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Design and development of a novel knowledge-based decision support system for industrial safety management at drilling process

HAZFO Expert 1.0

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Abstract

Purpose – Annually, hundreds of drilling crew suffer from major injuries during performing oil and gas drilling operation because of the deficiency of an adequate hazard safety management system for real-time decision-making in hazardous conditions. According to previous studies, there is a sheer industrial need for an effective industrial safety management decision support system for accident prevention at oil and gas drilling sites at both drilling domains. Therefore, this paper aims to focus on the design and development of knowledge base decision support system (KBDSS) for the prevention of hazardous activities at Middle Eastern and South Asian origins' onshore and offshore oil and gas industries during drilling operations.

Design/methodology/approach – In this study, data were gathered from safety and health professionals from targeted oil and gas industries in Malaysia, Saudi Arabia and Pakistan through quantitative and qualitative approaches. Based on identified data, KBDSSs (HAZFO Expert 1.0) were systematically developed and designed by adopting Database Development Life Cycle and Waterfall Software Development Life Cycle models. MySQL and Visual Studio 2015 software were used for developing and designing knowledge base and graphical user interface of the system.

Findings – KBDSS (HAZFO Expert 1.0) for accident prevention at onshore and offshore oil and gas drilling industries based on identified potential hazards and their suitable controlling measures aligned with international safety standards and regulations. HAZFO Expert 1.0 is a novel KBDSS that covers all onshore and offshore drilling operations with three and nine outputs, respectively, to achieve the current trend of Industry Revolution 4.0 and Industrial IoTs for workforce safety.

Practical implications – This industrial safety management system (HAZFO Expert 1.0) will be efficiently used for the identification and elimination of potential hazards associated with drilling activities at onshore and offshore drilling sites with an appropriate hazard controlling strategy.

Originality/value – Moreover, the developed KBDS system is unique in terms of its architecture and is dynamic in nature because it provides HAZFO Expert 1.0 data management and insertion application for authorized users. This is the first KBDSS which covers both drilling domains in Malaysian, Saudi Arabian and Pakistani industries.

Keywords Decision making, System design, Drilling operation, Industrial innovation, Industrial safety management, Knowledge base decision support system

Paper type Research paper

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1. Introduction

Oil and gas drilling activities have been reported as one of the most hazardous and risky professions worldwide (Asad *et al.*, 2018a, 2018b, 2018c; Handal, 2013). Every year, hundreds of drilling crew die and thousands are critically injured during performing drilling operations at onshore and offshore sites because of the lack of suitable hazard controls and effective multimedia-based hazard preventive resources (Hassan *et al.*, 2017; Utvik and Jahre-Nilsen, 2016). Oil spill, fire explosions, blowouts and environmental hazards are the major causes of accidents at onshore and offshore drilling sites (Asad *et al.*, 2018a, 2018b, 2018c; Pranesh *et al.*, 2017).

In this study, development of a knowledge base decision support system (KBDSS) based on the potentially hazardous onshore and offshore drilling operations with identified characteristics of potential hazards, level of hazardousness, identified potential hazards controls with preventive masseurs and their recognized characteristics for effective hazards by utilizing quantitative (survey instrument) and qualitative (Semi-Structure Interviews) approaches. For the development and planning of this KBDSS, which has been named as HAZFO (Hazard Free-Operation) Expert 1.0, Database Development Life Cycle (DBDLC) for knowledge base development has been used. Software Development Life Cycle (SDLC) model and ADDIE model for the development of graphical user interface (GUI) were used to systemize the designing process.

2. Problem statement

Over the past five years, an average of nearly 70 people had died and 2,500 have suffered major injuries yearly as a result of various incidents in oil and gas drilling process because of several underlying causes related to insufficient accident prevention planning and safety training activities (Asad *et al.*, 2018a, 2018b, 2018c). As per previous researchers, there is a sheer need of a particular KBDSS based on updated hazard controlling factors in combination with the training capabilities; this can be a vital solution to cater to safety issues (Asad *et al.*, 2018a, 2018b, 2018c; Baram, 2010). Decision support systems and expert systems are widely and efficiently used in oil and gas sector for calculating annual revenue, environmental and climate prediction and hazard reorganization at site (Hassan *et al.*, 2017; Bjerga and Aven, 2015).

