Bayesian network modelling for offshore installations: Gas turbine fuel gas release with potential fire and explosion consequences

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ABSTRACT: This paper illustrates the benefits of applying a Bayesian Network in quantitative risk assessment. The focus of the illustration is based on the potential release of fuel gas from a gas turbine used for electrical power generation on an offshore platform. The potential consequences that follow said release, such as fire, explosion and damage to equipment within an electrical generation module are also analysed. The construction of a Bayesian Network model, based upon initial research work, illustrates the interactions of potential initial failures, hazards, barriers (gas detectors and fuel shut off systems) and the subsequent consequences of a fuel gas release. This model allows for quantitative analysis to show partial validity of the BN. Partial validity of the model is demonstrated in a series of test cases.

1 INTRODUCTION

This work focuses on the development of a Bayesian Network (BN) model for modelling control system and physical failures of a gas turbine utilized in offshore electrical generation. The intention is to model a sequence of events following several component failures, under certain conditions and assumptions. These initial failures are defined in two categories: control system failures and physical or structural failures. This should provide a base with which to expand the BN to facilitate the requirement of having a dynamic risk assessment model that allows for accurate representation of the hazards and consequences associated with gas turbine fuel gas releases.

The research presented within this report is an expansion of previous research conducted for an electrical generation system of an offshore installation. The initial research, conducted by Loughney & Wang (2016), focused on creating a dynamic risk assessment model for an electrical generation system, based upon one initial component failure in the form of a Rotor Retaining ring failure. The dynamic risk assessment model is for application in an Integrity Case. The Integrity Case is, in principle, an extended Safety Case. From the initial research a sequence of events and a BN was produced to demonstrate the cause and effect relationships between the safety critical elements of the electrical generator. The BN demonstrated a number of potential consequences, such as: Gas Import Riser failure; High Pressure Gas Flare Drum failure; and, Fuel Gas Release & fire. These final consequences were not expanded or demonstrated in great detail to keep the initial model as simple as possible while achieving valid results. The BN to be presented here is an expansion of the previous model, focusing on the consequences Fuel Gas release and Fire & Explosion. In the initial BN, a gas fire was represented as a single event in the network, this research expands by constructing an entire new network to demonstrate the consequence of fuel gas release in much more detail (RMRI Plc., 2009).

2 BACKGROUND

Gas turbines are used for a variety of purposes on offshore installations, such as: power generation, compression pumping and water injection, most often in remote locations. Gas turbines are most commonly duel fuelled. They have the ability to run on fuel taken from the production process under normal operations, known as fuel gas. They can also run on diesel fuel in emergency circumstances. Typically, offshore gas turbines run from 1 to 50 MW and may well be modified from aero-engines or industrial engines. The most often used gas turbines are Aeroderivative, particularly for the gas generator. It is known that relatively little information is contained within safety cases regarding the operation and safety of gas turbines. What is contained is the model, manufacture, ISO power rating (in Mega Watts (MW)), the fuel types and the location of the turbine shown on the respective installations drawings. Additional information can be found on occasion, such as: text regarding the power generation package or back-up generators. However, information in reference to integrity management and maintenance can be very limited (HSE, 2006). This information, or lack of, provides sound reasoning to produce dynamic risk assessment models regarding the integrity and safety of gas turbines.

Industrial power plants are critical systems on board offshore platforms as they supply electrical power to safety critical systems, which not only provide safe working for crew and other personnel, they also protect the integrity of the offshore platforms systems and structures. All of this protection stems from power supplied by the electrical generation systems, which is why offshore platforms and marine vessels ensure they have back-up generators in the event that one or two generators fail to operate (Perera, *et al.*, 2015). Usually, on offshore platforms, there are three electrical generation systems, with two in the same module and the third in a separate module on a higher level which usually acts as the emergency generator. Despite the safety precautions behind the number of generators and their locations, there is still the possibility of all generators failing to operate (Ramakrishnan, 2007).

