Next-Generation Verifiers

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Abstract

The introduction of a risk-based verification regime in the United Kingdom is the most important development after the disastrous Piper Alpha accident which cost 165 precious lives on the 6th July 1988. It requires the duty holders of offshore installations to take a proactive role to prevent and mitigate Major Accident Hazards (MAHs). Despite the systematic framework and verification process, the regime is still reactive and not delivering the goals of the UK Offshore Safety Case Regulations (OSCRs). Multiple case studies, recent hydrocarbon leaks, and improvement and prohibition notices from the regulator suggest that MAHs can still occur with the existing assurance process. The regime is about to enter its fourth decade and the need for real change is long overdue. Therefore, this research focuses on the proactive implementation of the risk-based verification regime for offshore installations in the United Kingdom Continental Shelf (UKCS). In line with the known concerns of the industry, the research emphasises the strengths and weaknesses of the existing verification process and the role of key stakeholders. The research starts by analysing the internal assurance process of duty holders and explores factors behind being reactive. Later, based on literature review and primary data, the study proposes a framework that can be used to initiate a proactive assurance process. Moreover, the role of verifiers commonly known as Independent Competent Persons (ICPs) is critically evaluated. ICPs' views on the barriers affecting the proactive implementation of the verification process are documented, validated and critically discussed. The verification software applications are analysed and discussed; these applications play a significant role in delivering the verification process. The study thus provides important insights into the existing verification process and proposes guidelines to implement an improved proactive verification process. Finally, the study demonstrates Bayesian Network (BN) capabilities to evaluate the availability of Safety Environment and Critical Elements (SECEs), produces toolkits for duty holders and ICPs to analyse repeated SECEs failures, and presents Lloyd's Register's verification software application, V-Connect, as the data analysis tool for Independent Verification Bodies (IVBs) and duty holders. The research findings suggest the necessity of having next-generation verifiers who are capable of foreseeing the weak signals of Major Accident Events (MAEs).

1.0 Introduction

The history of the oil and gas regulations in the UKCS and across different countries such as Norway and the USA has many similarities. Unfortunately, the transformation of the prescriptive legislative regime into a proactive risk-based regime is a journey of lessons learned from accidents, such as the “Sea- Gem” sinking, the Ekofisk Bravo blowout, the Piper Alpha explosion and the Deepwater Horizon environmental disaster. Consequently, it is realised that health and safety is not necessarily the prime responsibility of a regulator, and it cannot be achieved with statutory instruments and instructions. Moreover, it is recognised that effective legislation can also be created while sharing the responsibility and making the industrial stakeholders responsible and accountable.

The present-day United Kingdom offshore oil and gas industry is well-established, providing jobs to 280,000 workers; its infrastructure constitutes 320 fixed installations, 7,800 wells, more than 20,000 kilometres of pipelines and 250 subsea systems [24]. Workforce safety and the avoidance of major accidents like the Piper Alpha disaster are the main goals of the current legislation, known as a risk-based regime. However, the regime is not delivering the benefits as initially conceived. Health and Safety Executive (HSE) studies relating to the UK offshore assets find profound gaps in the system’s effectiveness [11,12,30,23,35]. While discussing the limitations of the regime, Wang et al. [36] identified three areas to focus on: a) all parties should be proactively involved in the verification process, b) lack of data may hinder the effectiveness of risk assessment and c) the knowledge of ICPs. In the same vein, a critical review of investigation reports relating to 45 hydrocarbon leaks suggested that opportunities for true learnings are lacking, and hazard potentials are under-communicated [34]. More recently, five major hydrocarbon releases were reported and each of these events had the potential to cause a major accident [33]. The recurrence and similarities of these hydrocarbon leaks suggest that proper improvement measures are not in place [8]. Due to these concerns, Paterson [26] rightly warns the industry to look for blind spots, be self-critical and not to overestimate self-control. Failure of the risk-based regime would certainly strengthen the belief of its critics, as indicated by Steinzor [30], who perceives it as an unsupervised exercise under self-regulation and one which is bound to fail.

Despite the above-mentioned concerns, no major accidents have been reported in the UKCS since 1992 when the Offshore Safety Case Regulations (OSCR) were introduced. Therefore, this strengthens the belief that regulations prepared for the public interest do reduce accident rates [1]. Current offshore oil and gas industry regulations play a pivotal role in reducing incidents and accident rates. Considering the importance of an adequate legal framework to avoid major accidents including environmental accidents, oil exploring/producing countries around the world have started to develop risk-based legislative regimes [22]. It is also encouraging to note that globally the proactive risk-based regimes are principally similar, and they are also modified to meet the local requirements. Although the compliance is based on proactive risk-based principles, prescriptive requirements still exist in legislation. The relevant literature suggests that globally there is a lack of coordination among stakeholders. The commonalities include a degree of approval from regulators, verification, certification and/or validation by the third parties. The degree of inspections, the effectiveness of audits, and the quality of published guidelines vary in different countries.

Globally, we have experienced a few inspirational stories: an Irish duty holder demonstrates the will and commitment to implement the verification regime towards the end of field life; a Cyprus regulator educates their inspectors to implement the EU directive while inspecting first oil and gas exploration in the country; and the Nigerian offshore workforce is keen to learn the different facets of the risk-based regime. These inspirational stories and many more provide positive indications that risk-based regimes will be strengthened in years to come and implemented in many more countries.

Whilst the need for an effective verification process has grown in importance, very few researchers have investigated the strengths and weaknesses of the existing systems. This research provides an important insight into the risk-based verification regime; its strengths and weakness are examined. The applicability of the research is the main driver of this study, which is geared to motivate duty holders and next-generation verifiers to step back and re-evaluate their role and improve the quality of their deliverables. Moreover, it will encourage the duty holders to be self-critical, improve their internal assurance process and conduct cold audits so that they can confidently self-regulate and use Independent Verification Bodies (IVBs) to their full potential.

Maxwell [21], a lifetime leadership mentor, highlights the significance of asking the right questions; the author views questions as: (a) an engagement tool, (b) challenging a particular mind-set and (c) providing a code to open locked doors. Therefore, it is suggested that legislators, regulators, duty holders, IVBs and other stakeholders should critically evaluate some of the fundamental observations/questions: Has the Safety Case quality improved over the years; have the new areas been explored? Why are the identified Safety Environment and Critical Elements (SECEs) generally identical whereas each installation has a separate safety case or risk case? Why are common errors repeatedly found in written schemes of verification and well-examination schemes? Why are the previously identified degraded SECEs in the HSE studies still reported as degraded through ICPs' recommendations and regulators' enforcement notices (cranes, deluge systems, hydrocarbon leaks, *etc*.)? Why do regulators still have to raise observations on the lack of implementation of the permit to work system? Does current legislation adequately cover the relationship between the verification process and the management systems? If not, how can it be established? How confidently do duty holders respond to questions during a regulator's audit? Do the current ranking criteria used by regulators reflect the true picture of duty holders' maturity to manage risks? Do duty holders see regulators as a partner in safety management or just regulators asking difficult questions? Do duty holders still need a reminder that they are accountable and responsible under the proactive risk-based regime? Have IVBs performed to their potential and have they successfully shared their experience? Are there any training and development gaps identified for IVBs? How can the current legislation become even less prescriptive; is the industry ready for the change? If any of the above questions require attention (partially or completely) and/or validate industrial concerns, then all stakeholders of the industry are encouraged to re-visit their approach. The above-mentioned questions/observations certainly gained attention within the scope of the study.

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Given the importance of a risk-based regime and the high consequences of major accidents, it is essential to investigate further how the regime can become a proactive one. On the basis of the above discussion, the aim of this research is to develop tools and test methodologies that will enable the proactive implementation of the risk-based verification regime for offshore installations on the United Kingdom Continental Shelf (UKCS).

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To accomplish the aim of the research, the following objectives were established:

1. To develop and implement a methodology for the proactive assurance process. This will enable duty holders to improve their assurance process and provide a tool for the industry to evaluate the SECEs' availability.
2. To analyse factors influencing the verification process and propose measures to improve the process.
3. To critically analyse data from the verification software application and offer important insights concerning the strengths and weaknesses of verification stakeholders (IVBs and duty holders).

This study conducts a detailed assessment of the existing verification process. Moreover, the research critically assesses and evaluates the results of the verification process. The assurance process should be improved every year, and this can only be achieved if all stakeholders consciously try to improve their deliverables.

The proposed proactive verification framework, Bayesian Network (BN) models, toolkits, data analysis and concept of a dynamic risk-based scheme will contribute to the effective implementation of the UKCS regime. It is imperative to note that the proposed solutions and the need to change the current verification process should be taken seriously; otherwise, the precursors of a major accidents may lead to a disaster. The findings of the study should also benefit the oil and gas sectors of other countries which have opted to implement the regime either in its entirety or as a hybrid regime. A high-level overview and research findings are provided below.

