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Review of Practical Applications of the Bow-Tie Approach Especially in Offshore Oil and Gas Industry

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Abstract

The Macondo blowout was the major motivational force to put the offshore petroleum industry under intense focus and has disclosed the need for efficient hazard analysis and control of the associated risks. Risk analysis techniques are pivotal tool to develop strategies for accidents prevention and consequences mitigation. Amongst various obtainable techniques, the bow-tie method is the common and most significant technique for high hazard industries to promote process safety. It is graphical relationship among basic causes, critical events and ultimate consequences of unwanted events by combining fault tree and an event tree. This paper aims to perform extensive review of the various practical significance and uses of the bow-tie model in the conducting safety and risk analysis for different high risk industries in general and having a special focus on the applications directly related to the offshore oil and gas industry. The review depends on available papers and researches that have been already published in open literatures overtime. The best gain of the bow-tie is the obtaining a clear picture of the risk that is readily understood by humans even less experienced individuals. On the contrast, the greatest drawback is the uncertainty during quantification. So, many researches and developments have been started in the past and still continuing at present to in order to handle the limitations of the bow-tie. Bow-tie plays essential and intrinsic role to analyze and control the process risks during the design and operational phases as well as it is highly important to take the appropriate decisions to enhance the offshore safety in the offshore petroleum environment.

Keywords: *Bow-tie, dynamic risk analysis, safety barriers, FTA, ETA, Bayesian network.*

1. Introduction

With the running out of the readily accessible oil formations, the exploration and production processes of the oil and gas has initiated in harsher and more hostile offshore environments [1] . Offshore oil extraction is very tough and poses many critical challenges such as high pressure and temperature and poor experience of Personnel etc [2]. Consequently, Drilling operations are more prone to major events that have driven to considerable major rig accidents in the past such as, Piper Alpha explosion in the North Sea in July 1988 and Deepwater Horizon drilling rig explosion, in April, 2010 [3]. The Macondo blowout has raised serious concerns about the offshore safety level of deepwater drilling [4]. Blowouts are the most catastrophic scenarios during offshore drilling and the associated risks are extremely difficult to be controlled [5] and [6]. The blowouts cannot be prohibited completely but the accidents probability and severity extent can be reduced by applying suitable Safety measures [6]. Well integrity methods were applied to keep the well under control by placing specific safety barriers in order to prevent or mitigate the accident [7]. So, The Safety during offshore operations is highly important. Safety level is often represented in terms of risk. Risk is defined qualitatively by SRA [8] as the product of occurrence probability and consequences severity [9]. Risk analysis is an essential tool for developing plans for accident control. Risk analysis is a technique for qualitative and quantitative determination of risk and considered as the prime step of safety management [10]. Khan has discussed the current risk assessment techniques with advantages and disadvantages [10]. They also presented a valuable set of advanced methodologies to carry out the effective and optimal risk analysis. Marhavilas [11] has performed a review study of risk assessment related to various work environments. The models for process safety, the risk assessment and risk analysis tools have been revised by Khan [12]. Khan concluded that quantitative techniques developments is a gradually increase in number over time whilst the qualitative is steady. Terje [13] has performed review of the advances of the Risk assessment and management approaches and their valuable contributions in supporting decision-making. In offshore drilling operations, risk analysis has great applicability due to safety concerns with objective for promoting process safety and developing accident control plans. It determines acceptability of the risk as well as specifies the major risk influencing factors which must be controlled [14]. It is gradually used in the offshore oil and gas industry during the planning phase of wells to identify the most likely hazards [15]. Fault tree (FT), event tree (ET) and the bow-tie (BT) methods are the most common risk analysis techniques that have been widely used to minimize the failure rates in the offshore processes [16]. Based on the results obtained from blowout fault tree, Grayson [17] have conducted a comparative risk analysis study between managed pressures drilling (MPD) and overbalanced drilling (OBD) techniques. Additional studies have been performed for risk analysis of the overbalanced drilling [18] and [19]. BT model is widely applied to identify and analyze the potential risks in many hazardous industries such as offshore industry [20]. The BT model provides a pictorial display of risk and clarifies the relationships between safety barriers and organizational and managerial factors by emerging the fault-tree and event-tree through safety barriers [21], [22], [23] and [24]. Visser has proposed an integrated BT framework involving of number of causes – consequence method [25]. The BT approach has also been used to manage the occupational risks [26]. Ruijter and Guldenmund [27] have categorized the bow-ties into two main types: Quantitative bow-ties and Qualitative bow-ties. Moreover, it is commonly employed an efficient graphical model for risk analysis of process accident especially in offshore drilling works [28]. In 1998, a stochastic model has been developed by Andersen based on the physical mechanism of the kick which is the initial event of the blowout. Afterwards, the fault tree was used to rate the kick likelihood for every drilling sub-operation. The static fault tree has been extensively used in analyzing the risks of oil and gas wells kicks and blowouts [29]. However, many researchers have conducted studies related to offshore industry and evaluated the associated risk of using BT; this is discussed in subsequent sections. Despite of the BT is worldwide risk analysis tool, it still pose major concerns such as result uncertainty because of dependency on generic data which makes it none specific for particular situation. In past and till now, a number of researches have been established to handle these limitations. Bayesian network [28] and fuzzy set and evidence theory [30] are most widely used to vague and uncertainty which were addressed in the coming parts of this article.