Furthermore, in recent years there has been a marked increase in fires associated with fuel gas leaks with offshore gas turbines. A detailed review of offshore gas turbines incidents conducted in 2005 showed that there were 307 hazardous events over 13-year period, from 1991 to 2004. The review concerned itself with over 550 gas turbine machines. The analysis concluded that the majority of incidents (approximately 40%) occurred during normal operations, with approximately 20% during start-up, another 20% during or after maintenance and the remaining 10% of fuel gas leaks occur during fuel changeover. With the majority of incidents occurring during normal operations, the fuel gas detection is heavily reliant on either turbine fuel detectors and/or fire and gas system detectors. This is due to the modules containing the electrical power generators being almost totally unmanned during normal operation. It was also found that based upon the review conducted on machines in the stated 13-year period, shows that approximately 22% of gas leaks remained undetected. Subsequently, 60% of those undetected leaks were found to have ignited (HSE, 2008).

It is situations such as those described that increase the requirement for a dynamic risk assessment model to accurately monitor the consequences of failures within gas driven generators as they are critical in the survival of crew members as well as the integrity of the respective offshore installation.

3 FUEL GAS RELEASE MODEL

The model representing the potential for fuel gas release from an offshore gas turbine, along with the further consequences of fire and explosion, begins at the point of several initiating events. These events are the beginning of the sequence of events and continue through the point of a potential gas release, the barriers involved in preventing and stopping the release and the potential consequences should these barriers fail. A full step by step procedure of constructing the BN can be found in the initial research of Loughney & Wang (2016).

3.1 *Model Limitations*

3.1.1 *Space and Domain Limitations*

The purpose of the model is to show the effects of several component failures on a gas turbine, and how these can lead to a fuel gas release. Hence, the consequences of said fuel release are analyzed. To do this, the boundaries of the model need to be defined. These boundaries are concerned with the affected area, the detail of the consequences and the ignition types and sources. The outlined assumptions and limitations concerned with the model domain are as follows:

- The model has been built for the situation where the offshore platform contains no crew and hence does not consider fatalities. There are two key reasons for this: The first is that the BN model is for an NUI (Normally Unattended Installation) Integrity Case, where persons are not present on the platform for extended periods of time, and the installations are monitored from other platforms or onshore. Secondly, the BN is part of continual development of an Integrity Case which focuses on maintaining the integrity of the equipment as a priority, as well as the effects of incidents on the environment. Hence, fatalities are not part of the BN model consequences.
- The model is designed to demonstrate the hazards and consequences associated with the fuel gas release from an offshore gas turbine. Hence, the consequences regarding fire and explosion are not concerned with the probability of other hydrocarbon releases contributing to fires and explosions.
- The scope of the model is primarily within the power generation module of a large fixed offshore platform. Therefore, the section of the model assigned to the probability of equipment damage due to fire and explosion is confined to the equipment and machinery located only within the stated module.

- The model is representative of fuel gas being released into the module and not within the gas turbine itself. This is due to the fact that should there be a gas release within the turbine, it is assumed that the combustion chamber is of sufficient temperature to ignite the fuel. However, the presence of an ignition source within the confines of the module is not a total certainty. The node “Ignition Source” represents this uncertainty and possibility of a source being present.
- While the level of consequence is confined to the module, and the presence of an ignition source is not certain, it is still possible for the gas levels to reach dangerous levels. These dangerous levels do not represent a direct threat to personnel as they are not present. The dangerous levels relate to the potential environmental impact of harmful substances being released into the atmosphere. This is in conjunction with the revised requirement of safety cases for offshore installations to contain precautions for potential environmental impact of offshore incidents and accidents (HSE, 2015).

3.1.2 *Data Limitations*

It is important that some remarks are made regarding the uniformity of the data within the model. Statistics exist in a number of formats and originate from many sources. When formulating a model as specific and confined as the one created in this research, it is almost impossible to gather data sets from the same consistent sources.

It is important to understand that many statistics are not fully representative of reality. For instance, there are cases where the full extent of an incident is not reported, such as a fuel gas release. For example, from 1992 to 2014, 40% of fuel gas and power turbine gas releases were not detected by an automatic sensor, but were detected by personnel. Such detection was largely via smell, visual observation and use of portable detectors. In the instances of personnel detection, the recording of information is scarce, with 56% of fuel gas release incidents having little to no information regarding the location and cause of the release and in some cases, the extent of the dispersion. Furthermore, the majority of the 56% of releases with incomplete information and data were regarded as “Significant”, in terms of their severity level (HSE, 2014). It is issues within the data, such as this, that provide sound reasoning to limit data to automatic detection and fuel shut down barriers.

