Executive Summary

The oil and gas industry relies upon safety barriers to mitigate risk and allow for continual safety in operations. Inadequate safety barriers can lead to severe consequences in the event of a negative incident. Current models for evaluating barrier effectiveness were examined in this work, exploring the hypothesis that there were gaps in available models. This hypothesis assumed that a more effective barrier evaluation approach would be beneficial to consider as opposed to any existing method that would be used in isolation.

The importance of this work is defined by the great risk of loss to people and assets that is associated with failed barrier performance. Losses can occur when barriers either fail to perform as expected, or when they are ineffectively chosen as the most appropriate barrier for an application. Therefore, to evaluate when a barrier is most effective is a key step in reducing chance for loss.

The fundamental step for identifying the potential performance of a barrier requires a critical action. The action is to identify factors by which to evaluate barrier performance. Such factors were lacking in clarity, and one objective of this work was to rectify this by identifying factors which should be used in evaluating barrier effectiveness.

Through the analysis conducted in this work, key factors or themes were established which could be critical for evaluating safety barrier performance. The factors have been successfully tested for Content, Criterion and Construct validities. Seven (7) factors were identified which influence barrier performance for onshore gas drilling operations based on Factor Analysis. The factors are Performance, Defense, Trust, Limit, Perception, Dependency and Robustness. These factors and the underlying 25 variables formed the basis for building future risk models or barrier analysis methods. Additionally, the factors were validated by a group of representatives from the Drilling industry. An overall score of 4.8 / 5 was obtained based on the feedback from the representatives. Through the evaluation of these factors for individual safety barriers, it could

assist in the overall re-assurance of process safety (by evaluating safety barrier performance) in onshore gas drilling operations.

The research presented an active risk monitoring method which evaluates barriers and transforms the existing Bow-Ties to a Bayesian Risk Model considering an onshore gas drilling environment. The driver for this research was lack of linkage in any of the existing risk frameworks between barrier performance and the associated risk impacts. A Major Accident Hazard (MAH) puts personnel, production, capital investment and corporate reputations at risk. A review of MAHs was conducted for three (3) onshore sour gas drilling operations within the region of the United Arab Emirates (UAE). Based on the review, Asset-C was selected as the asset for application of the transformed Bow-Tie and Bayesian Risk model due to the comprehensive listing of the MAHs and the associated safety barriers. Based on the identified MAHs for Asset-C, only six (6) out of the eleven hazards were related to core drilling operations. The MAHs were further decomposed into thirteen (13) threats and six (6) consequences. The consequences considered for this research were focused on personnel and asset impacts. The MAHs comprised of twenty eight (28) threat barriers and eighteen (18) recovery measures.

It was observed that a majority of the threat barriers and recovery measure barriers were associated with plant hardware or fully automated equipment. The drilling MAH Bow-Ties were transformed into potential accident pathways. Since risk is a combination of threats and consequences, it was decided to split the accident pathways into Threat and Consequence event pathways respectively. In the next stage, Drilling and HSE personnel from the specific asset under consideration were required to rate each of the safety barriers using the identified factors. The ratings were carried on a five (5) point scale, where one (1) related to Very Low (ineffective) and five (5) related to Very High (effective). The average scores from all the participants were normalized by conversion of the rating scale from 1-5 to a normalized scale of 0-1 for usage as an input in the Bayesian Networks.

The Bayesian Network for this analysis was developed using AgenaRisk Version 6.0 software. This software has been in use since 2005 and is widely used in defense, transport, banking, telecommunications and safety engineering companies owning safety critical systems for which quantitative risk assessment is required (Fenton & Neil, 2014).

Each of the safety barriers were modeled using the ranked nodes. Ranked nodes represent discrete variables whose states are expressed on an ordinal scale that can be mapped onto a bounded numerical scale that is continuous and monotonically ordered (Fenton et al., 2007). Ranked nodes were defined on an underlying unit interval [0-1] scale. A five-point scale such as {very low, low, average, high, very high}, was chosen to model the individual safety barriers in the Bayesian Network. The interval width for each state was 0.2. Thus, “very low” was associated with the interval [0 - 0.2], “low” was associated with the interval [0.2 - 0.4], and so forth. Ranked nodes enabled the Bayesian Network construction and editing task to be much simpler than was otherwise possible. Through this method, each of the threats and consequences were transformed into a dynamic Bayesian Network diagram. Threat barriers and consequence barriers were evaluated using the constructed Bayesian Networks – an overall barrier performance was thereby evaluated for each of the thirteen (13) threats and six (6) consequences associated with all six (6) major accident hazard events.