2. Bow-Tie Overview

Butterfly diagram is the original name of the BT which developed from the cause consequence diagram in 1970 [31].The Queensland University in Australia has presented the Hazan Course Notes 1979 in which the earlier mention of the BT has appeared. Certainly, the Royal Shell Group was the first big company to introduce the whole BT model totally into business practices [32]. The using of the bow-ties has spread out and circulated among companies and industries. Several examples of BT analysis have been published by the world organizations such as the Health and Safety Executive (UK) [33]. The BT method presents an easily comprehended conception of the relationship between the causes of incident, the proactive safety barriers that avoid the incident occurrence and the reactive barriers which reduce the consequences severity. A BT model is a combined diagram that couples a fault tree on the left side and an event tree on the right side of the diagram. It represents basic causes, plausible events and final outcomes. General structure of the BT diagram is shown in Figure 1. The basic elements of the BT are causes, fault tree, critical event, event tree, safety barriers, and consequences [34], [35], [36] and [37]. The quantitative analysis of BT determines the probability and pathways of accident occurrence.

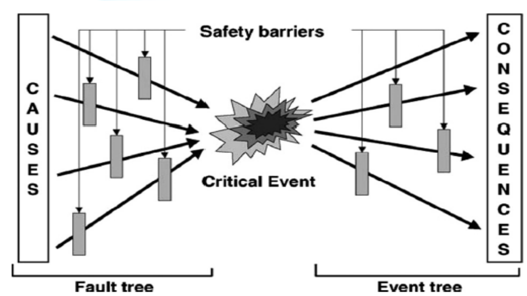

Fig.1. General a bow-tie diagram [22]

The quantitative analysis can be preceded based on the traditional assumptions and mathematical operations for FTA and ETA .The quantitative evaluation is to estimate the top event probability of the fault tree and the occurrence frequency of the consequence for event tree. To do so, the conventional calculation operation for "OR" gates and the "AND" gates have been described by Vesely (1981) and Ferdous (2010) [35] and [38].

Furthermore, the authors have focused on the dealing with the uncertainty of the input probabilities.

3. Practical Significance of The Bow-Tie in The Industrial Safety Aspects

The practical uses and contributions of the BT have been traced in the available literature. The BT has vastly used as a powerful technique for risk analysis in process industries, so the most important practical uses and significance of the BT have been reviewed based on available published researches and reports. To make these review readily and clearly understood; they have been categorized for five categories according to type of contribution in industrial safety management system as following:

3.1. Layer of Protection System

Layer of protection analysis (LOPA) is an efficient semi-quantitative analytical method for evaluating the sufficiency of protection layers which used to minimize and control the related risks of the process accidents in the various industries. Initially, Over last two decades, the BT emerged into LOP system. Dowell has applied BT diagrams for conducting Layer of Protection Analysis in order to identify the needed Safety Integrity Level (SIL) of a Safety Instrumented System (SIS) [39]. It determines level of protection and enables conservative estimates of place residual risk which then compared against risk acceptance criteria. However, the BT model carries clear attenuating circumstances which are met in the calculations of the causes and consequences probabilities. In majority, this obvious weakness arising from unavailability or inaccuracy of the input reliability data. The encountered uncertainties and doubts have been successfully reduced by the fuzzy logic application. Markowski and Kotynia [40] have conducted research to reduce the BT uncertainty. They have combined the BT diagram with layer of protection analysis and fuzzy logic to build an integrated model to analyze and evaluate an accident scenario in a hexane distillation unit. Further work has been done by Rachid and Ali [41] in which new model was proposed by integration between LOPA and BT analysis to precisely calculate the consequences frequencies using fuzzy sets. The proposed model is the best solution for reliability assessment and improves the safety integrity level to enhance the safety value and minimize the risk value for the storage tank holding a flammable liquid. The obtained results are more powerful than logical method. Recently, Yazdi did study in which they have carrying out the risk management for high concentration H_2S in oil processing unit by using BT with LOPA tool [42]. Accordingly, they have recommended appropriate solutions to diminish the adverse impacts and promote SIL aiming to improve safety performance of plant. The fuzzy logic application enables the utilization of the vague input data provided by expert and converting them into accurately planned outputs.