There are some differences in terms of data relating the type of installation operating the same type of gas turbine generator. However, the location of the installations is restricted to the UKCS (United Kingdom Continental Shelf) and the North Sea. Much of the data represented in the model is adapted from gas turbines operating on fixed platforms, yet it is not feasible to obtain data from all sources relating to fixed installations. This limitation with the data goes back to either the absence of data or the lack of appropriate data recording. Hence, data is obtained from fixed installations and FPSOs (Floating, Production, Storage and Offloading) which make use of very similar gas turbine machines.

There are also differences with the age of the data and the data sources used in the Fuel Gas Release model. All data utilized is taken from sources post 2002. Most of the data close to 2002 have been obtained from OREDA-2002 (Offshore Reliability Data), as full access to the database at this time was available. On the other hand most of the conditional data used to complete the CPTs (Conditional Probability Tables) for the nodes, in the BN, are from risk assessment projects conducted on offshore installation for gas turbines, with the main focus of the projects being hydrocarbon and fuel gas releases. These risk projects were conducted post-2009 by RMRI, Petrofac and Maersk.

Finally, most of the nodes are based upon statistics, while two of the nodes incorporate subjective judgement by utilizing a symmetric algorithm. By combining information in this way it allows for situations that have little to no information to be addressed. This process does not compromise the validation and analysis of the model although it is important to take note of this when interpreting the information presented in the results.

3.2 *Structure of the Model*

The fuel gas release model is shown in Figure 1, which also depicts the marginal probabilities for each node. The BN is primarily designed to represent key initial events of gas turbine failure, in two main areas: the turbine control system and the physical structure. Following the initial events and failures the BN model is designed to show the possible progression of these failures into fuel gas release and the potential fire and explosion consequences that can occur. There are a number of more intimate functions that the model provides. Firstly, the initial stages of the model demonstrate which initial event or hazard demonstrates the greater probability for potential gas release, as well as whether the greatest threat originates from the turbine control system or the physical structure. Secondly, the cause and effect relationships between the barriers are demonstrated in terms of the probability of whether a certain barrier operates as expected, based upon the operation of the previous barriers. Thirdly, possible consequences can occur following a fuel gas release. These can be: none, a gas leak only, fire, explosion and a fire/explosion resulting in equipment damage.

The graphical structure of the model is designed to keep the nodes that fall under the same group together and organized in a “top down” manner. The five root nodes and the inference node are close together at the top. Then the categorized nodes are next in the top down sequence. Continuing from the failures there is a potential incident, which then leads to the barrier nodes. Pending the probability of success or failure of the barriers there is potentially another incident (“Continuous Gas Release”). Following from the barriers there are further incidents, accidents and consequence nodes which are systematically introduced. One node does remain slightly anomalous from this organization. The “ignition Source” node is grouped along with the incidents, accidents and consequences as it directly affects one of the incidents.

There is one transfer node within the fuel gas release BN which links the initial research conducted by Loughney & Wang (2016). This node is “Fuel Gas Feed Impact”. Through this node any updates from the initial BN model results in updates to the posterior probabilities of the fuel gas release BN. The model contains nineteen chance nodes with either two or three states. Figure 2 demonstrates the structure of the fuel gas release model.

3.3 *Establishing Conditional Probabilities*

When constructing a BN, the prior probabilities are required to be assigned locally to the probability link, $P(Parent(A_i)) \rightarrow P(Child(B_i))$, as a conditional probability, $P(B_i|A_i)$. Where i is the number of possible states of the parent node and the child node. However, it is not always a straightforward process to obtain the relevant data. In principle, the majority of the data can be acquired through failure databases or experimentation. However, designing and conducting experiments can prove difficult and historical data does not always satisfy the scope of certain nodes and CPTs within a BN. Therefore, in practice, it is necessary to rely on subjective probabilities provided by expert judgement as an expression of an individual’s degree of belief. However, since subjective probabilities are based on informed guesses, it is possible for deviation to occur when the data is expressed as precise numbers. It is possible to apply a fully subjective approach to construct conditional Probability Tables (CPTs) in a BN (S. Loughney, 2016).