Correspondingly, these KBDSSs are also used in some areas of drilling operation in world-renowned oil and gas industries, such as maintenance, electric work and vibration calculation, but they have been reported insufficient in terms of performance and competence because of limited database with hazard identification methods (Penning *et al.*, 2014). KBDSSs that already exist in drilling industries are closed in nature. It means that only the vendor can update and modify that particular system. These vendors usually get paid to organize workshops to brief about their system usability. Such training workshops are not prioritized because they cost large amount of financial investments to the organizations (Asad *et al.*, 2014).

Therefore, in this study, data have been gathered on the basis of seven onshore and nine offshore drilling operations at Malaysian, Saudi Arabian and Pakistani oil and gas industries. In total, 150 potential hazards and 510 hazard controlling factors and measures have been quantitatively (descriptive statistics) and qualitatively (what-if analysis) recognized for onshore and offshore drilling operations. Likewise, based on the identified hazard controlling factors and measures, an open-source KBDSS has been designed and developed to align with safety and health international standards and regulations for occupational safety and health administration under Ministry of Labor, USA.

3. Research objective

The major aim of this study is to design and develop a KBDSS for accident prevention and industrial safety management at onshore and offshore oil and gas drilling operations at Malaysian, Saudi Arabian and Pakistani domains.

4. Decision support systems' development techniques for safety and health domain

The rule base decision support system can be explained as a system which obtains and gathers knowledge from experts of that field and represents that knowledge in the form of rules, such as IF and THEN. These rules can then be used to perform operations on data for implication to reach a suitable conclusion or recommendation (Asad *et al.*, 2018a, 2018b, 2018c). These inferences are essentially a computer program that provides a methodology for reasoning about information in the rule base or knowledge base and for formulating conclusions. Figure 1 shows the block diagram of rule base decision support system.

Furthermore, the development of rule base decision support systems for health and safety in oil and gas and petroleum industries is carried out for following utilizations and applications: consultative system, knowledge verification/validation, forecast strategy, knowledge acquisition, knowledge demonstration, bio separation, resource utilization, biochemical, permit control and monitoring, working at height to confined spaces, safety and health, training system, geosciences and risk assessment system. The extensive details and system development methodologies of exiting systems based on literature review are shown in Table I.

5. Existing knowledge-based systems for safe oil and gas drilling operation

Oil and gas drilling activities have been reported as one of the most hazardous and risky professions worldwide (Hassan *et al.*, 2017). Every year, hundreds of drilling crew die and thousands are injured during performing drilling operations at onshore and offshore sites because of the lack of suitable hazard controls and effective multimedia-based hazard preventive resources (Utvik and Jahre-Nilsen, 2016). Oil spill, fire explosions, blowouts and

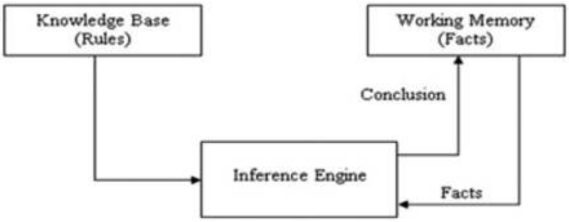


Figure 1.
Block diagram of rule base inference

Table I.
Decision support system with rule base inferences for health and safety domain

Name of DSS	Industrial domain	Techniques
Permit Control and Monitoring System	The system covers working at height to confined spaces	Rule base
Confined Spaces Advisor 1.1	Confined spaces that have hazardous conditions	Rule base
DUST-EXPERT	Explosive dusts	Rule base

environmental hazards are the major causes of accidents at onshore and offshore drilling sites (Asad *et al.*, 2018a, 2018b, 2018c).

As per previous studies, there is an urgent need for a particular KBDSS based on hazard controlling factors in combination with the training capabilities; this can be a vital solution to cater to safety issues (Asad *et al.*, 2014). Decision support systems and expert systems are widely and efficiently used in oil and gas sector for calculating annual revenue, environmental and climate prediction and hazard reorganization at site (Asad *et al.*, 2018a, 2018b, 2018c). These KBDSSs are also used in some areas of drilling operation in world-renowned oil and gas industries, such as maintenance, electric work and vibration calculation, but they have been reported to be insufficient in terms of performance and competence because of limited database with hazard identification methods (Hassan *et al.*, 2017). KBDSSs that already exist in the drilling industries are closed in nature. It means that only the vendor can update and modify that particular system. These vendors usually get paid to organize workshops to brief about their system usability. Such training workshops are not prioritized because they cost large amount of financial investments to the organizations.