2.0 Current Assurance Process

How critical is the assurance process? An unclear, vague or reactive assurance process cannot achieve the objectives of well-defined performance standards and written verification schemes. The term assurance refers to the activities carried out by the duty holders to ensure that performance standard criteria are achieved which are required to set meaningful key performance indicators to gauge the effectiveness of the assurance process [11,31,25]. The assurance process consists of several activities, which include planning and implementation of maintenance activities (routine and corrective maintenance) through a Maintenance Management System (MMS), review of outstanding work, audits, operational risk assessments (ORAs), review of technical authorities and root cause analysis activities, *etc*. [31,36]. This should be regarded as the duty holders' internal system by which they verify the performance standard. This would reassure the duty holders (DHs) that the parameters set for the SECE are in a healthy state. It would thus be beneficial to the DHs if the assurance criteria in the performance standard

were strengthened. Then, the ICPs' activities are a confirmation of the effectiveness of the assurance process rather than assurance itself. As the goals and objectives of assurance and verification activities appear to be similar, sometimes it is unclear whether assurance is achieved by ICP activities or by the duty holders' assurance process. Moreover, the Key Programme 3 (KP3) study suggests that relatively few duty holders measure and comply with the availability criteria [11]. It is also suggested that duty holders still struggle to evaluate and produce availability and reliability reports. Further, the quality of the produced reports varies. Moreover, the availability assessment is limited to the individual SECEs, although various studies do acknowledge that interacting SECEs do affect the availability [32,36]. However, no functionality and assurance criterion is set for interacting SECEs.

The assurance framework (Figure 1) highlights the current assurance process. This framework will vary with different duty holders, but the main features remain the same. Planned Maintenance Routines (PMRs) and integrity inspections usually cover a five-yearly cycle, *i.e.*, one to 60 monthly activities. Safety Critical (SC) work orders take priority over non-safety-critical work orders. This framework highlights that availability/reliability reports are generally issued after one year, at times delayed or not issued at all. Mostly, these reports are based on historical data and the current status of the plant is not analysed. Duty holders' internal audits, including Technical Authorities' (TAs) reports, are used as assurance means. Figure 1 also highlights that ICP recommendations are raised following the inspection, testing, review and audit activities.

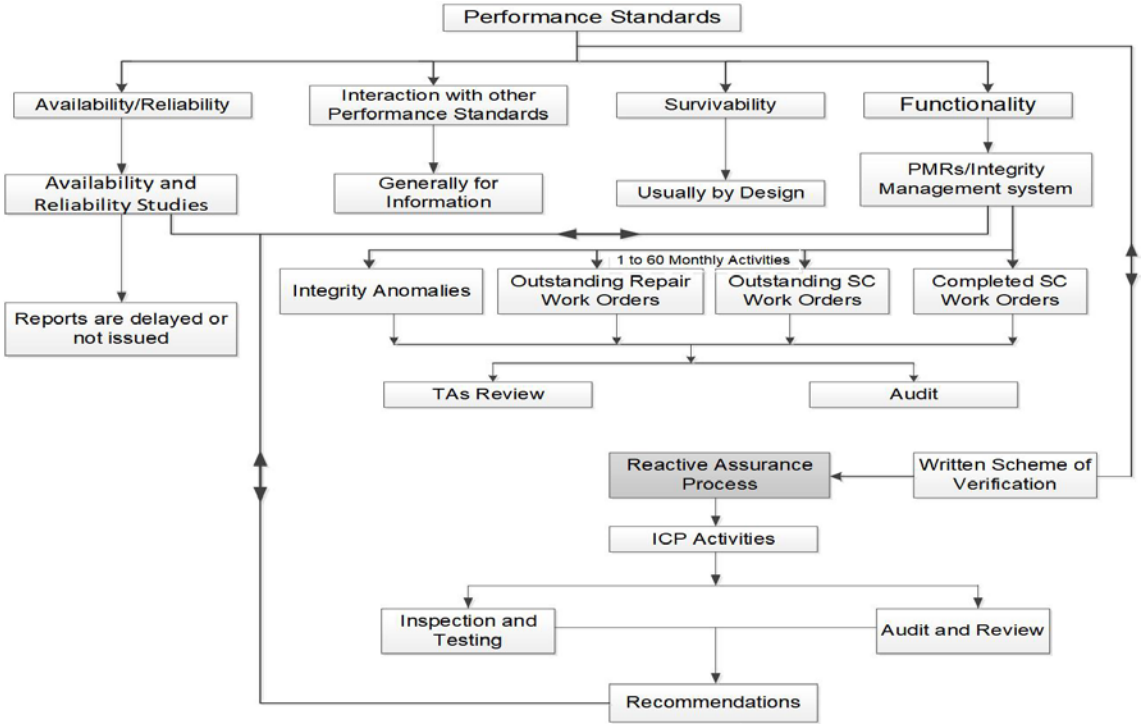

Figure 1 Current Assurance Process

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The current assurance process greatly relies on the PMRs, internal audits and ICP activities to confirm the functionality, availability, reliability and survivability of a Performance Standard (PS). The process becomes a reactive one if it exhibits the following characteristics:

1. It identifies means of assurance; however, it does not evaluate whether PMRs are achieving the desired goals or not. The quality of closeout work orders remains questionable.
2. Maintenance management system and relevant data are not proactively analysed. Data analysis is dysfunctional or does not exist.
3. To a certain extent, it is dependent on ICP activities to provide assurance.
4. An ICP verification finding is not seen as a direct failure of the internal assurance process unless it is a level 3 finding or letter of concern/reservation.
5. Duty holders struggle to measure and comply with the availability and reliability criteria. Assurance criteria do not consider the availability of interacting SECEs while assessing the availability of an individual SECE.
6. It relies on a traditional audit technique, which is reactive in nature, and audit findings are not addressed in a systematic and proactive manner.

2.1 Proactive Assurance Process

What is not yet clear is a concept of a proactive assurance process. This study describes proactive assurance as a process which not only identifies the means of assurance but also proactively evaluates the outcome of assurance, proposes corrective actions and improves the existing assurance process.

In order to achieve a proactive assurance process, this study proposes the use of a Bayesian Network (BN) to evaluate the availability of the SECE in question. This is based on the BN's ability to analyse the data, especially under uncertainty, and its ability to incorporate expert judgement. Further, the BN makes structured learning possible, and utilises a causal relationship among knowledge, theories and hypotheses to build models. Finally, it provides a fast response and it is a useful tool for both qualitative and quantitative assessment. The literature review suggests that BNs are used in the offshore industry [39,4,38]. However, the studies are limited to the analysis of blowout preventer, environmental consequences of major accidents and well data analysis for production enhancement. What is now needed is the use of BN models in the verification process, which will report the state of SECEs and foresee the development of MAHs. This will be a step towards achieving proactive verification. In the absence of such tools, verification will remain reactive in nature, resulting in risk tools only being developed after accidents have occurred.

This study presents the proactive assurance process framework (Figure 2). The BN can take collective input from completed SC work orders, outstanding SC work orders, completed repair work orders and outstanding repair work orders on a quarterly basis. The BN can take collective input from completed SC work orders, outstanding SC work

orders, completed repair work orders and outstanding repair work orders on a quarterly basis. The BN model can be used to assess the impact of interacting performance standards along with the SECE in question. The obtained results can be used to assist duty holders in decision-making about where they should allocate their resources. ICP activities are defined as a complementary activity and provide an external audit to verify whether the internal assurance process is effective or not.

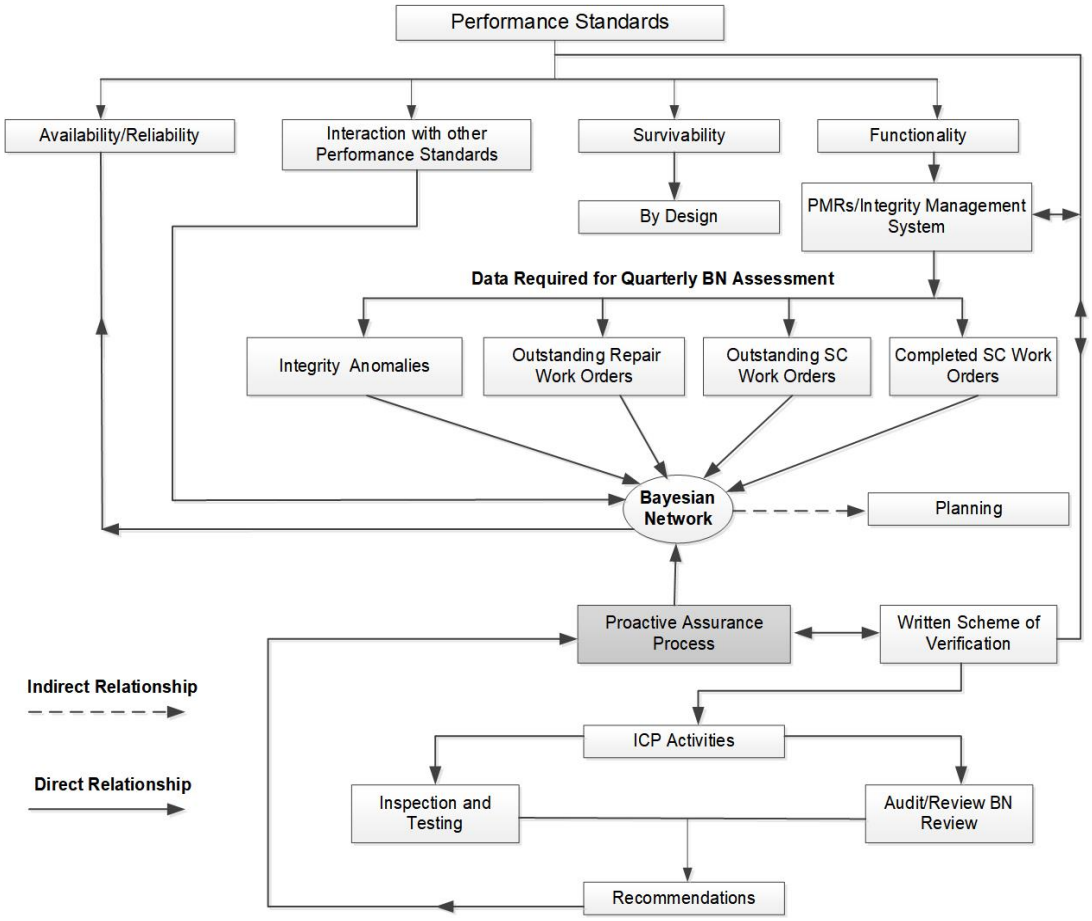

Figure 2 Proactive Assurance Process

The proposed proactive assurance process has the following advantages:

1. Monitors and advises on the health of SECEs.
2. Drives data management and analysis.
3. Considers the expert judgement in the analysis.
4. Assesses SECE availability on a quarterly basis or a bi- annual basis (as required).
5. Provides valuable input and data for internal audit.