This process involved experts providing their judgement through a Pairwise Comparison (PC) method. The data from the PC were further analyzed using Analytical Hierarchy Process (AHP) and relative importance weights were determined from this for each parent node in question. These weights were then applied to an algorithm that allows a large child CPT to be constructed cell by cell. This method of compiling data for large CPTs proved simple to implement and produced accurate results for the BN. However, it was found that a time-consuming part was the gathering of data from experts through PC questionnaires.

As the process of creating PC questionnaires, distributing them and waiting for feedback can be time consuming it is proposed that this process is amended by utilizing hard data from risk assessment experimentation and historical data. This entails utilizing hard data from the parent nodes and sections of the child node CPT to create relative weights for the parent nodes and apply those to the symmetric method algorithm.

3.4 *Symmetric Algorithm Utilizing Hard Data*

The symmetric method provides an input algorithm which consists of a set of relative weights that quantify the relative strengths of the influences of the parent-nodes on the child-node, and a set of probability distributions the number of which grows only linearly, as opposed to exponentially, with the number of associated parent-nodes. Yet the most common method of gathering the required data for the algorithm is to use expert judgements. However, it is also possible to utilize the symmetric method with historic data and experimentation. While it is very difficult or not possible to complete a large CPT in a BN using only hard data, it is possible to obtain key conditional probabilities for a node and apply them to the symmetric method to complete the CPT.

The derivation symmetric method algorithm is not outlined here, but the method of determining the relative weights of parent nodes is outlined. The derivation of the symmetric method can be found in Das (2008).

3.4.1 *Determining Relative Weights Utilizing Hard Data*

To demonstrate the method of determining relative weights through hard data, take the example network in Figure 1.

While it is not possible to accurately obtain $P(D|A, B, C)$ or even $P(D|A, B)$ through historical or experimental data, it is possible to obtain the conditional probability of event Z given the individual parents. i.e.; $P(D|A)$, $P(D|B)$ and $P(D|C)$. These conditional probabilities can be used to develop normalized weights for the parent nodes.

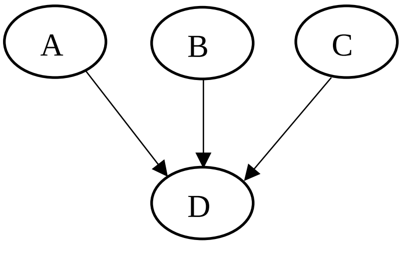

Figure 1: Simple BN representing 3 parents and 1 child

As mentioned previously, in the symmetric model the individual local conditional probabilities of the parent to child can be distributed by relative importance for the associated child node, i.e. the normal-