Moreover, based on the detailed literature review from over past 10 years, different systems have been developed for decision-making during hazardous condition worldwide. But there is no such knowledge-based decision support system available in the industries with mutually integrated onshore and offshore oil and gas drilling operations based on identified hazard controlling factors and measures. Table II reflects the names of the existing decision support systems and their countries for safety of oil and gas drilling domains based on extensive literature review (Asad *et al.*, 2018a, 2018b, 2018c).

6. Methodology and architecture framework of knowledge base of knowledge base decision support system

The hazard controlling factors associated with oil and gas drilling operations have been analyzed through quantitative (survey instrument) and qualitative (what-if analysis) methods. The overall methodology flowchart of the developed HAZFO Expert 1.0 is shown in Figure 2. The knowledge base is considered as an essential element for any decision support and expert system which is based on the briefed database and contains with expert's opinion and suggestions depends on the specific problem or issue (Asad *et al.*, 2014). In the architecture of this knowledge base of HAZFO Expert 1.0, databases of targeted oil and gas extraction industries from Malaysia, Saudi Arabia and Pakistan have been separately developed based on their onshore and offshore oil and gas drilling operations. Similarly, the data acquired from the targeted industrial experts were further analyzed through quantitative and qualitative approaches for the reduction and elimination of potential hazards associated with onshore and offshore oil and gas drilling operations. Furthermore, identified data were substituted in the knowledge base of HAZFO Expert 1.0 through MySQL (2015) software, as shown in Figure 3.

6.1 Development of knowledge base of knowledge base decision support system

For the development of knowledge base of decision support system, the model of DBDLC has been adopted for the database designing and development. According to the DBDLC model, a developer should follow four main phases for the designing of systemized and effective knowledge base of any management system: database initial study, database design and implementation, database operation and database maintenance (Utvik and Jahre-Nilsen, 2016).

Name of Systems	County	Industry type	Industrial domain	Utilization and application
PCMS	UK	Oil and Gas, Pharmaceuticals	Working at height to confined spaces, and excavation to electrical work	This system identifies workplace risks and hazards. It ensures that the permits are correctly completed in a user-friendly workflow set-up
SPONCOM	USA	Mining work and Oil and Gas	Fire prevention	Design for mining and oil and gas industries to access causes by fire and heat
Confined Spaces Advisor 1.1	USA	Oil and gas and chemical industries apply the OSHA Permit Required Confined Spaces Standard	Confined spaces that have hazardous conditions	The OSHA Confined Spaces Advisor was designed to provide users with interactive expert help to apply the OSHA Permit Required Confined Spaces Standard
Fire Safety Advisor 1.0a	USA	Oil and gas and chemical industries apply the OSHA Permit Required fire safety Standard	Fire Safety	OSHA's Fire Safety Advisor provides users with interactive expert help to apply OSHA's Oil and gas and chemical industries Standards for fire safety and emergency evacuation
DUST-EXPERT	UK	This system was produced by Adelard for the Health and Safety Executive	Explosive dusts	The system provides information on the safe design and operation of plant that are subject to dust explosions
CSHM	China	Construction and oil Gas Industries	Construction and Oil Gas	This expert system identifies workplace risks in the Chinese construction industry by monitoring and assessing construction safety and health performance
Action Checkpoints for Comfortable Work	Japan	National Institute of Industrial Health (NIIH) (Japan)	Workstation Interface and general work industries	This expert system identifies workplace risks and their solutions
EASE System	UK	This system was produced by the Artificial Intelligence Applications Institute (AIAI) for the Health and Safety	Hazardous Substances	This tool guides risk assessment by providing both authorities and manufacturers with computer-based guidance from the Regulator
Oil and gas well drilling and servicing E-tool	USA	Occupational Safety and Health Administration (OSHA), USDepartment of Labor	Oil and gas industry drilling operation (Onshore)	Supports regulatory compliance by providing you with information on to how to go about oil and gas drilling

Table II. Existing Osh management systems

6.1.1 Knowledge base initial study. In this first phase for knowledge base development, a developer has to focus on designing an appropriate knowledge base for decision support system for Malaysian, Saudi Arabian and Pakistani oil and gas drilling industries based on identified potential hazards and their preventive controlling factors and measures