From the analysis of overall barrier performance, it was observed that the threat barrier effectiveness ranged from 68% (induced well control and plugging pilot hole threats) to 78% (related to core drilling operations). This signified barrier controls required more focus for induced well control and plugging of pilot hole operations in relative comparison to other threats. Similarly, consequence barrier effectiveness ranged from 70% on controls related to mitigate on-field impacts (fire, explosion and toxic) to 75% on controls related to off-site and public impacts. In the next stage, Inherent Risk (IR) and Mitigated Risk (MR) were referred from existing Risk Ranking Reports.

IR was evaluated as a criterion for MAH identification considering "NO" safety barriers. MR was ranked considering safety barriers are perfectly functional (100%). IR and MR were ranked using ADNOC 5 X 5 Semi-quantitative Risk Matrix (ADNOC, 2014). Meanwhile, risk control was built on the reduction of the frequency of occurrence of the major dangerous phenomena, taking into account the safety barriers' performance so that the dangerous phenomena were defined with an acceptable couple, i.e. gravity of the event (consequence) and frequency of occurrence (Dianous & Cecile, 2006). In reality, the Actual Risk (AR) exposure was correlated with safety barriers' performance. It was observed that the AR for personnel was very close to the High Risk region and the risk is in the higher "as low as reasonably possible" (ALARP) region in comparison to the MR. For the asset related risk, the AR was around the lower ALARP region in comparison to the MR which was in the Low Risk region.

Therefore, comparing the Personnel and Asset Risk, the AR exposure of personnel risk was slightly higher. The barrier based risk model and results were validated through a workshop consisting of a mixed group comprising of HSE Manager, Process Safety Engineers, Senior Drilling Engineers, Senior Well Integrity and Regulators (Safety Department Manager). The validation parameters included were overall conceptual framework (barrier performance factors), relevance of data, models / techniques, interpretation of risk and overall applied value of the risk model (Abbas & Routray, 2013). The respondents gave a score of 4.8 to overall conceptual framework and models / techniques, 4.6 overall for applied value of the risk model, 4.5 for the interpretation of the results and 4.3 for the relevance of the data. The average of all the components was 4.62 which revealed high reliability for the model.

In conclusion, the respondents found value for the model application in real life. The risk assessment model allows for real analysis of barrier effectiveness in an onshore gas drilling application. The risk model presents the AR exposure to the Drilling operations which will assist the decision making of the Management in a Drilling organization to identify the progressive deterioration of barriers and initiate corrective actions proactively.

This research was conducted with structure, method, and attention to depth. However, there were noted limitations in the process of conducting this research. It is recommended that future researchers take note of the following limitations related to this study, and consider the implications for future work in this area of barrier analysis.

The research for this work revealed a confirmation of the hypothesis regarding gaps in existing evaluation models, as no single barrier evaluation technique was complete as a sole analysis method. The data provided evidence that there was room for further development in barrier analysis techniques, which implied there would be higher risk in barrier safety until such technique evolves.

The conclusion of the research moved from understanding the problem and offered a solution for consideration. The solution accounted for positive aspects of existing models, and took a hybrid approach to bridge gaps in available models. The developed risk model was tested with inputs based on an onshore gas drilling process within the United Arab Emirates. Onshore industry personnel were involved in the validation exercise and feedback from these personnel was positive and assuring of the importance and benefit of the proposed model.

The solution met the goal of two objectives. The first objective was to offer factors by which to identify barrier effectiveness. The second objective was to present an active risk evaluation method for evaluating barrier performance. This research and proposed solution met both objectives. The results offered a theoretical contribution of research which advanced the level of certainty by which decisions can be made regarding choice of barrier in an application. Such decisions can be made through weighting of specific factors and predictive evaluation of barrier effectiveness. The contribution of this research supports more informed selection of barriers in order to decrease the life and asset losses in the onshore drilling industry.