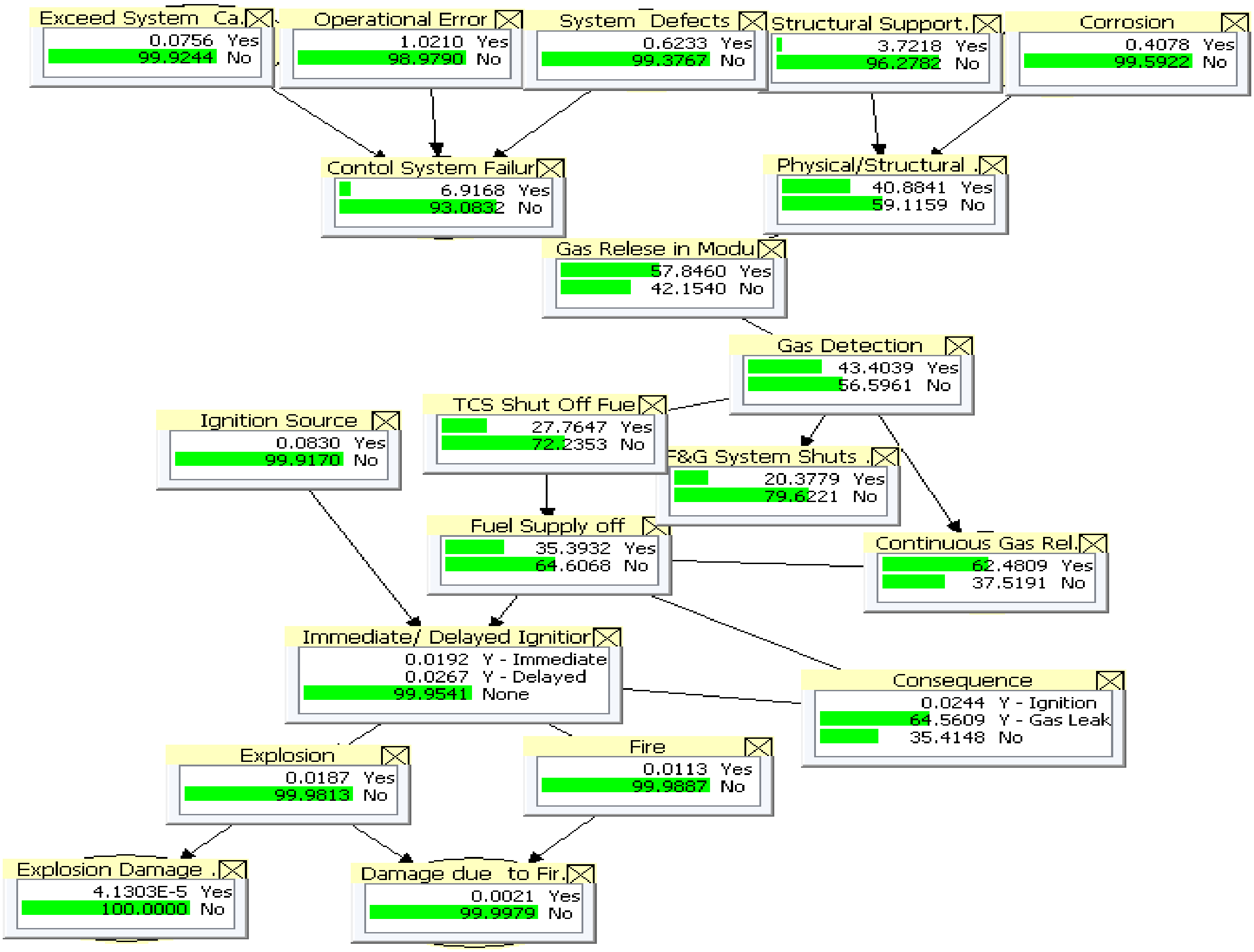

Figure 2: Marginal probabilities for each node within the Fuel Gas Release BN

ized weight. Hence, in normal space and using the notation outlined in Figure 1, the probability of *D* being of state *“Yes”* given that the probability of *A* being in state *“Yes”* is equal to $\hat{X}_a$, where $\hat{X}_a$ is the relative importance of the parent node *A*. This is applied across all the parent nodes and is demonstrated by Equation 1 (Riahi, 2010).

$$P(\hat{X}_a) = P(D = \text{“}Yes\text{”}|A = \text{“}Yes\text{”}) = \frac{P(X_a)}{\sum_{m=a,b,\dots}^{n} P(X_m)}$$

$$\dots \qquad (1)$$

$$P(\hat{X}_n) = P(D = \text{“}Yes\text{”}|n = \text{“}Yes\text{”}) = \frac{P(X_n)}{\sum_{m=a,b,\dots}^{n} P(X_m)}$$

Therefore,

$$P(\hat{X}_A) + P(\hat{X}_B) + \dots + P(\hat{X}_n) = 1$$

In normalized space, based on the influence of each parent node, the conditional probability of a binary child node "*D*" given each binary parent node, X_r, where $r = a, b, ..., n.$, can be estimated using Equation 2.

$$\begin{aligned} P(D = \text{“}Yes\text{”}|A = \text{“}Yes\text{”}) &= w_1 \\ P(D = \text{“}Yes\text{”}|B = \text{“}Yes\text{”}) &= w_2 \\ &\dots \\ P(D = \text{“}Yes\text{”}|n = \text{“}Yes\text{”}) &= w_n \end{aligned} \qquad (2)$$

$$\sum_{n=1}^{n} w_n = 1$$

Following from Equations 1 and 2, it is possible to calculate the weights of the parents given the individual parent to child conditional probabilities (Riahi, 2010). In order to demonstrate the calculation of relative weights for parent nodes, the network shown in Figure 1 is used as an example. Table 1 shows the local conditional probabilities for the child node “Control System Failure” (*“D”*) given each individual child node.