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6. The BN model is capable of identifying the area of improvement in the safety critical system.
7. The BN model can be used to assist in proposing changes in the maintenance management system, integrity managements system and SECE strategies.
8. The BN model can help in proactive planning and resource allocation in high-risk areas.
9. Foresees SECE failures and development of MAHs.

The proactive assurance process has the following limitations:

1. Requires BN skills.
2. The workforce will need to be educated to appropriately complete the work orders, as MMS data will be used.
3. Duty holders need to carry out brainstorming sessions, and investment will be required to improve the functionality of the MMS.
4. Requires commitment from DHs to include the BN model in the assurance process, as a failure to comply with the BN model assessment will result in performance standard failure.

BNs are also called belief networks, graphical probability networks, probabilistic cause and effects models, probabilistic influence diagrams, *etc*. This technique builds networks known as directed acyclic graphs (DAGs). Acyclic means such graphs do not have cycles, as in the case of chain graphs. These networks express dependence and independence statements. The BN supports deductive (causal), adductive (diagnostic) and inter-causal reasoning [39,4,38]. Figure 3 shows a causal dependence between SECEs' failure and a major accident. The figure shows that SECEs' failure is a parent node (cause) and the major accident (effect) is a child node. In this example, SECEs' failure is a root node and the major accident is a leaf node when assessed independently. The probability distribution of a child node is conditional, whereas the parent node has an unconditional probability.

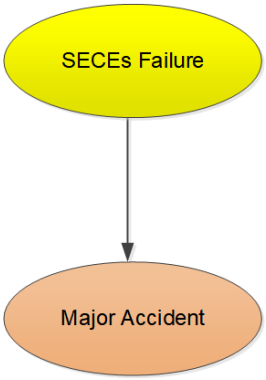

Figure 3 Parent (SECEs Failure) and Child (Major Accident) Node Relationship

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The proactive assurance process framework is based on BN models. Preparation, analysis and application of the model are based on a six-step methodology. Initially, the area of interest/problem is defined with a clear objective. The methodology is shown in Figure 4.

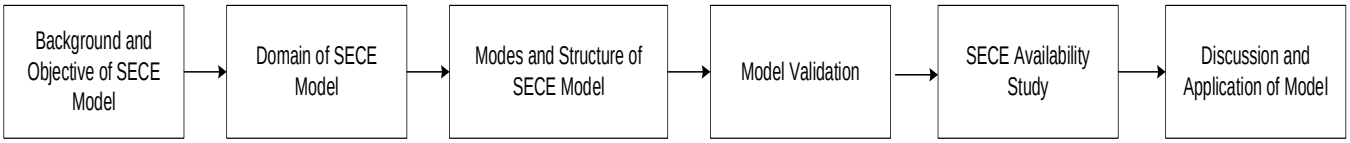

Figure 4 BN Methodology

Step 1: This step explains the background of the SECE under assessment.

Step 2: Domain of the model - This step draws the boundary for the SECE model. Areas, which are excluded in the model are also explained.

Step 3: Structure and Nodes of the model - This explains the network logic, node connections, limitation of the model, model data and conditional probability tables.

Step 4: Model Validation - This step represents the quantitative features of the model. It is important that model validation is conducted before concluding results.

Step 5: Availability study - The availability of the SECE in question is evaluated by using BN software application.

Step 6: Discussion of the model - This step sums up the assessment of the model. Assess the SECE's availability on a quarterly basis or a bi- annual basis (as required).

A sample model of an Active Fire Protection System is shown in **Appendix A**. It is important to note that each duty holder can modify the model structure and data assessment based on each installation configuration and their preference to evaluate each individual SECE or combine interacting SECEs. The data from the MMS and integrity management system can be incorporated. Technical Authorities, Offshore Installation Managers (OIMs) and verification engineers' input can be used as expert judgement in the BN assessment. To assign the prior belief of states, Conditional Probability Tables (CPTs) are developed. Multiple regression analysis of case studies/axioms is completed as per defined methodology. Pilot studies can be started with duty holders.

The most obvious finding validates that the duty holders' current assurance process should move to a proactive assurance process. Therefore, the proactive assurance process and framework are presented. Further, a methodology is proposed (Figure 4) to achieve the objectives of the proactive assurance process.

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3.0 Factors Influencing the Verification Process

The purpose of this section is to analyse factors influencing the verification process and propose measures to improve the process.

Are there any factors that influence the effective implementation of the verification process? If yes, then what are those factors? Perhaps this is the first study that identifies, analyses and documents factors that drive the verification process, incorporating the verifiers' perspective. Therefore, the objectives of this study are: a) to identify the factors influencing the current verification process, b) to seek input from the ICPs on the current verification process, and c) to critically examine the ICPs' feedback and discuss and propose measure to improve the proactive verification process.

A conceptual framework is primarily a model that helps researchers to better understand the research problem, explain how systems are working, and include their own ideas about the phenomenon being studied [20]. Therefore, this research employs a conceptual framework based on the reviewed literature and researchers' experience. This provides a baseline to evaluate key factors contributing to achieve a proactive verification process. It is postulated that the proactive verification process is a dependant one. This is based on these four factors: a) verification schemes, b) assurance process, c) ICP surveys and reports, d) communication and feedback. The key factors shown in the conceptual framework are further broken down into independent but related variables (refer to Figure 5). Categorisation of independent variables also makes it easier to examine these through subjective judgements where necessary. In summary, this study is set to investigate 10 independent variables that are derived from the above-mentioned four key factors.

The identified Independent variables influencing proactive verification process (DV) are listed below.

- Performance Standard and Written Schemes (PSWS)
- Methodology and Risk Assessment Techniques (MRAT)
- Maintenance Management System (MMS)
- Assessment of MMS (AMMS)
- External Assurance Process (EAP)
- Internal Assurance Process (IAP)
- ICP Surveys and Commercial Constraints (SCC)
- ICP Recommendations (ICPREC)
- Communication with ICPs and Forums (ICPCOM)
- Duty holders' Internal Communication and Forums (DHICOM)

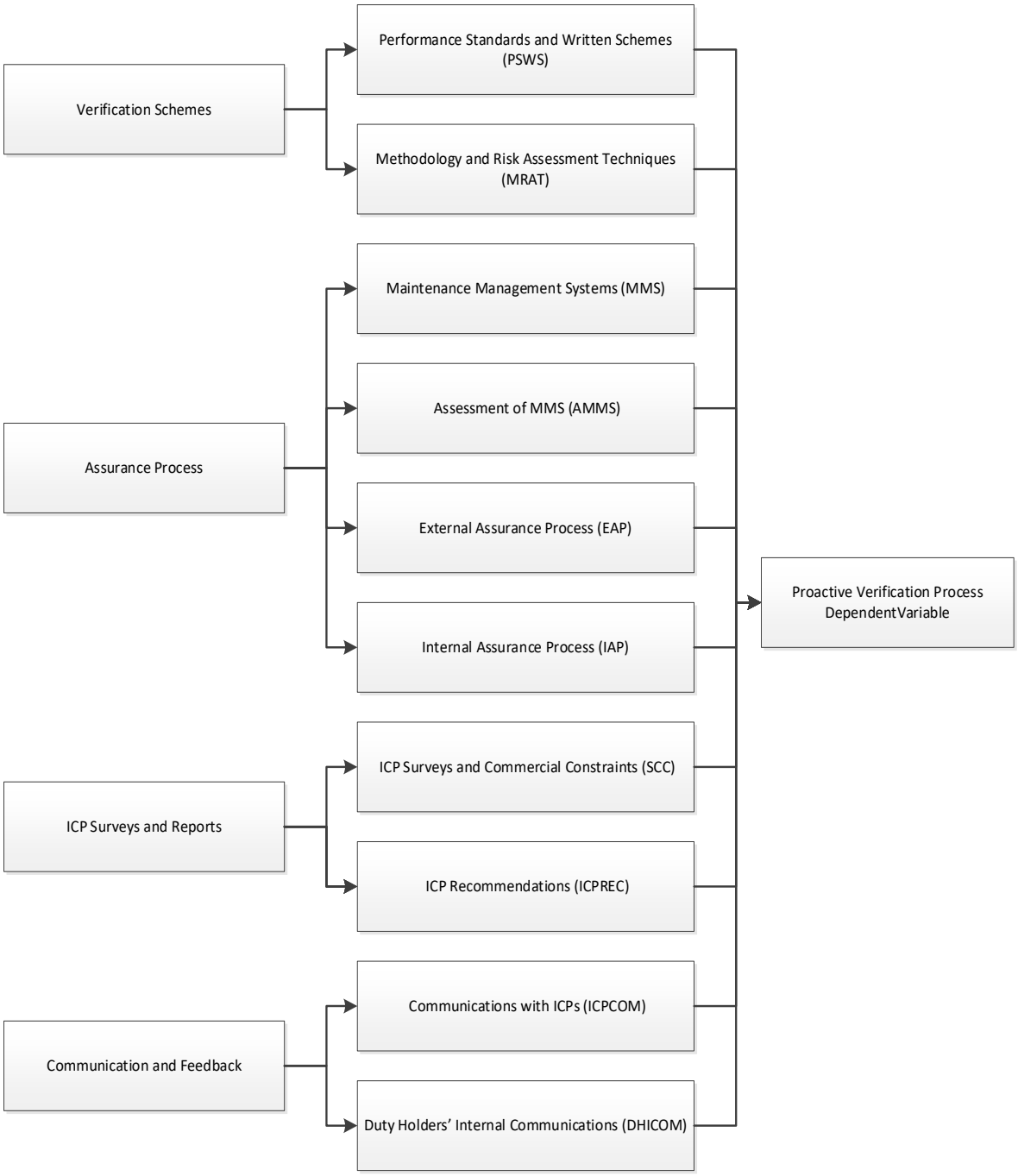

Figure 5 Conceptual Research Framework

In order to validate the relationship of the postulated factors, a defined methodology is required. In this study, the methodology is based on a deductive approach, leading to survey development, data collection, data analysis,

