity loss incurred at failure and repair.

An example of this would be the logic used to prevent a common spare from being used by two or more production trains at the same time.

The failure and repair information used in the model for unscheduled events was obtained from the sources shown below. The sources are listed in order of priority,

1) Qatargas maintenance records

2) Equipment manufacturer data supplied in response to the project reliability questionnaire and protected by confidentiality agreements.

3) Report issued by the Gas Research Institute (GRI) on Development of an Improved LNG Plant Failure Rate Database.

4) Offshore Reliability Data (2^{nd} & 3^{rd} edition OREDA 92 & 97)

5) IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component and Mechanical Equipment Reliability Data for Nuclear Power Generating Stations.

Scheduled shutdown events used in the model were based on equipment manufacturer specifications and Qatargas experience.

Even though the accuracy of the failure rate data describing the performance of the different systems is limited, the Monte Carlo simulations used for statistical analysis is a powerful tool for studying such a complex problem and very helpful in determining interrelationship between systems. In general, it can be said that the uncertainty built into the absolute value of a result is greater than the results obtained by relative measures with respect to a base case. Thus, the model’s absolute results have to be interpreted as a performance indicator rather than as a quantitative deterministic value of the reliability/availability for the complex. However, any relative results (movement from a base case or results from parametric sensitivity study) will provide a very good indication of the system’s behavior in not only a qualitative aspect but also quantitatively.

It should be emphasized that human error factor is an important part of the overall reliability analysis. Studies have reported that human error in the operation of a chemical plant accounts for 50 to 70% of all errors. Normally reliability methods only account for equipment failures mainly for the reason that equipment can be analyzed in systematic and comprehensible ways, while human being performance varies greatly depending upon the personal situation and social environment. Even though it is difficult to develop a quantitative model of operators, their failure rates are usually included into equipment failure rate data. Thus, implementation of Process Safety Management programs directed to improving operating procedures, providing more technical and safety training, etc. can be used to recognize human factors in reliability issues and should have a large effect on overall plant reliability and profitability.

MODELLING ASSUMPTIONS AND EXCLUSIONS

The main assumptions made in the generation of the model were:

1) The facility operating life is 20 years.
2) P&IDs used in the construction of the model are an accurate reflection of the physical facilities.
3) All production wells have equal production capacity, which does not vary through the 20-year field life.
4) The storage and tanker loading system only affect production if it were to fail while tanker-loading operations were taking place.
5) Tanker loading transfers all LNG held in the tanks (no losses).All tankers will arrive pre-cooled with a capacity of 125,000m^3. Tanker loading rate is 10,000 m^3/hr.
6) The methanol injection systems located on the wellhead platforms are only used during well start-up operations. Therefore, any failure of the methanol system must be combined with a requirement to bring a well on line before any losses will be incurred.
7) The diesel system is only considered for its impact on power generation. Fuel gas is considered the primary fuel; therefore, failures of the diesel supply system will only affect production when they are concurrent. This is modeled using conditional logic to ensure an effective representation.
8) Split range valves are modeled as series elements throughout the model. Loss of control of either valve is assumed to incur a production loss.

Systems or equipment that do not form part of the normal and continuous operation of the facility were excluded from the model since their failure do not have an adverse effect on production. Example of these are: offshore chemical injection systems, open and/or closed drain systems, defrost gas system, propane de-inventory system, pig launchers/receivers, certain ESV valves in the pipeline reception facilities which are normally isolated during operation, etc.

Once the model was assembled and running, an independent audit was conducted by an expert in reliability and a representative of Qatargas to certify its validity.

MODEL RESULTS / DISCUSSION

Overall Performance Analysis

The simulation was run for 100 life-cycles (each cycle corresponds to 20 years of operation) and from these cases, an average base case percentage production was obtained. The variation from the mean for each of the 100 simulation runs is shown in Figure 1. Based on a confidence level of 95%, the LNG percentage production had a range of +/- 0.2 percentage points.