Table 1: Individual conditional probabilities for Control System Failure

D	A	B	C	Sum
	Yes	Yes	Yes	

Yes	0.0584	0.0610	0.1330	0.2524

The information presented in Table 1 can be represented by Equation 3:

$$P(D = \text{“}Yes\text{”} | A = \text{“}Yes\text{”}) = 0.0584 = P(X_a)$$
$$P(D = \text{“}Yes\text{”} | B = \text{“}Yes\text{”}) = 0.0610 = P(X_b)$$
$$P(D = \text{“}Yes\text{”} | C = \text{“}Yes\text{”}) = 0.1330 = P(X_c) \qquad (3)$$
$$\sum_{m=1}^{n} P(X_m) = 0.2524$$

Hence, with the individual conditional probabilities, the relative weights of the parent nodes can be calculated utilizing equation 1.

$$P(\hat{X}_a) = \frac{P(X_a)}{\sum_{m=a,b,..}^{n} P(X_m)} = \frac{0.0584}{0.2524} = 0.2314 = w_1$$

$$P(\hat{X}_b) = \frac{P(X_b)}{\sum_{m=a,b,\ldots}^{n} P(X_m)} = \frac{0.0610}{0.2524} = 0.2417 = w_2$$

$$P(\hat{X}_c) = \frac{P(X_c)}{\sum_{m=a,b,\ldots}^{n} P(X_m)} = \frac{0.1330}{0.2524} = 0.5269 = w_3$$

Following from this, Equation 2 can be used to show that the summation of the relative weights should be equal to 1.

$$\sum_{n=1}^{n} w_n = w_1 + w_2 + w_3 =$$
$$0.2314 + 0.2417 + 0.5269 = 1$$

As the relative weights for parent nodes *A*, *B* and *C* have been calculated and assigned accordingly, they can be applied to the weighted sum algorithm. Along with the linear compatible parental configuration then a complete CPT can be produced.

Two CPTs were compiled using this method due to the nature of their scope being specific to this model. These nodes are “Control System Failures” and “Physical/Structural Failures”. Figure 2 shows the complete BN and the marginal probability distributions for each node.

4 BN TEST CASES

The BN has been used to analyze a series of possible real world scenarios. All variables from external BNs, i.e. the transfer node “Fuel Gas Feed Impact”, remain unchanged and only those directly linked to the study for Fuel Gas Release shall be altered using the Hugin BN software. The Hugin software allows for evidence to be inserted to all nodes within the network in its “*Run Mode”* function. This evidence is to the degree of 100% in a given state of a node. It is the posterior probabilities that are of interest and are computed given particular evidence of specific nodes.

4.1 *Test Case 1: Control System Failures*

This case study demonstrates the effects of individual and combined control system failures within the fuel gas release model. The effect on the likelihood of a gas release is demonstrated along with the effects on the fuel shut off system. The consequences from these likelihoods are also demonstrated. In this case the likelihood of a continuous fuel release is analysed as well as the probability of the “Consequence” node being in states “Y-Leak” and “None”. This case study is split into two test cases: 1A) is a demonstration of the effects of control system failures on the network, 1B) is a demonstration of the control system failures with the presence of an ignition source.