3.2. Risk Assessment and Hazard Management

Risk assessment process usually focuses on the risk level only rather than counting all portions of the risk management. As the BT model visualizes the direct relation between the controls and management elements so, it provides wider coverage than HAZOP study or other techniques. The BT diagram has been established to link between the critical tasks of the health, safety, environment (HSE) required for threats control by maintaining the safety barrier. In 2004, Eslinger [43] have used BT analysis in hazard management process to identify and evaluate the hazards and associated risks of vehicle operations. To perform BT probability quantification. Rapid risk ranking based on the risk matrix has been combined with traditional BT diagrams [44]. This proposed framework used to construct the probability bow-tie (PBT) which applied to estimate and assess the risk level for chemical marine terminal. Furthermore, Chevreau [45] has used BT based on Aramis method to organize learning process and proposed an effective method for risk. This method depends on the communication between safety experts and local operators which in turn improve the organizational learning for safety. Furthermore, they depicted the application of the BT for accident analysis in a pharmaceutical production industry. Similarly, Upton 2009, it was no risk-analysis tool in healthcare operations to analyze risks, causes and consequences of potential serious cases. For this purpose, Wierenga [46] has studied the usefulness of the BT method in the hospitals with purpose to analyze the medication process risks and enhance the medication safety effectively. Recent improvement was achieved in the healthcare domain considering the Patient safety. Zhaleh and Hamid [47] have applied the BT technique for proactive risk assessment to maximize the patient safety in the intensive care unit. Practically, this application has provided good suggestions to remove or mitigate the identified hazards that need to be controlled for safe clinical operations. Mokhtari [48] have carried out risk assessment study for the offshore depots operations. This was done by coupling between a generic BT and risk management. Furthermore, Shahriar utilized the BT approach to analyze the risks regarded to the natural gas and oil pipelines using social, environmental and economic consequences [49]. In order to reduce the ambiguity of the input data, Fuzzy logic is applied to get the posterior probabilities of all causes and outcomes .The research results can support the decision-making process. The BT model has also been utilized to assess the safety level increase the confidence in the findings. Fredrick [50] has applied BT method to assess the environmental impacts associated with early design for offshore platform. Chris [51] has performed the risk assessment-based methodology to define the BT compatibility with the management of the risk and assist the engineering controls for many oil and gas facilities. Bower-white has proposed adequate and effective barriers to manage that risk effectively in the hazardous industries [52]. Yaneira [34] have successfully applied the BT methodology in the oil and gas downstream processes facilities in the USA. Faisal proposed a framework to improve the technique of the risk assessment in a chemical plant by combining Fishbone Diagram, and Failure Mode and Effect Analysis with FBT analysis [53]. Novel framework has been developed by Wackett based on technical integrity assurance utilizing a new execution of BT model [54]. In addition, a unique visualization method is presented to convey the regulator interaction with the organizations performing design, production and maintenance under their regulatory framework which is applicable in the high risk offshore and industries [55]. It is noticeable that, the BT can be a quizzical methodology in the safety management which enables the enhancement of the assessment performance of the risk from practicability point of view.

3.3. Safety Barriers System

Safety barriers represent a basic part of the BT diagram. Safety barriers are a physical or non-physical solutions aiming to eliminate, control, or mitigate the undesired situations [56]. Simple bow-ties are powerful in identifying functions of the safety barriers for each incident and determining their impacts on the accident path scenarios [57]. To enable the industrialists to get better knowledge about safety functions, the barriers performance assessment is quite needed. Duijm [21] utilized the BT to construct harmonic and useful safety-barrier diagrams of analyzing risk and safety systems documentation. Preventing of the serious accidents requires continuous monitoring of safety level in the process. Knegteringa and Pasman did study to set a conceptual method which relies on the received regular parameter signals and weak and slowly varying signals from different safety indicators in order to keep risk levels under tracking [58]. Additional studies were carried out to make further development towards a safer industry and better process performance [59]. It sounds possible to link the rates of technical failures with risk parameters acting over time and to apply action prior something goes wrong. Furthermore, to calculate the failure on demand (PFD) probability for SIS, Rachid has developed a novel mathematical approach [60]. BT method is integrated to analyze safety for the PFD evaluation of the safeguards. Afefy [61] has integrated FMEA with the BT model as new developed technique for hazard assessments that integrates. Finally, the BT is very useful to demonstrate the safety barriers influence on the on the accidents.