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discussion and conclusion. In the absence of existing data, this study opted to use primary data (survey). Before distributing the final version of the questionnaire for data collection, the researchers implemented a pilot test. This was performed in order to find any errors or difficulties that might have been introduced in the development phase. Then, the questionnaire was reviewed by a panel of four experienced individuals, two research experts from the academic sector and two team leads for ICPs. In this research, the Statistical Package for Social Sciences (SPSS) was employed to analyse the quantitative data. SPSS was chosen because of its popularity within both academic and business circles, making it the most widely used package of its type [2,27]. Moreover, SPSS allows command-line input and programming, as well as the use of graphical user interface analysis. The correlation technique is used to describe the strength and direction of the linear relationship of one variable to another [2,27]. The correlations matrix **(refer to Appendix B)** suggests that most independent variables have a significant positive/negative correlation with the dependable variable (Proactive Verification Process). Only one independent variable, 'Duty Holders' internal communication', showed no significant relationship with the dependable variable (DV), which was unexpected. The study concludes that the initially postulated independent variables are correlated with the DV; further, these variables are related to each other.

Once, the postulated relation among the four key factors and ten independent variables with the dependable variable (proactive verification) had been established, the next step was to analyse verifiers' views on these variables. This was achieved by using a structured questionnaire with the participation of 30 verifiers. Key findings are noted here:

1. The collapsed mean score and analysis of variance confirm that, overall, participants have less confidence in the existence of a proactive verification process in the UKCS. Interestingly, the same participants showed least confidence in two independent variables. These are internal assurance process and assessment of MMS.
2. The study has found that ICPs act independently. Further results show that ICPs are generally competent and able to assess and verify the performance standards.
3. 96.7% of participants (ICPs) confidently confirmed that duty holders have no influence on the selection of inspection areas and ICP reporting. The majority of them also confirmed that commercial constraints such as cost and available time have no impact on their surveys.
4. 83.33% of survey participants agree that performance standard and written schemes (PSWS) use qualitative and quantitative data, and these are aligned with the safety cases. However, participants tend to agree that they are still vague and unclear.
5. 73.33% of survey participants disagree that IVBs use a comprehensive methodology while reviewing and commenting on the PSs. Rather, they heavily rely on their experience. Further, duty holders need to recognise that performance standards and written schemes should be clear enough for the workforce to understand.

6. The results show that duty holders seldom involve ICPs while preparing bow-tie models and carrying out risk assessments and investigation studies.
7. The participants tend to agree that availability and reliability criteria are not measured effectively. This result is consistent with previous HSE study and LR experience [11,19].
8. 66.7% of the participants tend to agree that ICPs carry out offshore surveys on an annual basis. Moreover, they also conduct audits on an annual basis, typically covering the previous 12 to 15-month period. Onshore audits and offshore surveys give them a good overview to ascertain the condition of SECEs.
9. Finally, the evidence from this study suggests three areas on which IVBs should focus while planning training for ICPs:
    a) Firstly, IVBs should develop comprehensive methodologies to review PS/Written Scheme of Verification (WSV); internal workshops could be held enabling ICPs to challenge PS and WSV effectively during the initial development phase and later on while verifying performance standards.
    b) Secondly, a planned training and refresher courses should be arranged to review the MMS and SECE strategies. This would allow ICPs to confidently challenge the maintenance routines and identify the gaps, while focusing on the root cause of repeated failures.
    c) Thirdly, ICPs should be trained in assessing and challenging risk assessment techniques.

Safety Case regulations guidance suggests that ICPs should have the adequate knowledge and experience to make a judgement [16]. The International Federation of Surveyors (FIG) recognises that the definition of a surveyor may not be agreed but a surveyor should be a qualified professional in their home country, a profession must exist in the country, and there must be the existence of a political will to support the process [9]. Here, it is important to clarify that ICPs or verifiers are not traditional surveyors. They have a much greater role which includes but is not limited to motivating duty holders in achieving the objectives of a proactive verification regime through knowledge sharing, guidance and improving the duty holders' internal assurance process while maintaining their professional integrity and independence. Most importantly, ICPs should have leadership skills to peruse duty holders' management to invest in the proactive verification process. In this process, patience and perseverance are the key, as ICPs are partners in safety management not the police officers of regulators (as wrongly conceived at times). The above discussions and suggestions indicate that the industry requires next-generation verifiers who are auditors with the desired technical behavioural/people management skills. Further, researchers tend to agree with the HSE-funded research [28] that verifiers should have a full line of sight to deliver better results. Perhaps the industry requires next-generation verifiers who are capable of foreseeing the early signals of major accident events.

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The independent variables (predictors) influencing the proactive verification in the form of a conceptual framework are documented and validated. The generalisability of this conceptual framework is subject to certain limitations. For example, duty holders' organisations and other IVBs may also like to introduce other independent variables when analysing the proactive verification process, such as management role, vendor quality or assessing ICPs' expertise in certain areas. However, in the context of this study, nine Independent Variables (IVs) were found to have a significant correlation with the DV (Proactive Verification Process). The validation of the independent variables influencing the proactive verification has assisted LR to support its contract managers and verifiers in effectively engaging the duty holders and consciously improving its deliverables. This is reflected in our success story as the biggest and the most successful IVBs on the UKCS and beyond.

Overall, this study suggests a combined effort. This is based on duty holders' senior management making a conscious decision and efforts to challenge their internal assurance systems, considering ICPs' low-level, medium level and high-level recommendations as a direct challenge to the internal assurance process. Further, they should also focus on strengthening the management systems rather than heavily relying on the competencies of verification engineers, technical authorities and managers to bring the change. On the other hand, IVBs should also develop their workforce in the above-mentioned areas so that they can effectively support the objectives of a proactive verification process.

4.0 Verification Software Application

The purpose of this section is to critically analyse data from the verification software application and offer important insights concerning the strengths and weaknesses of verification stakeholders (IVBs and duty holders).

IVBs have developed various software applications and web-based tools for managing the verification process. These include V-Connect, Verification Scheme Dashboard (VSD), BVnet and Eagle. The applications assist in planning surveys and provide management tools to record the findings of both offshore and onshore surveys. In addition, these applications provide access to the verification reports, manage feedback pertaining to the recommendations, and enable duty holders to check the condition of SECEs across different assets. Once the data from these applications is collated, the natural progression could be to analyse and critically evaluate it. However, no evidence is available to suggest that this has taken place on a bigger scale and no major systematic investigation has been documented to identify the root cause of the ICPs' findings, their patterns and their effects on the verification process. It is hypothesised that the lack of a detailed analysis of ICPs' recommendations can lead to a reactive verification process. Therefore, this pilot study sets out to undertake a longitudinal analysis of an IVB software application. As a result, it offers some important insights in relation to the strengths and weaknesses of verification stakeholders (IVBs and duty holders) and identifies potential gaps where the verification process is reactive rather than proactive.

The current available data resources within the United Kingdom and globally do not collate data for all SECEs. An important question is, can these software applications become the source of a data and assessment tool? Therefore, this study sets out to critically analyse data from the verification software application and proposes measures to improve the verification process. The main objectives are:

1. To critically evaluate the pattern of ICP recommendations against an important but consistently downgraded SECE.
2. To critically examine five major accident barriers (prevent, control, detect, mitigate and evacuation).

LR verification software application, V-Connect, is the most widely used source of information for duty holders. More than 25 duty holders have used V-Connect. One of the key features of V-Connect is its client portal, assisting duty holders to gather key information. Furthermore, LR has been continuously upgrading V-Connect based on the feedback received from the duty holders, which shows their commitment to implement an effective verification process. This has enabled LR to roll out V-Connect globally, implementing EU directives and other local regulations where required [19]. Some of the additional key aspects of V-Connect are listed as follows [19]:

a) Assists duty holders and IVB (LR) to interact effectively.
b) The details of the survey planner, task completion and status of open recommendations are provided thorough V-Connect.
c) Duty holders can review and comment on open recommendations; therefore, duty holders and IVBs do not have to manage two different databases.
d) Survey reports are accessible to the duty holders and IVB (LR).
e) Modifications related to SECEs can be managed through V-Connect.

Degradation of any SECE is unavoidable; therefore, duty holders plan and execute inspection/maintenance routines in order to reduce such possible degradation. In order to identify a critical but continuously downgraded SECE, the HSE's KP3 study is used as a benchmark. The KP3 study concludes that Temporary Refuge (TR), Heating, Ventilation, and Air Conditioning (HVAC), TR doors, and deluge system are the worst-performing areas [11]. A random sample of V-Connect data on ICP recommendations for a five-year period (2015-2019) is assessed. The demography of the data is shown in Table 1. It is notable that the HVAC system and deluge system still degrade frequently, whereas the number of ICP recommendations relating to TR doors is lower in this period. Although this is an improvement against the above-mentioned KP3 findings, it is concerning to note that two critical mitigating performance standards (HVAC and Deluge) are still a focus of the ICPs' attention, indicating a failure of the duty holders' internal assurance.