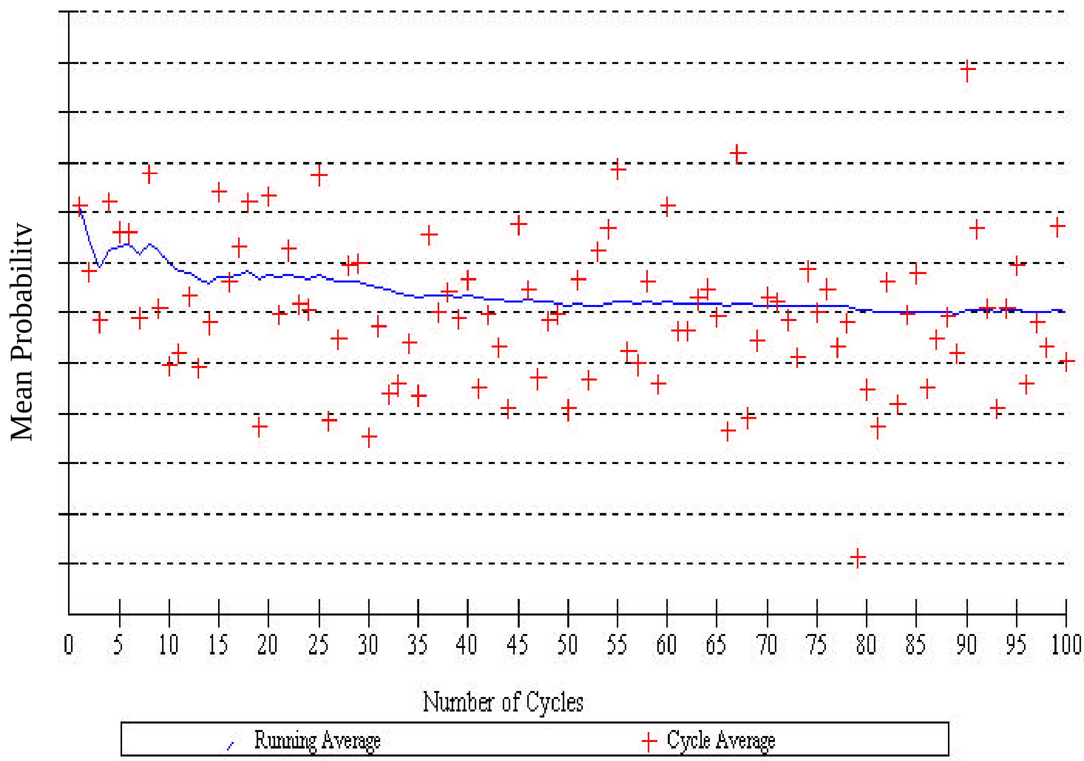

Figure 1-Average % Production per Simulation run

The resultant probability distribution is shown in Figure 2 below.

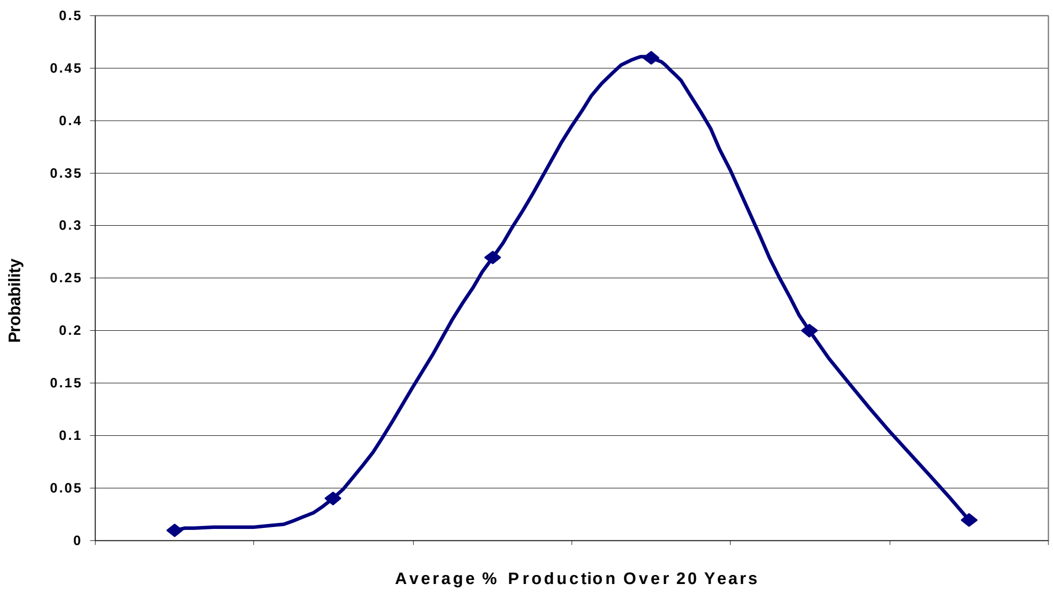

Figure 2- Probability Distribution for 100 Simulations

These figures show the result of the simulation falling within a reasonably small data band which indicates the model contains sufficient resolution to quantify results at an appropriate level of confidence for the Qatargas complex.

Figure 3 shows the expected facility efficiency profile for the 20 year life-cycle. As shown in the figure, the large spikes dominating the profile are caused by the planned shutdown events.