3.4. Accident Modeling

The accident models should be a platform for the process safety indicators. The BT metaphor has been evolved in different industries. It was employed as accident model to display the sequential path of accident occurrence [62], [63] and [64]. It was employed to differentiate between the leading and lagging indicators. BT doesn't consider the time factors or potential failures. Wagenaar [65] has proposed the new simplified BT model for adverse incidents in the petroleum industry, which consider not only the psychological precursors but also the unsafe acts. Lately, this model is well-known as Swiss cheese metaphor [66]. Ahmad [67] has performed work to modify the Swiss cheese metaphor with goal to study a causal event. This new model can provide a better clarity of the system with conjunction to the safety barriers.

3.5. Real-Time Risk Analysis

Quantification of the traditional BT is achieved using static probabilities of failure which cannot represent a specific case or particular state. So, the updating of the risk picture over time when new data becomes available is the major limitation of the static BT which should be used to precisely show the existing case [68]. Marseguerra was the first researcher who has discussed the feasibility of emerging of the process dynamic behaviour within the risk analysis by applying a neural network methodology [69]. Kalantarnia has proposed methodology to evolve the dynamic risk assessment [70]. In order to develop this approach, the Bayesian theory has been applied along with accident precursor data with purpose to update the failure probabilities of the components and safety barriers. Yang and Rogers have made an identical analysis to minimize the vague and uncertainty of calculation of the fault tree using Bayesian theory [71]. Furthermore, new methodology has been proposed by Ferdous to promote and improve the BT analysis performance by employing a fuzzy-Bayesian model [72]. It integrates the uncertainty properties, utilization of experts' data and updating prior knowledge with new evidence provided. Khakzad [73] applied BT in DRA of dust explosion accident at Sugar manufacturing industry. This done by incorporation of physical reliability approaches and Bayesian model to take into account the variations of occurrence probability of accident consequences which has been examined for offshore drilling [74]. In this method, prior probability of the primary events is evolved using reliability models. On the other side, the prior probability of barriers failure are timely updated using Bayesian network as new data occurs over process time. Ferdous and Khan [30] have evolved and analyzed the BT model of the BP refinery Explosion in Texas. Approaches based on Fuzzy- and evidence theory along with a sensitivity analysis technique were developed for BT analysis to handle the vague and the uncertainty and mitigate the risk as well. Input data uncertainties are still a major concern and may mislead the decision-making process. The weakness of the BT model is restricted to a visualization of various accident scenarios and ignores the real-time data of actual systems. Thus, the dynamic BT models still remains a significant concern. Novel Bayesian network has suggested building the BT diagrams which accounts the actual data which reflects the right behavior of the studied systems [75]. Xinhong [76] has employed the BT method to create a risk-based accident model which was used to conduct QRA for submarine pipeline failure which aims to prevent and mitigate probable oil leakage scenarios. Then, BT of oil leakage was converted into a Bayesian model to renew the prior probabilities when new observations happen. This model could consider the common cause failures and conditional dependencies, thus, it could be more realistic compared to the static BT. Efficient risk analysis was made by Xian with great significance for fires and explosions prevention and mitigation for natural gas pipelines [77].This proposed framework enhances the efficiency and the technical support for the natural gas pipeline management. Yang has applied the BT to establish a systematic model for corrosion failure to analyze the undesired events and to evaluate the subsea pipelines conditions aiming to anticipate the likely corrosion in effective way [78].

4. Applications of Bow-Tie in Offshore Oil and Gas Industry

The transfer of the offshore petroleum exploration into deeper, remote and hostile locations requires a better analysis, assessment and management of the relevant risks. These challenges have made the offshore industry is one of the most dangerous industries worldwide. As mentioned previously, blowouts are the most frequent accidents during offshore oil and gas exploration and as the uncontrolled influx of reservoir fluids into the rig floor which if not contained and controlled properly and immediately , may result in excessive fires and explosions [74]. The BT model has become popular and widely used as effective risk analysis technique in high risk industries especially in offshore well drilling phases. Extensive and clear review of common and various applications and contributions of the BT model in offshore oil and gas activities have been done in this article. This review has divided the applications into four categories according to the type of process in which BT applied as following: drilling ahead operations, well integrity operations, safety barrier management and offshore emergency management.