Table 1 V-Connect Data and ICPs Recommendations

V-Connect Data	
Safety Environmental Critical Systems	Deluge/HVAC/TR System
Assessment Period	2015-2019
Number of ICPs	10
Number of Duty Holders	8
Number of Installations	20
Type of Installations	Manned Installations
ICPs' recommendations raised against HVAC system Witness frequency: 12 months	163
ICPs' recommendations raised against Deluge system Witness frequency: 12-36 months	132
ICPs' recommendations raised against TR doors Inspection frequency: 12 months	42

Source: Adapted from LR (2020)

Unfortunately, this also shows that KP3 findings and the factors contributing to the Piper Alpha accident are still a cause of concern. However, with a small sample size, caution must be applied, as the findings might not be transferable to all assets of the UKCS. In order to further analyse the root cause of deluge system failures, the following case study was conducted.

4.1 Case Study – Deluge System

This case study focuses on details of the ICPs' recommendations against a deluge system. A detailed review of the randomly selected verification reports provided some additional information. For example, only one Level 3 recommendation, which is the highest level of recommendation, was raised, whereas several Level 2 recommendations (single performance standard failures) were reported. On 10 occasions, ICPs were unable to witness the deluge test and/or it was scheduled for the next verification visit. Duty holders cover the deluge system under two different performance standards, *i.e.*, active fire protection system and deluge system [19]. A detailed assessment of 104 recommendations was carried out as the remaining 28 recommendations relate to the fire pumps and their performance issues. Ten different ICPs, supporting eight different duty holders, issued similar recommendations, across 20 offshore assets, over a period of five years. Interestingly, the 104 recommendations repeatedly highlight nine failure modes of the deluge system. Details of these failure modes can be seen below:

A. Fully or partially blocked nozzles.
B. Failure to record data and/or inadequate data reported in MMS.
C. Deferral of deluge system work orders.
D. Requirement to update performance standards and/or work order task details.
E. Multiple failures such as degraded flow and coverage and blocked nozzles.
F. Failure to meet performance standard criteria.
G. Reliability issues related to initiation of the deluge test.
H. Integrity issues of the deluge system pipework.
I. Other reported issues include incomplete verification task to witness deluge test, poor quality of control air, damaged or incorrect gauges, blocked strainer, inadequate drainage after the deluge test, *etc*.

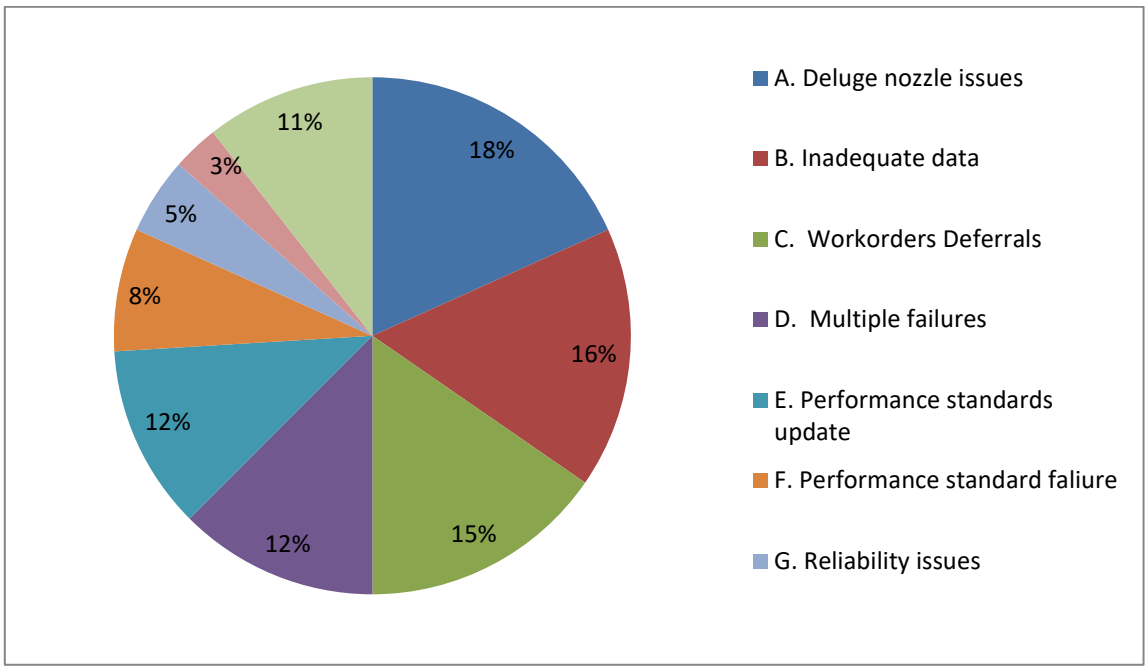

Figure 6 Deluge System Recommendations Breakdown
Source: LR (2020)

Figure 6 above presents a breakdown of the 104 ICP recommendations issued against the deluge system. These recommendations can be broadly divided into two categories, one related to MMS failures (inadequate data and work order deferrals) and the other related to operational failures such as blocked nozzles, inadequate flow, *etc*. Ineffective implementation of the maintenance management system causes operational failures. The key areas of MMS failure relate to the deferral of deluge system work orders (18%) and inadequate records on the deluge test results (16%). Collectively, these two areas constitute 34% of the ICP recommendations [19]. This is rather disappointing, as the HSE

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has issued an information sheet on the water deluge system, providing best practices for deluge performance measurement with a data sheet to record deluge test data [14]. Although it cannot be suggested that addressing these two areas can resolve other operational failures, the reliability of the deluge system should improve by recording data and taking corrective actions on a failure (blocked nozzles, inadequate flow, *etc*.) before it is highlighted in the ICPs' reports.

Drawing on the events leading to the Piper Alpha accident (in relation to the deluge system), here the researchers provide a comparative analysis with the above-mentioned failures highlighted in Figure 6. The Cullen report [7] suggested that 50% of the deluge nozzles were blocked in module C of the platform; the blockage was attributed to the condition of the galvanised carbon steel pipework. The report also highlighted various other contributing factors, such as: a) it took three years (1984-1986) to realise that a long-term solution was required to address the deluge system's issues highlighted in various modules; b) delays in completing the engineering package for replacement of deluge pipework; c) procurement issues; d) deferral of work to save and spread out cost [7]. The report further highlighted that the inspector from the Department of Transport (DoT) was not aware of the blocked nozzles' failures across different modules. One of the inspector's selection criteria for testing module "A" was a lack of control equipment in the area. It is possible that protecting the control system and preparing the area for a deluge system test is still a concern for many duty holders. This requires intensive preparation to avoid an unplanned shutdown and loss of production. Collectively, the accounts from the Cullen report of 1990 and the above data are remarkably similar. The majority of the failures, such as blocked nozzles, deferred work orders, degraded coverage and integrity issues, are similar in nature. The current practice for ICPs to review deluge system records is a positive development. Further, it can be seen that ICPs have a consistent approach in identifying deluge system failures. A review of these records also provides early warning signs of a degraded system. However, the pattern of repeated failures (see Table 1 and Figure 6) suggests that the oil and gas industry is yet again ignoring the early warning signs and taking too long to realise that a long-term solution is required.

Figure 6 and the above discussion provide important information on the deluge system's failure mechanism, identifying improvement in the duty holders' assurance process (nine key failure modes). This also raises two fundamental but important questions about the verification process. These questions are outlined below:

a) Is verification still a reactive process?
b) What different approaches can IVBs adopt to support duty holders?

Looking at the first question, the above discussions support the perception that the verification process is still a reactive process. Further, the ability of the duty holders' senior management in setting out meaningful Key Performance Indicators (KPIs) for the effectiveness of the verification process remains questionable [13]. Interestingly, similar recommendations (104) have been continuously raised and reactively addressed by eight duty

holders over a period of the last five years (2015-2019). This not only raises doubts concerning the effectiveness of the verification process but also questions the cost effectiveness of the process. It is estimated that the average direct cost of surveys (mobilisation, onsite survey and reporting) and managing the SECE recommendations (*i.e.*, one SECE, 104 deluge system recommendations) is £40,000. This excludes indirect costs including planning, procurement, scaffolding, mobilising specialist vendors, and their working hours' charges, *etc*. Moreover, the direct and indirect costs will be in addition to the cost of planned assurance activities.

Turning to the second question, IVBs may also take some basic but important steps to support duty holders to address the root cause of degraded SECEs. In this case study, only one Level 3 (highest level of recommendation) was raised against the deluge system. This may be attributed to the IVBs' survey and audit schedule, as they conduct and report their offshore surveys and onshore audits separately. IVBs may start to consider combining the recommendations from offshore surveys and onshore audits to raise the Level 3 recommendation for a repeatedly degraded SECE. They can also study and present a pattern of individual SECE recommendations to the duty holders, as shown in this case study.

The above-mentioned results and summary of deluge system recommendations (Figure 6) can be beneficial for various stakeholders. In particular, IVBs and the duty holders can use them to support the verification process. The HSE and Offshore Reliability Data (OREDA) may be other indirect beneficiaries of this data. The HSE can use this data to prioritise their inspection. The HSE Parliamentary Affair Division is also required to provide answers to parliamentary questions. This data may help to prepare and support the responses to relevant parliamentary questions. Similarly, the UK Oil and Gas Forum often seeks data from duty holders and IVBs to produce guidance while supporting third-party research.