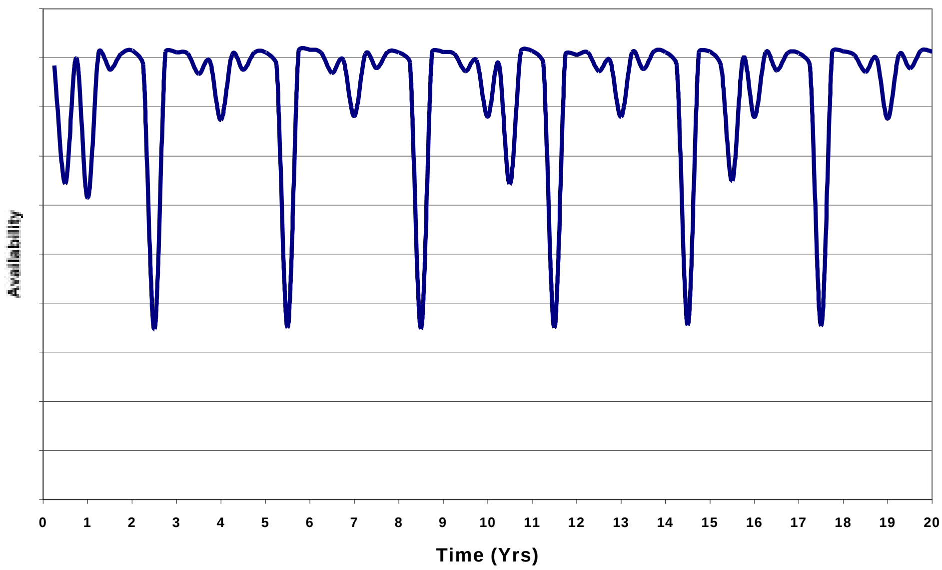

Figure 3- Facility Availability over 20 Year Life

This graph indicates that a possible way of improving plant availability is by improving maintenance, operations and sparing strategies. If all the planned shutdown activities were to be removed, the availability of the Qatargas complex would increase by about 3.5 percentage points. Consequently, the outstanding difference, or the remaining factor preventing the facility from achieving 100% availability, is the unscheduled shutdown of the plant complex.

Analyzing Production Rates

The following chart (Figure 4) shows how much of the total plant operating life is to be spent at a given production capacity. This provides a good indication of the complex effectiveness. It shows the complex is operating at full capacity for about 82% of the 20 years life cycle, while it is shutdown about 1.7% of the time.

The 12% of the plant's lifetime spent at 66% operating capacity is mainly due to one of the three LNG trains being shutdown for planned or unplanned reasons.

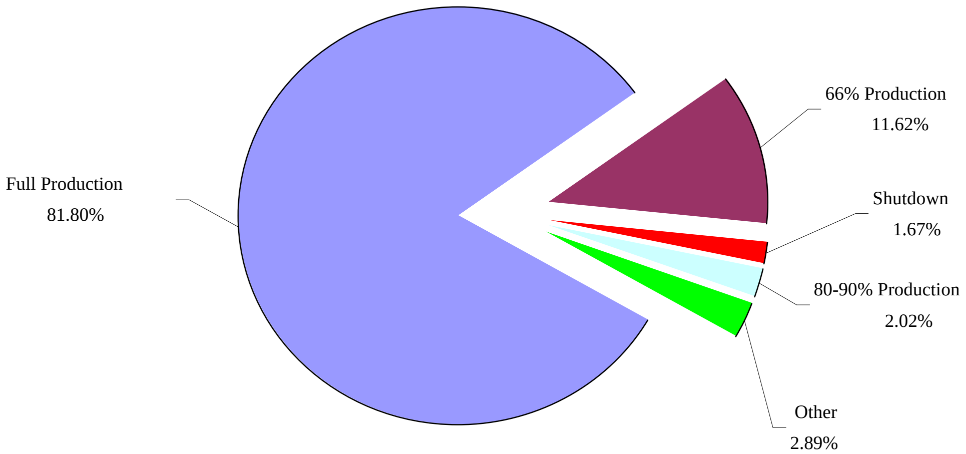

Figure 4 - Percent Life for Each Production Rate

Losses Breakdown By Levels

The following table, Table 1, outlines the sequential study of losses associated with the different units/systems of the Qatargas LNG complex. The complex is broken down into levels, starting with a broad system/aspect of the complex and working down through detailed areas within this system. For the purpose of the paper, only a few of the areas are expanded in detail. Figures throughout the paper that illustrate the breakdown of the losses associated with the different levels are noted in the table.