4.1. Drilling Ahead Operations

Deepwater drilling processes are the highest risk and pose the greatest record of adverse accidents as compared to other processes in the petroleum sector [80]. However, the highest significant challenge encountered is the narrow safe drilling range between formation fracture pressure and pore pressure, thus the narrower the margin; the riskier drilling phase and higher blowout potential [81]. As per records of the past occurred accident, the most offshore blowouts have taken place in the drilling phase [82]. Since four decades, many researchers have studied the risks in offshore drilling. Bercha in 1978 has applied the BT tool to analyze the drilling risk for the exploration wells in Canada. He has used a FT to estimate the blowout likelihood and the ET to identify the sequence of blowout [83]. In 2013, Khakzad, Khan and Amyotte [5] have conducted risk analysis for well integrity using BT approach. Assurance of the proper control of the well requires sequential application of the kick prevention, kick detection and blowout prevention. In this study, Fault tree for kick occurrence and detection, an event tree for kick escalation into blowout are developed for potential scenarios, and then emerged to construct a BT model. As the potential common cause failures and conditional dependencies among the primary events cannot be captured by static BT. Therefore, Khakzad and Khan [28] have mapped the BT into the BN which capable to handle and determine the common failures along with performing probability updating using accident precursors. Furthermore, Abimbola has emerged the BT into the DRA for offshore drilling blowouts [74]. This approach has incorporated the BT and real-time barriers failure evaluation of offshore drilling works including subsurface BOP. The BT model was applied to display the probable accidental scenarios, their causes and the likely consequences for offshore drilling blowout. On other hand, real-time predictive models use real-time observed data so, the key barriers failure probabilities and associated risks are timely updated which in turn was utilized to update the risk profile. Abimbola did a work to analyze the safety critical components and consequences of possible pressure regimes of constant bottom-hole pressure in managed pressure drilling (MPD) [79]. Initially, this study was initiated by applying the BT to analyze the UBD scenario which often result in a well kick and the OBD scenario which may lead to differential pipe sticking and lost circulation which can sustain to a blowout. The constructed BT has been transformed into BN model to model the conditional dependencies and update the static probabilities of the causes and consequences. Further researches are needed in future for more precise and effective dynamic BT analysis to face the uncertainties and facilitate the decision making.

4.2. Well Integrity Operations

The well integrity activities basically include the casing and cementing of the wellbore which are applied to save the well control and minimize the kick and blowout potential. Studies conducted by Izon about the blowouts in the Continental Shelf in U.S.A between1971 and 2006, the results have identified the casing and cementing failure [84]. According to the investigation reports of Macondo rig explosion in 2010, the major cause of the gas blowout were that the poor cementing operation [85]. Safety and risk analysis of casing and cementing are great requirement to maintain the integrity of the well. So there is essential need to analyze the risks related to these operations for deepwater wells. Abimbola and Khan [86] have modeled and analyzed the integrity of the well by employing the BT model to analyze the potential failures in casing for each section and subsequent cementing process. Thereafter, the BT model is converted into a Bayesian model to overcome the limitations of the BT such as probability updating and conditional dependency. Apparently, the bow-tie risk analysis of cementing and casing process is new topic, so further researches are required to promote the analysis process of the risks regarded with cementing and casing operations by considering the human and organizational factors and to model the conditional dependencies and update the prior probability in simple, easy and more powerful way.

4.3. Safety Barrier Management

Safety and accident model has become highly needed to enhance prevention and mitigation measures of offshore blowouts throughout the well life cycle. In 2010, Brazilian Petrobras [87] has used the BT tool to determine and manage all the qualitative risks of all offshore production installations. This will help him to make the best decision in order to maintain a high safety level of the platform. Pitblado [88] have suggested an accident investigation method that constructed on barrier-based bow-ties diagrams. However, there was necessity to find proper method to identify basic causes of a specific blowout and to create clear model for blowouts. For this purpose, new model was built by combining the Swiss cheese with the BT for drilling blowouts [82]. The model based on the Primary, secondary barriers and well monitoring barriers between them. Successful well monitoring of the warning signs of kicks help in quick recovery of the primary barrier or early activation of the secondary barrier to avoid blowout. The historical analysis of past offshore accidents has shown the great need of safety barrier management for accidents prevention. Framework has been established a for barrier management in offshore petroleum industry in Norway [89]. The BT methodology is vital tool in this framework and has been used to categorize the safety barriers. First, it was utilized to analyze the placed barriers and define their functions for each hazardous scenario .Then; it was applied to analyze the risk by performing frequency analysis and consequence analysis. William [90] has suggested a comprehensive, robust approach for dynamic barrier management for decision support. This approach Couples the bow tie diagram (provide information about the barriers that can control the accident evolution) with response trees (provide information on maintenance measures and barrier restoration). Common cause failures of the safety system and are not analyzed in this model. So, systematic and quantitative analysis of the barriers system is important goal for future research to improve the safety barrier performance and reliability.