What is now needed, perhaps, is toolkits that outline the questions that may assist both duty holders and IVBs to seek answers and come up with a better solution to overcome repeated failures. Keeping this in mind, this research has thus prepared a toolkit for the IVBs and one for the duty holders **(see Appendix C)**. The toolkits are based on the findings of the literature review, case study analysis and the researchers' experience. They outline the relevant questions/queries for ICPs and duty holders; through brainstorming sessions, root causes of repeated failures of SECEs can be identified and addressed. The proposed toolkits can be modified to suit individual IVBs and duty holder requirements.

4.2 SECE Barriers

The V-Connect application generates a report providing the total number of open recommendations against each SECE and links these details to SECE barriers [19]. In order to ensure anonymity and confidentiality, the duty holders and installations are selected randomly without disclosing their names. Fifteen duty holders managing 30 assets among them are selected for this study. Data about the degraded SECE barrier in terms of ICPs' open recommendations is shown in Table 2.

Table 2 ICP Recommendations and SECE Barriers

SECE Barrier	Number of ICP recommendations	Percentage
P (Prevent)	227	29%
D (Detect)	38	5%
C (Control)	134	17%
M (Mitigate)	147	19%
E (Evacuation, Escape and Rescue)	240	30%

Source: Adopted from LR (2020)

The above data shows that the detect barrier and its associated SECEs (*e.g.*, fire and gas detection system) are the most reliable. ICPs have issued the least number of recommendations (only 5%) against this barrier. This barrier acts as a bridge between preventative SECEs and mitigating SECEs. Without its activation, the deluge system (mitigating SECE) will either fail to start or have a delayed start, resulting in significant damage. The above results should also give the duty holders confidence in the reliability of the detection system and detect barrier.

Interestingly, the data in Table 2 shows that the first barrier (prevent) and the last barrier (evacuation, escape and rescue) are the worst performing barriers. The possible reason and explanation for the degraded 'prevent' barrier can be ageing assets; various studies looking at this have been conducted across different countries [10,15,23,6].

Going back to the baseline study of the verification regime, *i.e.*, the Cullen report, the significance of managing the last barrier of major accident hazards is highlighted. One hundred and six recommendations were raised in the Cullen report; around 50 of those recommendations were directed to manage the evacuation, escape and rescue barrier [7]. It seems that ICP recommendations are again indicating that the concerns raised in the Cullen report remain valid.

So far this pilot study has presented V-Connect as a source of data and established its use as an assessment tool for the verification process. There are a number of other possibilities where V-Connect can directly support IVBs and duty holders. For example, V-Connect is capable of producing data for incomplete ICP activities. Duty holders and IVBs can effectively plan and allocate resources to complete those activities. Where required, they can re-write the ICP activities to clearly define the requirements. IVBs can also conduct internal audits to assess how duty holders have closed ICP recommendations. An auditable trail of closed recommendations is available in V-Connect [19]. This enables IVBs to ascertain whether ICPs are consistent in their approach while closing recommendations, and if duty holders go beyond the expectations of the recommendations or only complete the required work.

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IVBs can assess the quality of ICP recommendations, their pattern and their ability to identify the root cause of recommendations. Individual ICP training and future development can be based on this assessment. This exercise also enables ICPs to reflect on their own work. ICPs' recommendations and assessment of V-Connect can support them to identify gaps in the SECE management.

In order to achieve the above-mentioned objectives, the current literature related to the verification processes is used along with the data from V-Connect. The results support the research hypothesis that, due to the lack of detailed analysis of ICP recommendations, the verification process has been reactive. This re-emphasises the significance of an object-oriented interaction between duty holders and ICPs. In addition to confirming the hypothesis, this section makes several noteworthy contributions such as: a) presenting V-Connect as a data source and its possible use as an assessment tool for the verification process; b) outlining typical failure modes of the deluge system from the ICPs' perspective; and c) presenting toolkits for duty holders and IVBs to find out and address the failure modes of SECEs. The main findings of the pilot study are noted below:

- Contrary to expectations, the pilot study data analysis of the software application V-Connect provides initial indications that the HSE KP3 study relating to worst-performing SECEs (HVAC and Deluge System) is still relevant, although some improvement has been noted. HSE-led studies do increase awareness among various stakeholders, but they cannot implement the change in the long term. Therefore, this study advocates that regulators need to revisit their approach and encourage IVBs and duty holders to lead their own gap analysis studies. In light of the above, this research proposed toolkits for duty holders and IVBs to reverse the reactive process and address the root cause of issues that are relevant to their installation and based on historical data.

- This pilot study validates the Oil and Gas UK forum data that high-level recommendations are rare. Further, duty holders and IVBs should also re-visit the KPIs of the written verification scheme, where IVBs should be encouraged and supported to target fundamental failures in the assurance process. This may initially result in an upward trend of high-level recommendations, but it will achieve the goals of the proactive verification process. Moreover, it may also reduce the regulators' improvement notices, although this should not be the leading indicator or the motivating factor.

- The data concerning the SECE barrier management of 15 duty holders was evaluated. This pilot study suggests that the detect barrier is the most reliable. Moreover, the data provides an initial indication that the first and the last barriers of a major accident event are the worst-performing barriers, *e.g.*, the prevent barrier and the evacuation, escape and rescue barrier. Overall, the results indicate that the probability of occurrence of multiple degraded SECE barriers is moderate (*i.e.*, the failure rate is 1:200 days). The failure of the prevent barrier resonates with the concerns of the HSE KP4 study, whereas the reported failures of the evacuation, escape and rescue barrier are well-known failures of the Piper Alpha accident. The implications of these results,

unfortunately, again validate the fears that the current verification process is reactive. One of the findings suggests that the reliability of the SECE barriers should draw its strength from the verification process, and it should be less reliant on the barrier management models and tools, although these also have their advantages and benefits.

Overall, the study presents a verification software application (V-Connect) as the biggest data source for ICP recommendations. Based on this pilot study, other IVBs may also use their verification software and web-based applications as the data analysis tool.

In the light of the above studies and discussions, LR proposes the concept of a dynamic risk-based verification scheme which is different from a traditional risk matrix approach. The scheme will seek data and input from relevant stakeholders. BN model assessment, barrier management tools and V-Connect data may be used. Further, dynamic assessment focuses on areas of concern and challenges faced by individual duty holders. Therefore, verifiers will target the key areas in detail, providing long-term solutions to the duty holders, making verification a cost-effective exercise. The dynamic risk-based scheme should be written and implemented in consultation with duty holders.

5.0 Discussion and Conclusions

The current regulations provide autonomy to the duty holders to explore and mitigate the risks. It appears that the potential for preparing and implementing a novel approach has not been fully realised; therefore, the lists of MAHs and SECEs are still generic. By virtue of regulations, duty holders have become more accountable in managing their assets. The IVBs' recommendations, regulators' improvement notices and the increasing number of hydrocarbon releases also create doubts that duty holders have become responsible. It appears that industry stakeholders tend to follow the guidance of the regulation but not its essence. In the same vein, Kloman [18, p.311], while critically rethinking risk management, acknowledges its significance and remains optimistic about its contribution to the society. The author also warns us that we need to consider "*how to live with this uncertainty so that risk can be an acceptable stimulus, rather than an acceptable threat".* Steinzor [30], as a critique of the Safety Case regime, highlights the KP3 finding that mangers intensively rely on the operational risk assessments. Unfortunately, the above discussion and findings suggest that stakeholders of the oil and gas industry have accepted living with an acceptable threat which is reversible.

Overall, although it is encouraging to note that the OSCRs are proactive regulations, the literature review suggests that regulations still need to be less prescriptive [26,30,35]. Hopefully, this will ensure that reactive amendments in the OSCRs are not required, as happened after the Macondo accident; *i.e.*, changes in the MAH list, and introducing environment safety critical elements. Although the inclusion of environment critical elements is a positive step, the ecologist may rightly expect more to deliver, e.g., more stringent regulations and positive validation for produced

water (a large by-product of offshore oil and gas extraction) and flaring rates. Over the years, the role of the regulator has changed, regulating authorities have changed, MAHs have been re-defined, the legislative requirements for safety and environment management system have been introduced, and the emphasis has been on improving the quality of the verification process.

All major accident studies suggest that operators demonstrated poor management skills and they lost various opportunities to avoid disaster [7,30,35]. The most robust management systems do deteriorate over time. The audit of the safety and environmental management system is conducted in-house by the duty holder's representative or by a third party, whereas the verification scheme and subsequent findings of verification audits are raised by the IVB. Currently, there is no legislative requirement to analyse the ICP recommendations along with the management system audit findings. Likewise, the Step Change in Safety guidance documents do not establish a relationship between them. The offshore legislations require the evaluation of human factors in safety cases [29,5] but fail to link this to SECEs. Perhaps the key interaction between the verification process and the management system is not fully realised. In the absence of a legislative requirement and an effective root cause assessment model, the IVB findings will remain a repetitive exercise until the management systems are improved and the defined standards are achieved in the industry. This study proposes an interim high-level management system framework for the improvement verification process **(refer to Appendix D)**. However, a joint research project should be initiated to assess the potential gap.