Table 1. Losses Breakdown Of An LNG Complex

Level 1 (Figure 5)	Level 2	Level 3	Level 4	Level 5
Offshore	**(Figure 6)** Utility System (PU) Prod. System (PU) Prod. System (PR) Wellhead Platform			
Onshore	**(Figure 7)** LNG Trains →	**(Figure 8)** Planned S/D Refrigeration → Gas Chilling/Liq. Acid Gas Dehyd./Mercury Others	**(Figure 9)** MR Ref. Comp. → C3 Ref. Comp. C3/MR Coolers	**(Figure 10)** LP MR Comp. MP MR Comp. HP MR Comp.
	Cond.Stabilization & Storage →	**(Figure 14)** Pipeline Recep. Flare System Cond. Storage OffGas Comp. Units Liquid Gas Others		
	Common Utilities →	**(Figure 15)** Steam System Fuel Gas System Seawater System HP & LP Flare System Fresh Water System Power Generation Air System		
	Metering Station			
LNG Storage & Tanker				

Figure 5 shows that the overall losses (scheduled and unscheduled) are mainly due to the Onshore facilities (76% vs 24% for the Offshore) The overall losses due to the LNG Storage and Tanker Loading System are very minor and thus not analyzed further:

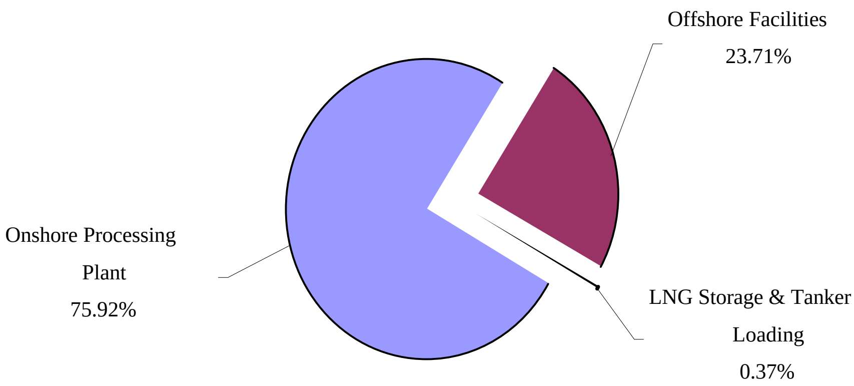

Figure 5-Systems Contribution to Overall Losses (Level 1)

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Of the Offshore losses the greatest percentage (68%) is associated with the utility platform. This is because the system supplies the utilities to both production platforms; thus, this system failure will result in total loss of production (see Figure 6).

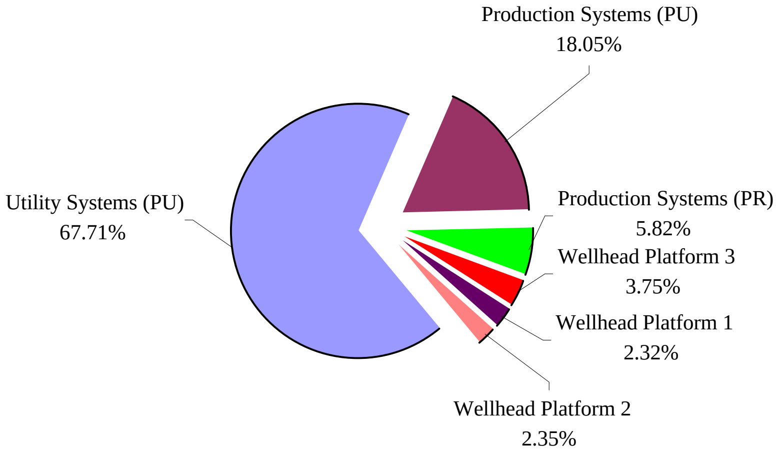

Figure 6- Offshore Facilities Relative Losses (Level 2)

The differences between the Wellhead platforms are due to the different number of wells which feed each platform with each well assumed to be equal. Further breakdown of the Offshore Facilities is not given here, but they are shown in the Overall Losses graph presented in Figure 12.

Looking at the Onshore facilities losses, Figure 7 shows that the three LNG trains are the largest contributors to relatives losses (94.5%).