4.4. Offshore Emergency Management

Offshore petroleum structures are classified as the hardest, most complicated and most fatiguing work environment in the world. Human factors play a vital role in the finalization of emergency measures. As, the human errors probabilities increase if the stress increases. Deacon and Amyotte [91] developed a method for safety barriers selection, failure reduction and assessment of the human errors during musters steps of the offshore emergency. The risk level identification and its acceptability based on the findings obtained from the past scenarios. Great Protocol was developed by employing the ARAMIS approach; this protocol used for selecting and evaluating the barriers to minimize and re-evaluate the risk. Deacon and Amyotte [92] also have presented a framework to determine and assess the risks of personal errors for crucial actions in the escape, evacuation and rescue (EER) operation on offshore installations. Expert judgments and past serious accidents investigations were integrated to assess the risk associated to the evacuation step. This research method has incorporated the assessment of the human errors using BT model and minimization technique (HEART) to quantify the occurrence probability and severity of the possible outcomes. Since, offshore platform carries heavy equipment and huge quantity of explosive and flammable hydrocarbons, fires and explosions are extremely hazardous on offshore platforms. The analysis of historical statistics demonstrates that the plurality of offshore fire and explosion accidents are arising from human and organizational errors [93]. A new methodology has been developed by Noroozi [94] to assess the cold and harsh environment impacts on the human performance reliability in offshore petroleum facilities. For purpose of analyzing the dynamic influence of human and organizational factors factors on offshore fire/explosion risk, in 2015, Wang has constructed a dynamic model for risk analysis of offshore fire and explosion by integrating between system dynamics, BN and BT [95]. The powerful prevention measures for risk control of offshore fire/explosion can be designed based on the root of human and organizational errors. This will provide guideline for risk management of offshore platform.

5. Conclusion

This review paper aims to analyse the practical applications and importance of the BT method in process safety management for high risk industries in general and most focused for offshore oil and gas domain. The review depends on available papers and researches that have been already published in open literatures overtime. This study offers an overview on BT diagram as conventional risk analysis technique and vital part of industry safety management especially for offshore industry field. It highlights how to apply this model and how it have been strengthened and developed in the industrial safety as well as showed its usefulness to promote the risk management. This article presents the practical contributions of the BT analysis in process safety management. The practical uses of BT were categorized into five categories based on the type of contribution in safety management system: 1) LOPA, 2) risk assessment and hazard management, 3) safety barrier system, 4) accident modeling and 5) real time risk analysis. Offshore petroleum industry is one of the most dangerous ones. It is frequently suffered catastrophic disasters in all time. So, special focus has brought in this article to analyze and present the old and current applications of the BT in this industry. For this purpose, the BT applications have been divided into for classes based on nature of process in which they were actually applied: drilling ahead operations, well integrity operations, safety barrier management and offshore emergency operations. A significant component of the BT risk analysis process is the identification of the safety systems which are necessary to prevent or control expected and unexpected uncontrolled blowout of wellbore fluids. This demonstrates the high significance of the BT; none the less, it still encounters many difficulties such as the dependency on general data thus, it doesn't represent the actual picture for specific case. In addition, it has limited capability to update the risk parameters dynamically to support decision-making over real process overtime. Recently, number of studies has been made aiming to cope of this limitation of by converting it to dynamic model particularly a Bayesian network and fuzzy logic model. This allows to consider the real-time changes of variables in the process effectively and updating the failures probability for certain operation. Eventually, BT is so significant in risk analysis to facilitate the decision-making process and has become a fundamental tool for risk assessment during design and operational phase as well. To meet the current and future challenges, there is need to build a robust base, more effective and precise approach to handle the BT uncertainty and promote the process safety, especially in the offshore petroleum environment.

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