IVBs capable of identifying the weak signals of major accident hazards can be the industry's best friend. Their auditing skills and knowledge sharing can be considered as a core competence and performance driver of organisations such as IVBs. The strength of the regime lies in the fact that IVBs have contributed to bringing the change without any authority. IVBs play an important and significant role in implementing the verification process and they are and always have been the duty holders' first choice of as verifiers [3] (BOMEL, 2005). Weaver [37] sees third-party verification as a privatisation of the verification process where there is no means to confirm whether their performance is good or poor. Despite this, IVBs' contribution in improving an individual duty holder's assurance process is well recognised and DHs thus tend to prefer the IVBs compared to in-house verification or other third-party verifiers. In addition, the IVBs actively participate in forums like the UK Oil and Gas and Step Change in Safety. However, the question remains valid as to whether IVBs have proactively shared their verification experiences with the industry. Collectively, IVBs have played a passive role in sharing their experiences with the industry in terms of publications and analytical studies. To a certain extent, the current gap is filled by regulators and non-profit organisations, but both lack first-hand experience of verification.

IVBs have a working model of the International Association of Classification Societies (IACS) where these classification societies share their classification experiences [17]. The IACS members are also the main verifying

bodies. Currently, there is no unified body to represent IVBs. The verification regime is now being introduced globally; the introduction of a unified body of IVBs has become a necessity. Therefore, this study advocates the need to introduce a global forum of IVBs. This will improve collaboration and knowledge sharing among IVBs, and benefit the offshore oil and gas industry, offshore workforce, duty holders and regulators.

In conclusion, this research focuses on the applicability of the areas in question and validates that no legislation (named proactive or not) is perfect; the only permanent thing is the change itself. The offshore oil and gas industry must embrace the change, otherwise major accidents may happen. Hopefully, this work will lay down the foundation for researchers, legislators, regulators, duty holders, offshore workforce and IVBs to improve on the above contributions and open up new avenues for research. This now leads us to the applicability of the research; some of the key points are highlighted below:

- The research presents the concept of next-generation verifiers who are able to foresee the weak signals of a potential MAE.
- The training and development areas of future verifiers (ICPs) are identified.
- This is the first study to document the barriers impacting the effective implementation of the verification process. These barriers should be evaluated throughout the verification cycle. The primary data from this study can be used in future research.
- A proactive verification process is proposed for the duty holders and IVBs.
- A BN model is presented as a tool to evaluate the availability of the SECEs and assist in quantifying the verifiers' judgement on individual or multiple SECEs.
- Toolkits are presented to the IVBs and duty holders to assess the root cause of degraded SECEs.
- A high-level framework is presented to evaluate management issues impacting SECEs.
- The study successfully presented verification software application (V-Connect) as the biggest data source and assessment tool for verification activities. The verification software application is demonstrated, and verification data analysis reports are being generated and presented to the duty holders as a result of this study.
- It is suggested that the UK regulators share the identified best practices of the European Union Offshore Authorities' Group (EUOGA), North Sea Offshore Authorities Forum (NSOAF) and the International Regulators Forum (IRF) with the industry.
- In the interests of both the industry and the public, IVBs should annually publish a white paper which highlights the positives and areas for improvement in the risk-based regime.
- This study advocates the need to introduce a global forum of IVBs. This will improve collaboration and knowledge sharing among IVBs, and benefit the offshore oil and gas industry, offshore workforce, duty holders, regulators and legislators.

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The desired results of a proactive risk-based regime have not been achieved; therefore, a change becomes a necessity. The verification process should be the driver of the change rather than a repeated exercise. Objective oriented and meaningful interaction among stakeholders triggers the change. The change is an ongoing process and this contribution is part of a bigger cycle; this includes developing next-generation verifiers, improving assurance processes and eliminating repeated failures. The resistance to change is inevitable, and the biggest limitation to change in the course of a reactive verification process is the commitment and quality of leadership to bring about the proposed change.

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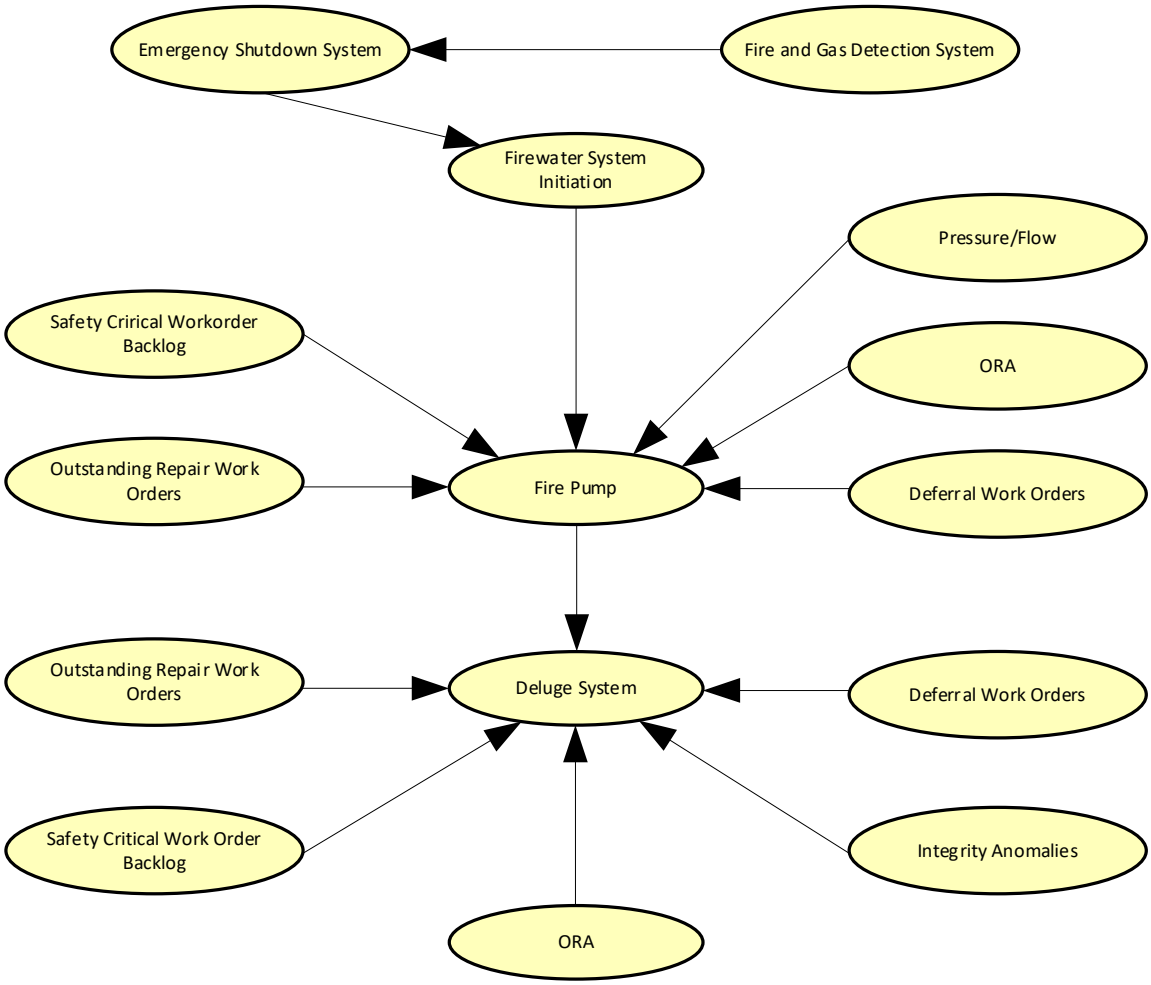
Appendix A- Bayesian Network Model for Active Fire Protection System



Appendix B- Pearson's Correlations with the DV (Proactive Verification Process)

	DV (PVP)	PSWS	MRAT	MMS	AMMS	EAP	IAP	SCC	ICPREC	ICPCOM	DHICOM
Proactive Verification Process (PVP)	1										
	N= 30										
Performance Standard and Written Schemes (PSWS)	-.691**	1									
	p=.000										
	N= 30	30									
Methodology and Risk Assessment Techniques (MRAT)	.838**	-.773**	1								
	p =.000	.000									
	N= 30	30	30								
Maintenance Management Systems (MMS)	-.553**	.781**	-.664**	1							
	p=.002	.000	.000								
	N= 30	30	30	30							
Assessment of MMS (AMMS)	.724**	-.728**	.890**	-.790**	1						
	p=.000	.000	.000	.000							
	N= 30	30	30	30	30						
External Assurance Process (EAP)	-.601**	.668**	-.724**	.804**	-.741**	1					
	p=.000	.000	.000	.000	.000						
	N= 30	30	30	30	30	30					
Internal Assurance Process (IAP)	.594**	-.733**	.796**	-.797**	.857**	-.732**	1				
	p=.001	.000	.000	.000	.000	.000					
	N= 30	30	30	30	30	30	30				
ICP Surveys and Commercial Constraints (SCC)	-.442*	.648**	-.562**	.813**	-.685**	.643**	-.766**	1			
	p=.014	.000	.001	.000	.000	.000	.000				
	N= 30	30	30	30	30	30	30	30			
ICP Recommendations (ICPREC)	.671**	-.799**	.897**	-.716**	.826**	-.767**	.831**	-.567**	1		
	p=.000	.000	.000	.000	.000	.000	.000	.001			
	N= 30	30	30	30	30	30	30	30	30		
Communication with ICPs and Forums (ICPCOM)	.690**	-.865**	.870**	-.727**	.832**	-.723**	.789**	-.592**	.935**	1	
	p=.000	.000	.000	.000	.000	.000	.000	.001	.000		
	N= 30	30	30	30	30	30	30	30	30	30	
Duty Holders' Internal Communication and forums (DHICOM)	-.278	.597**	-.382*	.783**	-.587**	.501**	-.715**	.879**	-.444*	-.484**	1
	p=.137	.001	.037	.000	.001	.005	.000	.000	.014	.007	
	N= 30	30	30	30	30	30	30	30	30	30	30

In order to investigate and portray the relationship between independent and dependent variables, SPSS correlation matrix is shown above. SPSS correlation table contains at least 3 pieces of information: 1. The size of the correlation, which has a range between -1 (perfect negative correlation) and 1 (perfect positive correlation). If the correlation is "statistically significant" SPSS also flags this number with either a (**) [highly significant if values lies between ± 0.50 and ± 1] or (*) [significant if values lies between ± 0.30 and ± 0.49]. When the value lies below + 0.29, then it is said to be a small correlation. There is no correlation when the value is zero. 2. The level of significance for the correlation *i.e.,* p value. If p value is 0.05 or smaller, it is considered statistically significant. 3. The number of participants (N) that were considered.