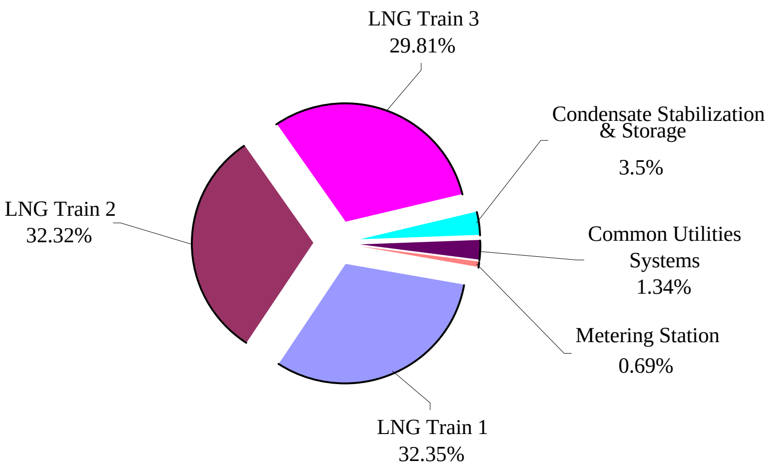

Figure 7 - Onshore Facilities Relative Losses (Level 2)

Figure 8 shows the breakdown of the losses internal to any one of the LNG Trains. Of these losses, the scheduled shutdown events together with refrigeration losses account for 84% of all losses, each contributing 42%.

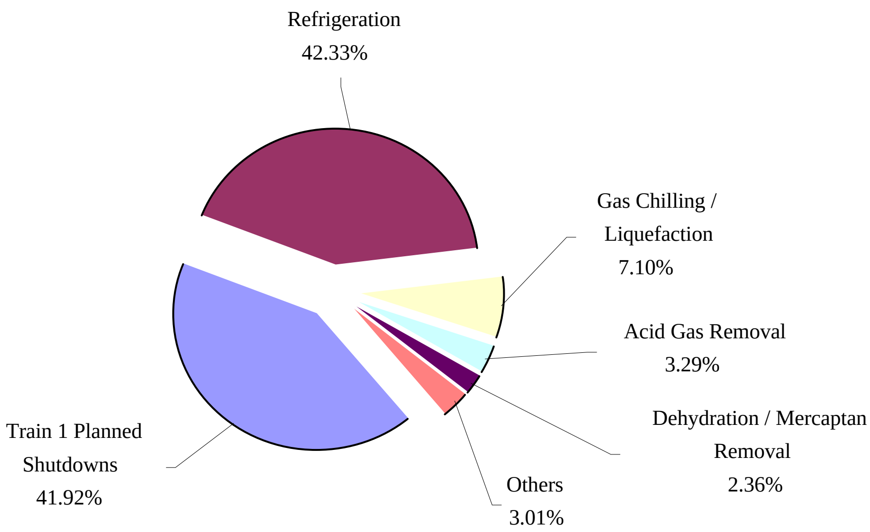

Figure 8 - LNG Train Relative losses (Level 3)

The losses associated with the LNG Train refrigeration systems are shown further broken down to the next level in Figure 9. It can be seen that the MR compressors are the largest contributors to relative losses (63%).

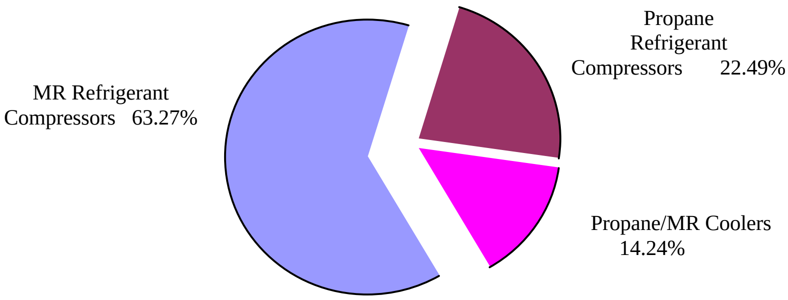

Figure 9 - LNG Train Refrigeration Systems Relative losses (Level 4)

Breaking down the MR compressor losses to the next level shows that the losses are approximately equal (33%) for each compressor (LP,MP,HP). See Figure 10.

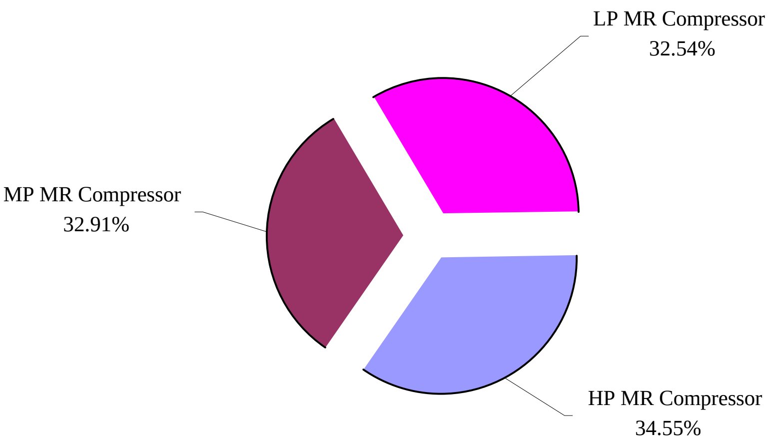

Figure 10 - LNG Train MR Refrigeration Compressor Relative Losses (Level 5)