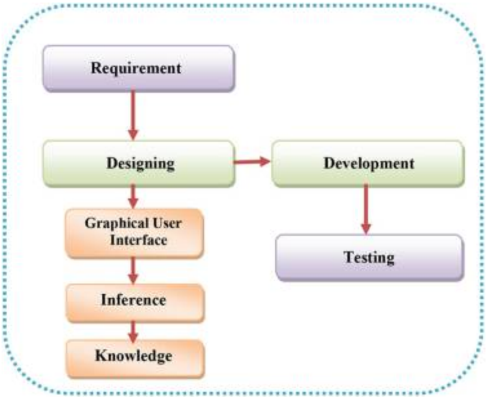


Figure 2.
Flow chart for the development process of HAZFO Expert 1.0

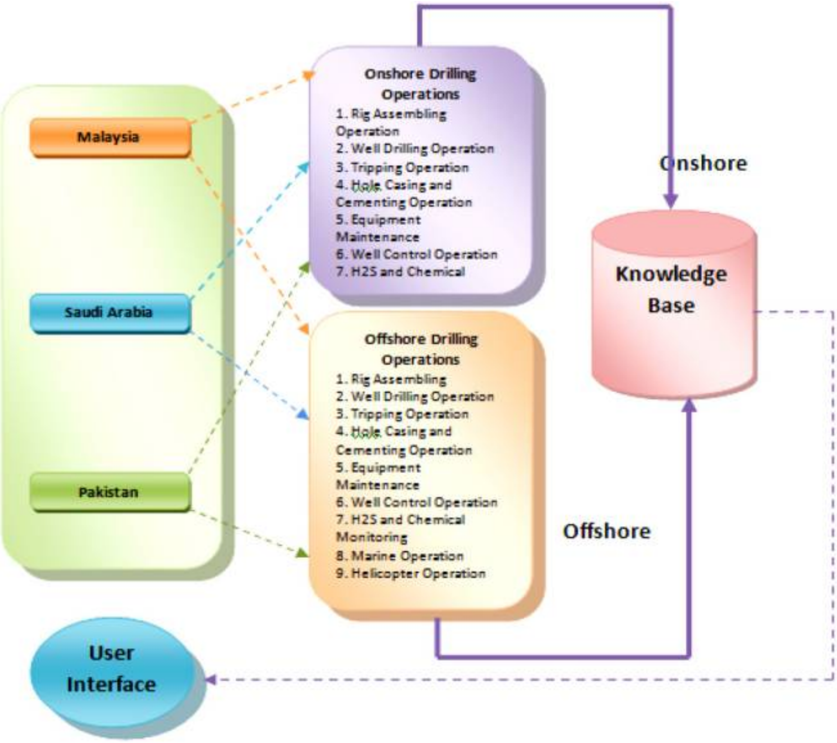


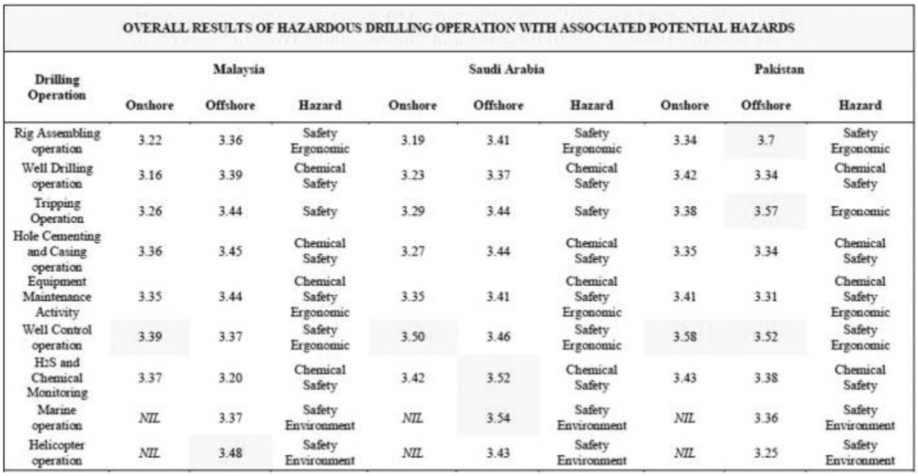
Figure 3.
Architecture of knowledge base of HAZFO Expert 1.0

(occupational health and safety); the sample of identified qualitative and quantitative data is shown in Figures 4 and 5. However, in this knowledge base, the developer has to execute and manage numerical (nature of hazardousness of each on and offshore drilling operation) and alphabetical data (characteristics of hazard, controls, expert recommendation and

Overall Findings for Hazard Controlling Factors for Well Drilling Operation (What-If Analysis)