The probability of a fuel gas release from a gas turbine due to the turbines control system is mostly dependent on three key events; “Exceeding System Capability” (ESC), “Operational Error” (OE) and “System Defects” (SD). The results of test case 1A are presented in Table 2, which shows the probability of gas release, fuel shut off, continuous release and the consequence (“Y_Leak” & “None”)

Table 2: Effects of the turbine control system failures on the posterior probabilities of "Gas Release", "Fuel Shut Off", "Continuous Gas Release" and "Consequence; States: Y-Leak & None"

Focus Nodes	No evidence (%)	ESC (%)	OE (%)	SD (%)
Gas Release	57.85	63.00	63.18	69.50
Fuel Off	35.39	38.43	38.53	42.25
Cont. Release	62.48	59.21	59.09	55.08
Y-Leak	64.56	61.53	61.43	57.71
None	35.41	38.45	38.55	42.27

It is evident that a major system defect would have the greatest effect on the probability of the gas release, as shown by the increase in probability from 57.85% without evidence, to 69.5% when a potential system defect causes a failure. The likelihood of consequences and continuous release decreases with the inserted evidence in control system failures as it is assumed in the model that the gas detection system has no reason to not function correctly at this stage. Therefore, the increase in the probability and level of gas release will increase the probability of gas detection.

Test 1B demonstrates the effects of the control system failures, in the presence of an Ignition Source (IS), on ignition, fire and explosion nodes. Table 3 demonstrates the results of test case 1B.

Table 3: Effects of Turbine Control System failures, with an ignition source present, on the posterior probabilities of "Gas Detection", "Consequences", "Immediate/Delayed Ignition", "Explosion", "Fire" and "Damage due to Fire & Explosion"

Focus Nodes	100 % IS (%)	ESC (%)	OE (%)	SD (%)
Gas Detection	43.4	47.25	47.38	52.1
Y-Ignition	29.34	27.97	27.92	26.23
Y-Leak	9.29	8.85	8.84	8.30
Immediate Ig.	23.31	22.04	22.01	20.68
Delayed Ig.	32.20	30.69	30.64	28.78
Explosion	22.51	21.45	21.42	20.12
Fire	13.56	12.93	12.9	12.12
F&Ex Damage	2.55	2.44	2.43	2.29

The probability of gas detection increases proportionally to the probability of gas release. This affects the relationship between the probability of detection and the probability of accidents and consequence. When evidence is inserted into the "System Defects" node, the posterior probabilities for fire and explosion decrease from 13.56% to 12.12% and 22.51% to 20.12%, respectively. This is because the probability of the gas detection increases with the probability of the gas release, as it is assumed that the gas detectors function as expected. This also has an effect on the fuel gas shut off by increasing the probability that fuel gas will be shut off. Hence, the probability that a fire or explosion will occur decreases.

4.2 *Test Case 2: Gas Release without Gas Detection*

Test case 2A demonstrates the effects a malfunctioning gas detection (No GD) system in the event of a gas release. In test 2A it is assumed that one or more of the initial events has occurred and a Gas Release (GR) is observed. In this case the likelihood of a continuous fuel release is analysed as well as the probability of the "Consequence" node being in states "Y-Leak" and "None". Table 4 demonstrates the results.

Table 4: Effects of a Gas Release without Gas Detection on "Consequences", "Continuous Gas Release", "Fuel Shut Off" (TCS, F&G and Fuel Off) and "Gas Detection"

Focus Nodes	No Evidence (%)	GR (%)	No GD (%)
Gas Detection	43.4	74.87	-
None	35.41	60.2	1.22
Y-Leak	64.56	39.78	98.74
Cont. Release	58.81	29.26	99.57
Fuel off: TCS	27.76	47.47	0.58
Fuel off: F&G	20.37	34.7	0.61
Fuel off (All)	35.39	60.19	1.18

If there is a gas release and the gas detectors do not function, then there is a very high probability of a continuous gas release. The continuous leak would occur because the fuel shut off systems would not react to the gas detection. This effect can be seen in the posterior probabilities of the fuel shut off systems. Furthermore, given a gas release and no gas detection, the probability of a continuous gas release increases from 58.81% to 99.57%, and the probability of a gas leak, increases from 64.56% to 98.74%. The significance of these percentage increases in the posterior probabilities indicates that the gas detection system is a vital barrier in the mitigation of accidents resulting from fuel gas releases.

The emphasis of Test Case 2B emphasises a gas release not being detected and the effects of an Ignition Source (IS) on the posterior probabilities of several nodes. The nodes in question are; "Consequences" (States "*Y-Ignition*" and "*Y-Leak*"), "Immediate/Delayed Ignition" (States "*Immediate*" and "*Delayed*"), "Explosion", "Fire", "Damage due to Fire & Explosion" and "Explosion Damage to Adjacent Areas". Table 5 demonstrates the results of Test Case 2B.