Overall

Figure 11, provides a summary of the overall losses for the main systems and includes the breakdown of losses per train. The figure shows the LNG trains as being the largest contributors to actual losses. This area is followed by the offshore production and utility modules, the condensate stabilization and storage, common utilities and the three wellhead platforms.

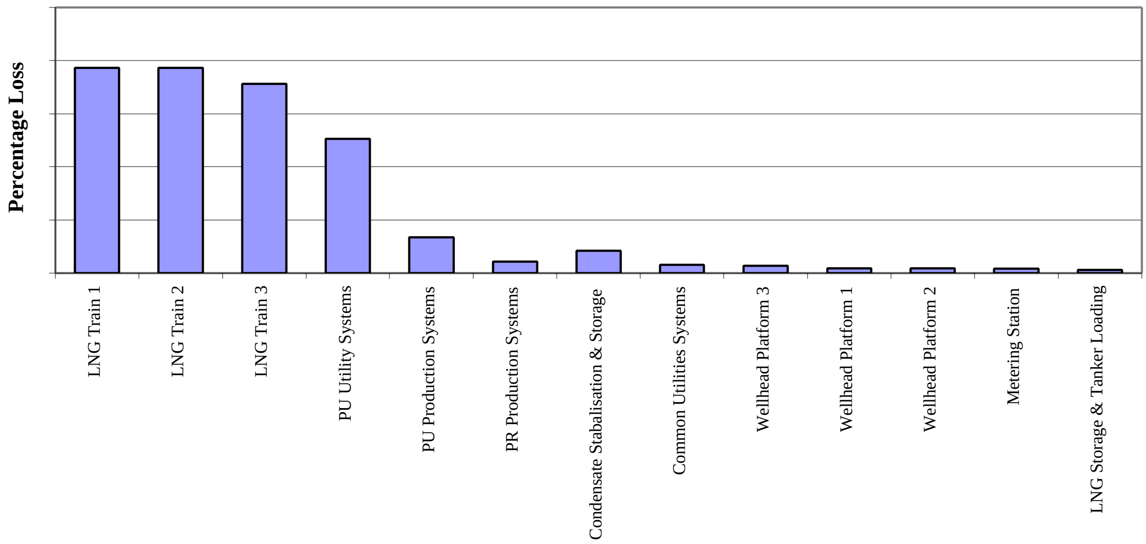

Figure 11 - Main Complex Overall Relative Losses

The following two bar charts provides an increasingly detailed breakdown of the losses incurred by elements of the model. At these levels of detail, the total number of lines on the chart becomes very large (60 and 83 respectively), therefore, only 20/25 contributors are presented to provide a readable chart. The chart in Figure 12 shows again that next to the planned shutdown of the LNG trains and of the offshore facilities, the refrigeration systems are the main factor in terms of relative losses.