Activity	Hazard	Malaysia		Saudi Arabia		Pakistan	
	What - IF	Onshore Control	Offshore Control	Onshore Control	Offshore Control	Onshore Control	Offshore Control
Handling Drilling Pipes	Stuck Hazard during Latching Pipes to Elevator	Visual Cues Signals Communication	Visual Cues Signals Communication	Conduct RA and Job Safety Analysis	Conduct Risk Assessment and Job Safety Analysis	Maintenance of Elevator	Performance Assessment of Elevator
	Falling Tubular Hazard	Install Handrail with Toes Board	Install Handrail with Toes Board	Use Fork lifters and Make Safe Distance from Red Zone	Use Fork lifters and Make Safe Distance from Red Zone	Installed Level Pipe Racks and Assign Competent Supervision	Installed Level Pipe Racks and Assign Competent Supervision
	Knock on the Wire Sling Hazard	Wear Head Protective Equipment	Wear Head Protective Equipment	Routine Inspection of Wire Sling	Routine Inspection of Wire Sling	Replacement of Expired Slings and Wear Hard Hat	Replacement of Expired Slings and Wear Hard Hat
Preparing Drilling Fluid	Exposure to Chemical Dust	Inhalation Protective Equipment	Conduct Risk Assessment	Provide Respirators	Safety Goggles	Arrange Training for Safe Mixing Procedure	Arrange Training for Safe Mixing Procedure
	Caustic Soda during Mixing Fluids	Install Advance Chemical Mixing units	Post Hazard Sign	Conduct Hazardous Material checklist	Job Safety Analysis for Caustic Soda	Wear Hand protection and Avoid ignition sources	Wear Hand protection and Avoid ignition sources
	Calcium Bromide	Install Vent at Working Area and Wear Safety Mask	Install Vent at Working Area and Wear Safety Mask	Install Emergency Shower and Eyewash	Install Emergency Shower and Eyewash	Install Air purifier and Put on Respiratory Protection	Install Air purifier and Put on Respiratory Protection
Starting Drilling	Top Drive Vibration Cause Drop Object	Develop Drop object checklist	Wear head protection	Team Development for Drop object evaluation	Proper Housekeeping	Carryout RA for drop object and Put on Safety Hats	Carryout RA for drop object and Put on Safety Hats
	Borehole Instability	Well bore stability planning	Selection of Suitable mud-weight	Effective Formation Fluids	Effective Formation Fluids	Monitor and Maintain Pressure Changes	Monitor and Maintain Pressure Changes
Coring Process	Radioactive Materials	Respiratory protection and Inscribing Warning Sign	Respiratory protection and Inscribing Warning Sign	Medical Screening and RAM Awareness Program	Medical Screening and RAM Awareness Program	Concealment with UV-stabilized plastic	Hand protective gloves
	Stuck by Core Barrel	Visual Cues Signals Communication	Visual Cues Signals Communication	Conduct RA and Job Safety Analysis	Conduct Risk Assessment and Job Safety Analysis	Regular Maintenance of Elevator	Performance Assessment of Elevator
	Damage to Coring Pipe	Coring Pipe Scrutiny Prior to activity	Put on Protective Gloves	Proper Coring Pipes rack management	Coring Pipes Inspection	Dexterity Gripe Pinch Point Protection	Dexterity Gripe Pinch Point Protection

Figure 4.
Sample of identified qualitative data



OVERALL RESULTS OF HAZARDOUS DRILLING OPERATION WITH ASSOCIATED POTENTIAL HAZARDS

Drilling Operation	Malaysia			Saudi Arabia			Pakistan		
	Onshore	Offshore	Hazard	Onshore	Offshore	Hazard	Onshore	Offshore	Hazard
Rig Assembling operation	3.22	3.36	Safety Ergonomic	3.19	3.41	Safety Ergonomic	3.34	3.7	Safety Ergonomic
Well Drilling operation	3.16	3.39	Chemical Safety	3.23	3.37	Chemical Safety	3.42	3.34	Chemical Safety
Tripping Operation	3.26	3.44	Safety	3.29	3.44	Safety	3.38	3.57	Ergonomic
Hole Cementing and Casing operation	3.36	3.45	Chemical Safety	3.27	3.44	Chemical Safety	3.35	3.34	Chemical Safety
Equipment Maintenance Activity	3.35	3.44	Chemical Safety Ergonomic	3.35	3.41	Chemical Safety Ergonomic	3.41	3.31	Chemical Safety Ergonomic
Well Control operation	3.39	3.37	Safety Ergonomic	3.50	3.46	Safety Ergonomic	3.58	3.52	Safety Ergonomic
H2S and Chemical Monitoring	3.37	3.20	Chemical Safety	3.42	3.52	Chemical Safety	3.43	3.38	Chemical Safety
Marine operation	*NIL*	3.37	Safety Environment	*NIL*	3.54	Safety Environment	*NIL*	3.36	Safety Environment
Helicopter operation	*NIL*	3.48	Safety Environment	*NIL*	3.43	Safety Environment	*NIL*	3.25	Safety Environment

Figure 5.
Sample of identified quantitative data

international regulations) based on the qualitative and quantitative analysis. For the development of HAZFO Expert 1.0 knowledge base, Sequential Query Language Server Management Software (2014) was adopted for the structural design and programming through structural query language.