Table 5: Effects of no Gas Detection and presence of an Ignition Source on "Consequences" ("Y-Ignition" & "Y-Leak"), "Immediate/Delayed Ignition" ("Immediate" & "Delayed"), "Explosion", "Fire", "Damage due to Fire & Explosion" and "Explosion Damage to Adjacent Modules"

Focus Nodes	No Evidence (%)	No GD (%)	No GD & IS (%)
Y-Ignition	0.02	0.04	44.88
Y-Leak	64.56	98.74	14.20
Immediate Ig.	0.02	0.03	35.38
Delayed Ig.	0.03	0.04	49.25
Explosion	0.02	0.03	34.43
Fire	0.01	0.01	20.74
F&Ex Damage	0.00	0.00	3.91
Dam. Adj. Mod.	4.10E-05	6.31E-05	0.076

The emphasis in this analysis is on the more severe accidents and consequences in terms of fire, explosion and the damage that they can cause. From Table 5 it can be seen that in the event of a 100% failure of the gas detection system, the probability of there being any accidents or consequences related to ignition remain virtually negligible. However, the final column in Table 5 demonstrates the effects on the fire and explosion consequences given no gas detection and an ignition source present. The purpose of this is to show how sensitive the fire and explosion consequences are given an ignition source and a gas release. It can be seen that the posterior probabilities increase significantly when an ignition source is present without gas detection.

4.3 *Test Case 3: Effects of observed Consequences (Y-Leak and Y-Ignition) on prior probabilities*

To provide further verification of the BN model it is important to demonstrate the effects of inserting evidence as a consequence and observing the effects on prior nodes. The key node in this test case is the "Consequence" node, with attention being focused on inserting 100% evidence to states "*Y-Leak*" and *"Y-Ignition"*. Table 6 demonstrates the effects of 100% "*Y-Leak*" on the mitigating barriers of a gas release.

Table 6: Effects of 100% "Y-Leak" on the prior probabilities of the mitigating barriers and "Continuous Release" as well as 100% *"Y-Ignition"* on the consequence and accident nodes.

Focus Nodes	No Evidence (%)	Y-Leak (%)	Y-Ignition (%)
Fuel off (All)	35.39	0.00	-
Fuel off: TCS	27.76	0.10	-
Fuel off: F&G	20.38	0.03	-
Cont. Release	62.48	96.19	-
Gas Detection	43.40	13.44	-
Ignition Source	0.083	-	100.00
Immediate Ig.	0.019	-	78.82
Delayed Ig.	0.027	-	21.18
Fire	0.011	-	31.69
Explosion	0.019	-	14.80

Table 6 shows that given 100% probability of "*Y-Leak*", the prior probabilities concerned with the fuel shut off system nodes, all being State "*Yes*", greatly decrease to almost zero. Similarly, the probability of the gas being detected also decreases. However, not to the extent of "Fuel off (All)". Table 6 also indicates that prior to a 100% consequence of ignition, the likelihood of any ignition, fire and explosion accidents or consequences are almost negligible. However, when evidence is inserted into the state "*Y-Ignition*" in the consequence node, the prior probabilities greatly increase.

5 CONCLUSIONS

The BN model presented in this research demonstrates the effect that several initial failures have on a potential fuel gas release as well as the potential fire and explosion hazards that can occur. These consequences are equally important for offshore platform operators due to the additional HSE regulations within Safety Cases regarding hazards to the environment in any instance. Therefore, if there is a fuel gas leak without ignition, it poses a large issue for operators and duty holders given that the release is undetected.

The analysis presented in the three test cases clearly demonstrates the vital role that the mitigating barriers play in preventing severe consequences due to a gas turbine fuel leak. The BN model also clearly demonstrates that it can provide an effective and applicable method of determining the likelihood of various events under uncertainty, and more importantly show increased uses as a dynamic risk assessment tool. This is especially applicable in monitoring offshore areas where personnel are not normally present i.e. NU-Installations.

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