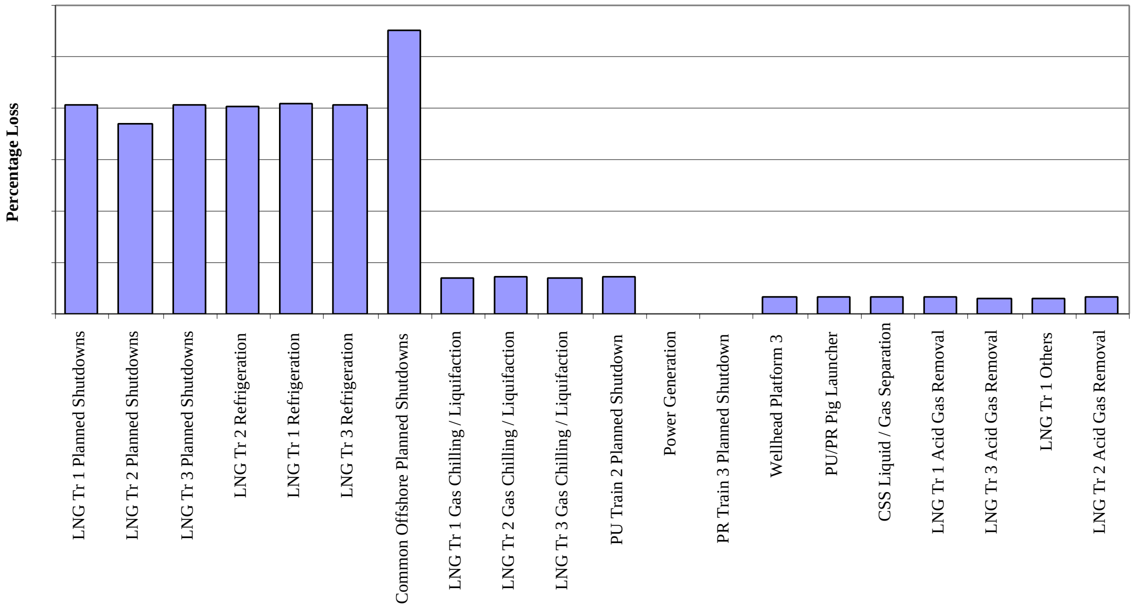

Figure 12- Sub System Relative Losses

Figure 13 shows that of all the systems studied in this LNG complex, the MR and propane compression systems are the most critical part of the refrigeration systems in terms of losses.

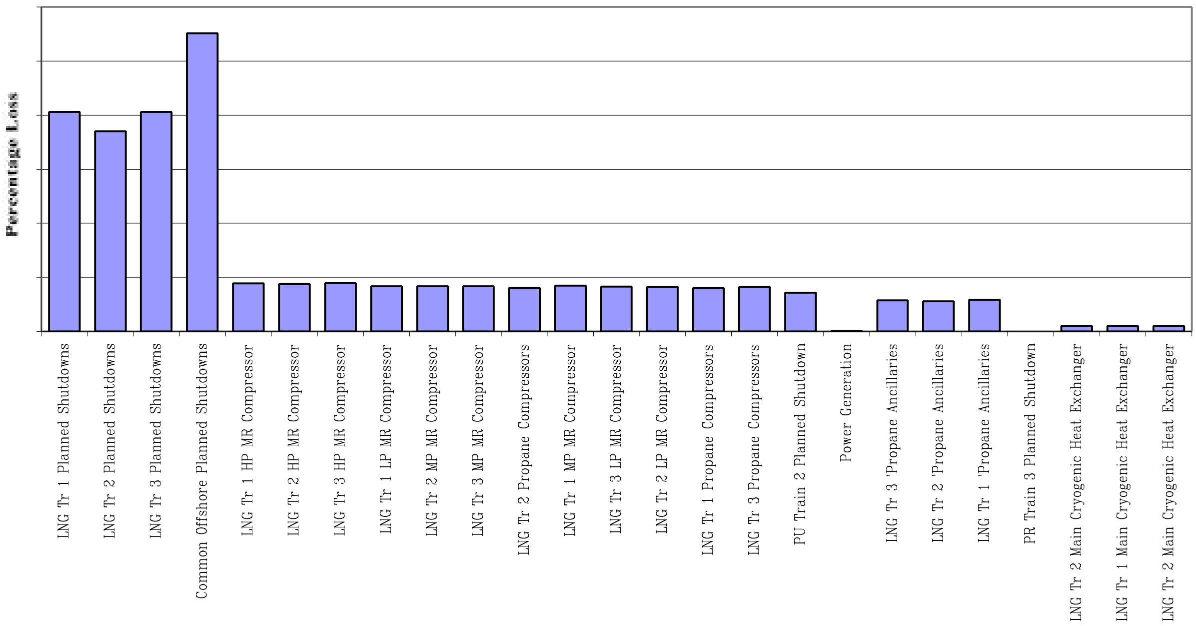

Figure 13-Lowest Level Relative Losses

This figure indicates that following improvement of planned shutdowns, efforts should be directed toward the reliability of the refrigerant compressors (MR and propane), followed by reliability of the propane ancillaries system (propane MR coolers, suction system and desuperheaters and condensers).

A detailed breakdown of the relative losses of the Condensate Stabilization and Storage Unit is shown in Figure 14. For that system the bulk of the relative losses are distributed between liquid/gas separation, pipeline reception facilities, flaring and condensate storage. Due to the high levels of installed redundancy the compression units do not account for significant losses.