6.1.2 Knowledge base design and implementation. According to the second KB development phase, the developer has to design six database tables for Malaysia, Saudi Arabia and Pakistan based on acquired data and findings from oil and gas drilling industries in the previous phase, such as country table, domain table (onshore, offshore), drilling operation table (seven for onshore and nine for offshore), drilling activities table (based on operations), potential hazards table (based on activities) and results/output table.

The result database table is subdivided into seven parts based on its outputs, nature of hazardous of drilling operation, potential hazards, characteristics of potential hazard, hazard controlling factors, characteristic of hazard control, experts' recommendation and international rules and standards for occupational health and safety, by using SQL software, as shown in Figure 6.

6.1.3 Knowledge base operation. Once the database is passed through the evaluation and testing phase of knowledge base development, it is considered to be operational (Asad *et al.*, 2014). At that point, the database, its management, its users and its application programs constitute a complete system. Consequently, after testing performance, load stress of the developed KB, the developer has to interface this developed knowledge base with HAZFO Expert 1.0 GUI to provide a friendly environment to end-users regarding any quires associated with oil and gas onshore and offshore drilling operation by using Visual Studio (2015) software.

6.1.4 Knowledge base maintenance. In this last and continuously performing phase of KB development, the organization and developer should continuously scrutinize, maintain and upgrade the database for upholding the command on that particular knowledge. For the maintenance of knowledge base of HAZFO Expert 1.0, the developer has to develop a "HAZFO Expert 1.0 Data Insertion Application". This developed application will allow the authorized occupational health and safety experts

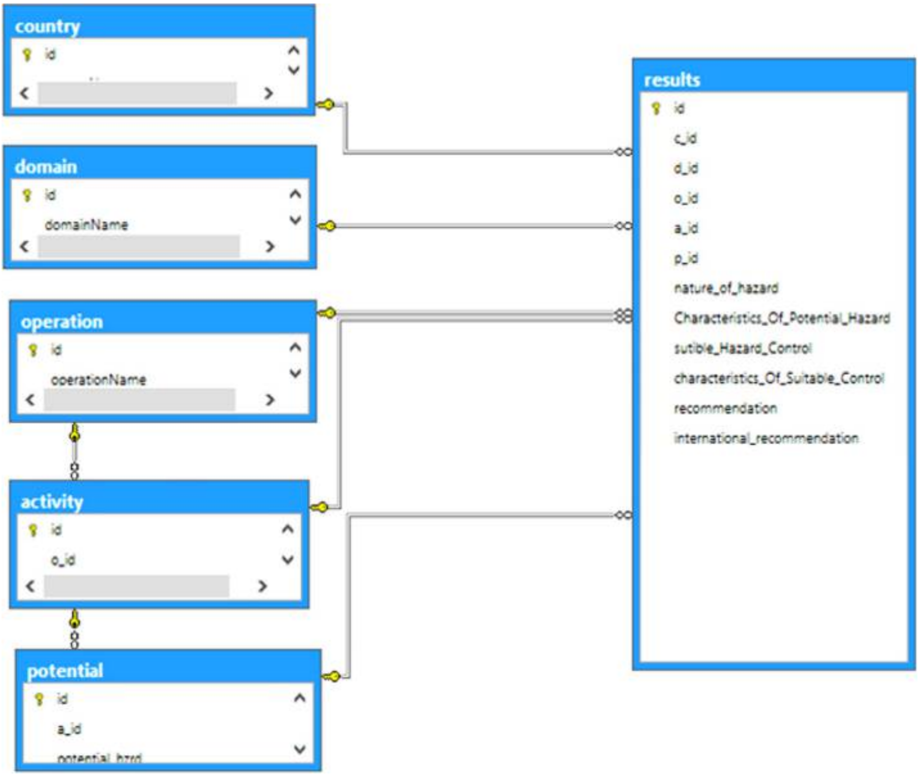


Figure 6.
Knowledge base design of system

or companies to update any new information by logging in to this application from anywhere in the world. This data insertion application will also allow the user to upload any new health and safety standard and regulation through its dynamically user-friendly environment, which is developed through C# programming language in Visual Studio. This data insertion application has been further divided in three portions, data insertion of drilling activities, data insertion of potential hazards and data insertion of results, as shown in Figures 7 and 8.