The above correlations matrix suggests that most independent variables have a significant positive/negative correlation with the dependent variable (Proactive Verification Process). Independent variables such as 'MRAT', 'CICP', 'IAP' and 'AMMS' showed positive correlation, whereas 'PSWS', 'SCC', 'EAP' and 'MMS' were negatively correlated with the DV. Only one independent variable, 'Duty Holders' internal communication and forums', showed no significant relationship with the DV *i.e.,* p is >0.05. Most independent variables also showed a significant positive/negative correlation with each other. For example, the external assurance process variable has a highly significant positive correlation (0.804**) with the assessment of maintenance management system variable. Similarly, the ICP recommendations variable showed a highly significant positive correlation (0.897**) with the methodology and risk assessment techniques variable. However, the methodology and risk assessment technique variable showed a highly significant negative correlation (0.773**) with the performance standards and written schemes variable.

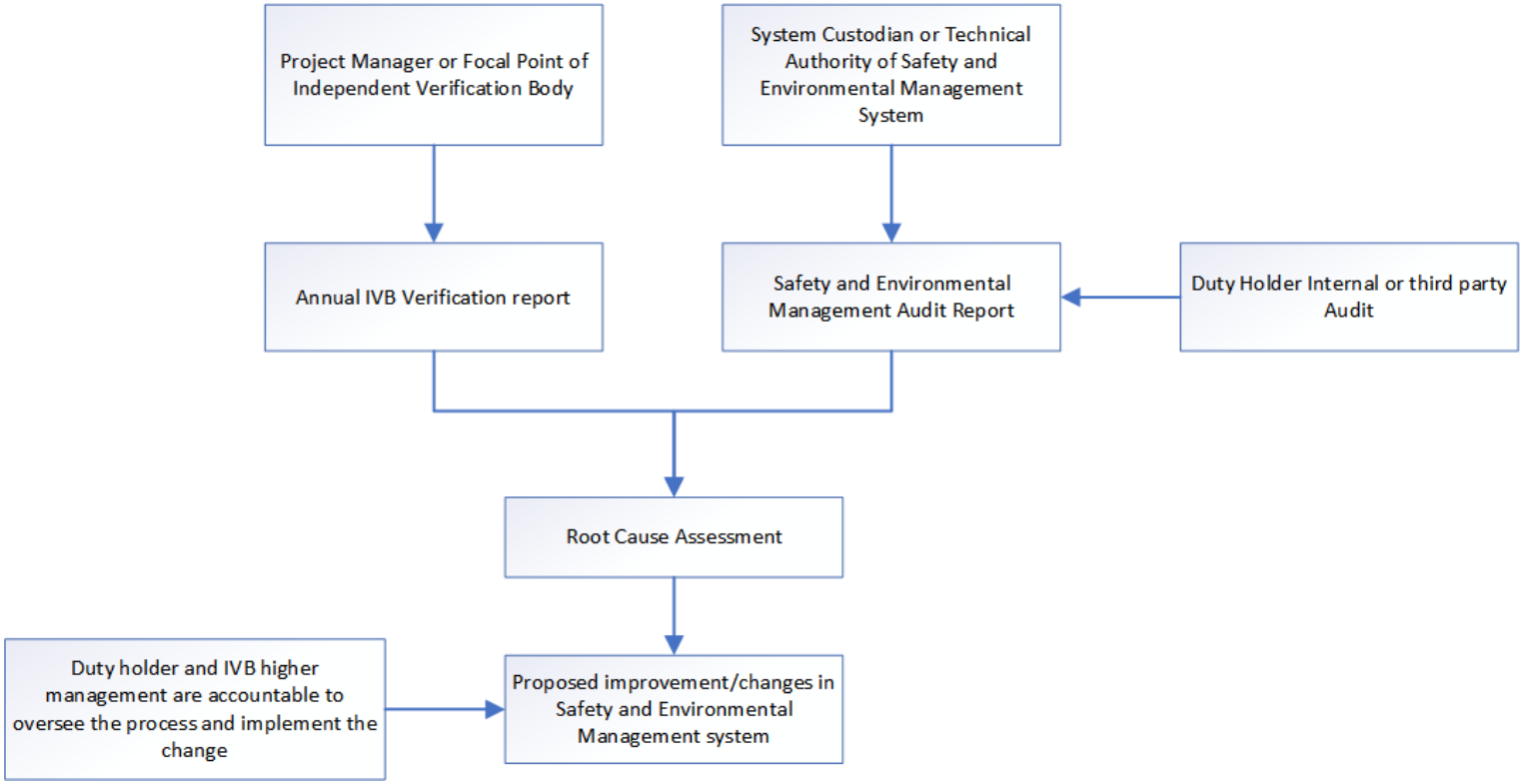
Appendix C- Toolkit for Duty Holders and IVBs

Toolkit for Duty Holders			
1.	List all failures reported in SECE work orders. Set a review period of three to five years or as frequent as appropriate.		
2.	Outline all the failure issues in these SECEs related to work orders/inspection.		
3.	Through brainstorming sessions, evaluate, record and report findings:		
Duty Holders Exercise			
	Items	**Findings**	**Results and actions**
i.	Check and confirm that frequency of SECE related work orders is adequate.		
ii.	Have we outlined the expectations and reporting requirements of these work orders?		
iii.	How can we ensure that closed work orders have sufficient history and supporting documents?		
iv.	Is our workforce trained and supported to complete the assigned task?		
v.	Do they have sufficient time and appropriate tools to complete SECE work orders?		
vi.	Have we effectively reported corrective work orders?		
vii.	Have we effectively managed the corrective work orders? If not, what are the barriers?		
viii.	Have we addressed the root cause of corrective work orders?		
ix.	Have we assessed and reported all failure modes of this SECE?		
x.	Which failure modes are repeated? Evaluate failure rates: are they acceptable?		
xi.	Is the deferral process robust? Have we adhered to the work order deferral process?		
xii.	Why have we had to defer work orders related to the SECE in question? What can be done to reduce the deferral requests?		
xiii.	Have we challenged the effectiveness of an internal assurance process?		
xiv.	Outline the gaps in the internal assurance process.		
xv.	Have we proposed solutions to the potential gaps in the internal assurance process?		
xvi.	Have we trained and supported the ICPs to review our internal assurance process, including the deferral process?		
xvii.	Evaluate findings of the annual availability report.		
xviii.	Review and assess the pattern of ICP recommendations; engage ICPs for a long-term solution.		
xix.	Are there any design issues involved in the failure of this SECE? If yes, outline these design issues.		
xx.	Are these design issues common in the industry? If yes, engage industry stakeholders through forums such as Oil and Gas UK.		
xxi.	Can the IVB design team help in addressing these issues? If yes, engage with the IVB team.		
xxii.	Are there any obsolescence issues involved in the failure of this SECE? If yes, outline these issues and initiate a management of change process to address them.		

Toolkit for IVBs	
1.	List all reported issues for a particular SECE. Set a review period of three to five years or as frequent as appropriate.
2.	Outline the issues raised in these recommendations.
3.	Through brainstorming sessions, evaluate, record and report findings:

IVBs Exercise			
	Items	**Findings**	**Results and actions**
i.	Have we raised the appropriate level of recommendations?		
ii.	Check and confirm that sample size of offshore surveys and onshore audits was adequate.		
iii.	Have we assessed and reported all failure modes of this SECE?		
iv.	Which failure modes were repeated?		
v.	What is the frequency of a failure rate; is this acceptable?		
vi.	Are we as an ICP familiar with the work orders deferral process?		
vii.	How well does a duty holder in question manage the work order deferral process?		
viii.	Is the deferral process robust enough?		
ix.	Have we challenged the effectiveness of an internal assurance process?		
x.	Outline the gaps in the internal assurance process.		
xi.	Review the SECE availability report. Evaluate and identify potential improvement areas.		
xii.	Why do other duty holders perform better in managing this SECE?		
xiii.	Have we proposed solutions to the potential gaps in the internal assurance process?		
xiv.	Are there any design issues involved in the failure of this SECE? If yes, outline these design issues.		
xv.	Are these design issues common in the industry?		
xvi.	Can the IVB design team help in addressing these issues? If yes, engage with the duty holder and present the case.		

Appendix D- The Interaction Between the Management System and the Verification Process



The above figure provides a high-level framework which encourages the interaction between the IVBs' verification focal point and duty holders' system custodian. They are required to share and analyse the end-of-year verification report along with the safety and environmental management audit report (anomalies and non-conformances). This will enable a collaborative culture between duty holders and IVBs. The root cause assessment report should identify barriers to the verification process and propose short- and long-term changes in the management system to address those barriers. The decision-makers (the higher management of the IVBs and the duty holders) should review the proposed solutions, oversee the change process and implement the change.