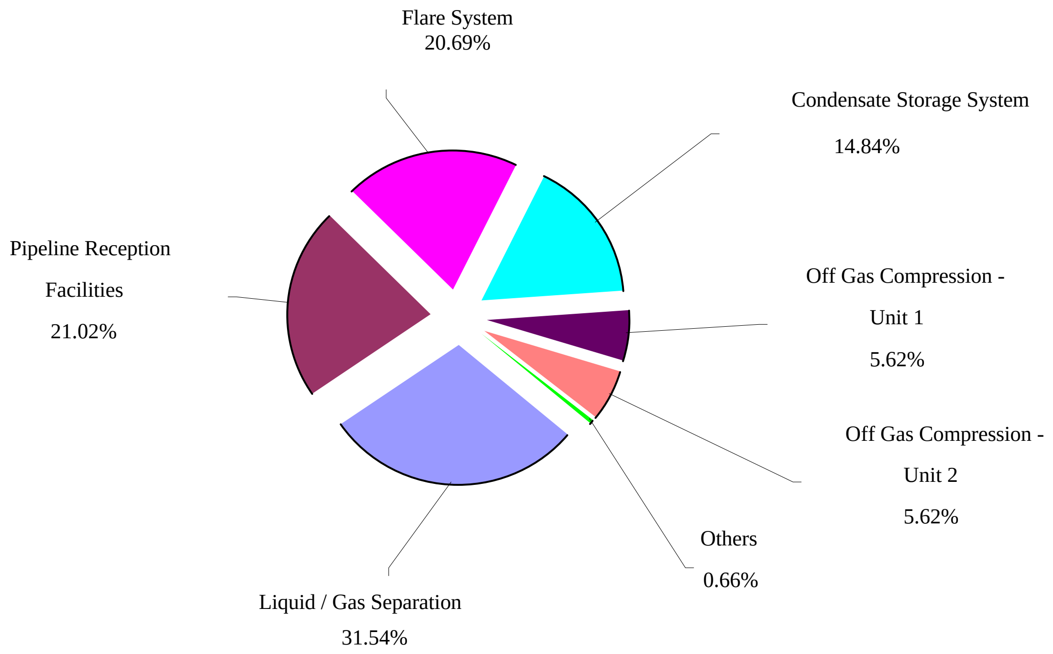

Figure 14- Condensate Stabilization and Storage Relative Losses (Level 3)

The Onshore Common Utility System is shown in Figure 15. It indicates that the steam system comprises the bulk of relatives losses associated with this system. The high level of redundancy within the utility system is the main reason for the low criticality in terms of product losses.

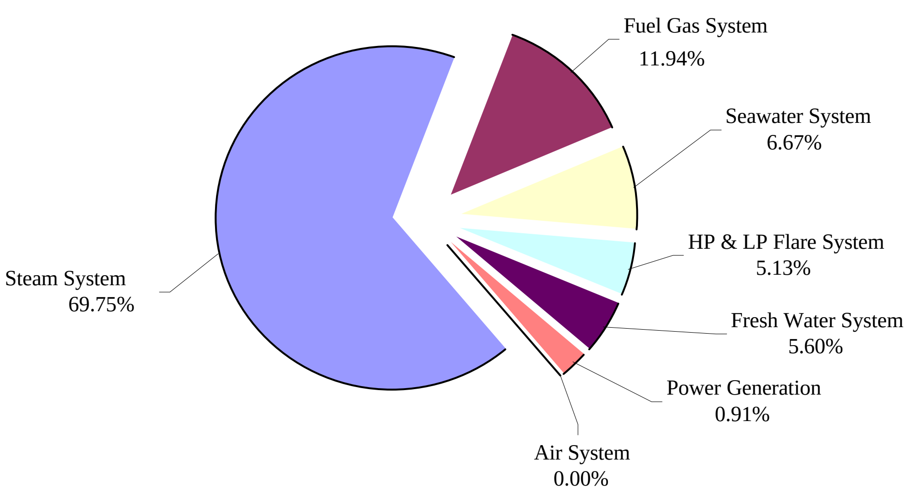

Figure 15-Onshore Common Utility Systems Relative Losses (Level 3)

Sensitivity Analysis

In order to determine the effect that the uncertainty in the failure rate data has on the reliability/availability of the plant, the whole system was also modeled increasing the compressor failure rates by a factor of two and four. The results are presented in Table 2 and indicate that the plant production rate is relatively insensitive to fairly large changes in the failure rate data of these equipment items.

Table 2. Failure Rate Data

Compressors Failure Rate Data	Delta Availability Percentage Points
Normal Failure Rate	Base
2 x Normal Failure Rate	-0.2
4 x Normal Failure Rate	-0.7

Similarly, a reduction in planned shutdown of about 25% generated an improvement of 0.3% points over the base case.

CONCLUSIONS

A RAM study performed for the Qatargas LNG complex verified and qualified their existing plant performance. In addition, the RAM model identifies performance improvements that could be achieved through a structured review of operations, maintenance and spare strategies.

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