6.2 Rule base inference for knowledge base of decision support system

The rule base inference approach has been used for assigning appropriate conditions for suitable decision-making in this HAZFO Expert 1.0 decision support system. These rules are simply patterned, and an inference searches for a pattern in the rules that matches patterns in the data. The "if" means "when the condition 1 is true take action A," "else" means "when the condition 1 is not true take action B," etc. In this system, these rules have been implemented in the form of quires between the knowledge base of the KBDSS, which has been developed in SQL server and GUI for each onshore and offshore drilling operation based on its selected activities and hazards in Malaysian, Saudi Arabian and Pakistani oil and gas industries. Similarly, conditions for input and output selections have been assigned based on the specified "if and else" rules in C# programming Language (Figure 9).

7. Architecture of graphical user interface of decision support system

GUI is the first impression of any computer-oriented system from the user's point of view (Ltifi *et al.*, 2013). Similarly, the architecture of HAZFO Expert 1.0 decision support system has been designed on the basis of its conceptual framework. This KBDSS architecture has been interconnected with the three parts: knowledge base of

Select Drilling Opertation: Hole Casing and Cementing Operation

Insert Drilling Activity: Installation of Casing Tools

Figure 7.
Data insertion application for hazards management

Select Drilling Opertation: Hole Casing and Cementing Operation
Select Drilling Activity: Installation of Casing Tools
Inseart Associated Hazard: Stuck by Casing Hazard

Figure 8.
Data insertion application for hazard controls management

```
private void button2_Click(object sender, EventArgs e)
    {
      string v_query = "";                                    (String for Query Declaration)
      country = operations.getCountry(rb_my,rb_sa,rb_pk);
      domain = operations.getDomain(rb_on, rb_off);
      if (country == 0)                                                (Rule and Condition)
      {
        clsMessages.ErrorMessage("Please Select Country");
      }
      else if (domain == 0)                                            (Rule and Condition)
      {
        clsMessages.ErrorMessage("Please Select Domain");
      }
      else if (cb_activity.SelectedIndex == -1)                        (Rule and Condition)

      {
        clsMessages.ErrorMessage("Please Select Acitivity");
      }
      else if (cb_hazard.SelectedIndex == -1)                          (Rule and Condition)

      }
```

Figure 9.
Sample of programming code (IF-Else)

three targeted oil and gas industries from Malaysia Saudi Arabia and Pakistan along with its seven onshore and nine offshore drilling operations. Second, rule base inference engine for taking appropriate decision based on specified condition of each oil and gas drilling domain. Last, the GUI architecture is designed to provide a user-friendly environment to oil and gas drilling crew based on their designated country, drilling operation and associated drilling activity for identified potential hazards and their most suitable control as per international occupational health and safety standards and regulations as shown in Figure 10.

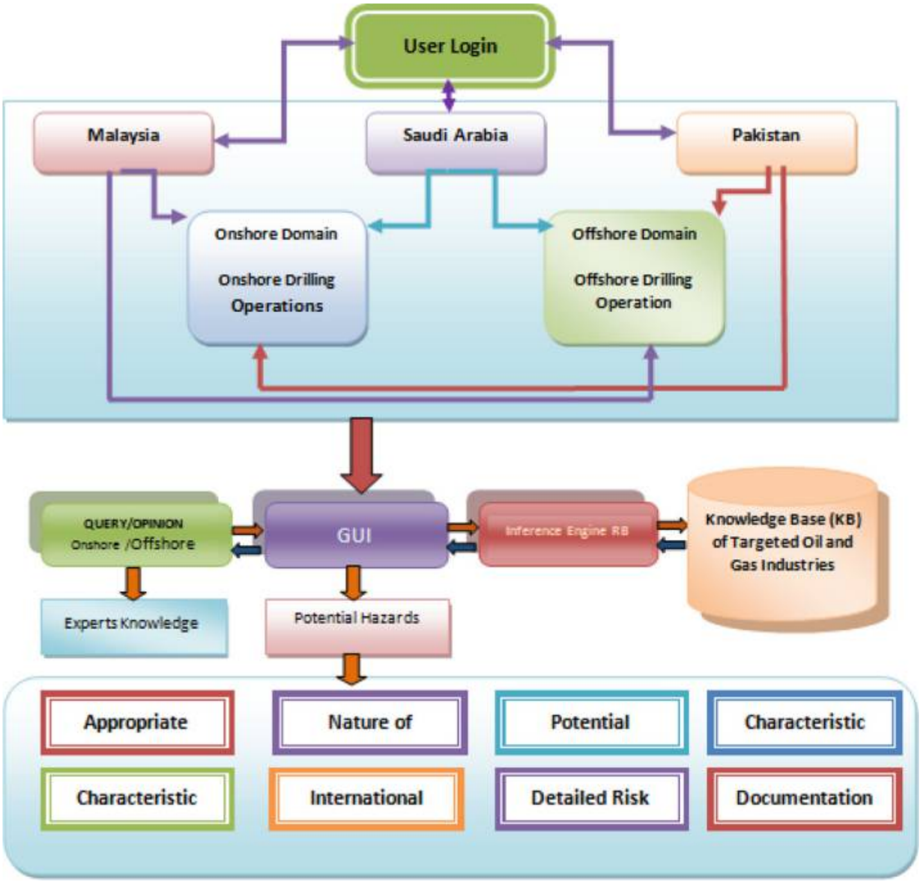


Figure 10.
Block diagram of GUI of system

7.1 Development of graphical user interface of DSS

For the development of HAZFO Expert 1.0 system GUI and whole system connectivity and functionality Water Fall Model (WFM) of SDLC and ADDIE models have been used as reference during design and development of this system. In this study, both models of instructional and system design have been combined for the sake of accuracy and effectiveness of system development process. For the development of GUI of HAZFO Expert 1.0, Microsoft Visual Studio 2015 has been used because it has advanced variety of tools to design an efficient GUI because Visual Studio provides an integrated development environment which is compatible with many different languages but remains simple to maintain the functionality of the application. C# language has been used for the programming and coding during GUI development for this knowledge-based decision support system due to its rich class' libraries, which make the implementation of several functions easy.

8. Conclusion and discussion

Oil and gas industries always place high priority on the health and safety of their employees and highly expensive drilling machinery during drilling operations (Hassan *et al.*, 2017).

However, because of various techniques and advanced methods of drilling operation due to the industrial revolution (IR) 4.0, the work place risk and hazard ratio is unpredictable and also rapidly increases with the introduction of advanced technologies. Each time, drilling crew and drilling safety professionals have to face new and uncertain hazardous situations during onshore and offshore drilling process. Hence, appropriate decision-making in such circumstances is complicated and challenging for accident prevention (Asad *et al.*, 2018a, 2018b, 2018c). Some software tools and resources that exist for facilitating the safety personals and drilling crew regarding work place safety, but they are not updated and only contain limited knowledge for decision-making during hazardous conditions at onshore and offshore drilling sites and vestibule training of drilling crew (Asad *et al.*, 2018a, 2018b, 2018c).

This research illustrated about the systematic designing and development of KBDSS based on the most hazardous drilling operations and potential hazards associated with hazardous drilling operations along with their most effective hazard controls and measure for accident prevention at Malaysian, Saudi Arabian and Pakistan onshore and offshore oil and gas industries. These three countries are selected because of the environmental diversity and large extraction of cured oil and gas, which leads to higher safety and health concerns. The execution of this KBDSS is to assist and facilitate the drilling safety professionals and drilling crew to adopt the most effective hazard controlling strategies according to the hierarchy of controls (engineering, administrative and personal protective equipment) for the elimination of potential hazards and manage the safety protocols according to the international safety regulations at both drilling sites in this new era of IR 4.0. The development process of HAZFO Expert 1.0 has been carried out after the identification of hazardous drilling operations, potential hazard associated with onshore and offshore drilling operations with their suitable control and measures, as shown in Figure 11. For the design and development of HAZFO Expert 1.0, software development life cycle, ADDIE and water fall models has been adopted by using MySQL (2015) and Visual Studio (2015) software because Microsoft Visual Studio is considered as an effective software development package with sufficient treatment tools (Asad *et al.*, 2018a, 2018b, 2018c).

Furthermore, this decision support system provides five inputs: selection of drilling operation, selection of drilling origin, selection of drilling domain, selection of drilling activity and selection of potential hazards. Based on input, this HAZFO Expert 1.0 provides seven outputs for the accident prevention at onshore and offshore drilling domains: nature

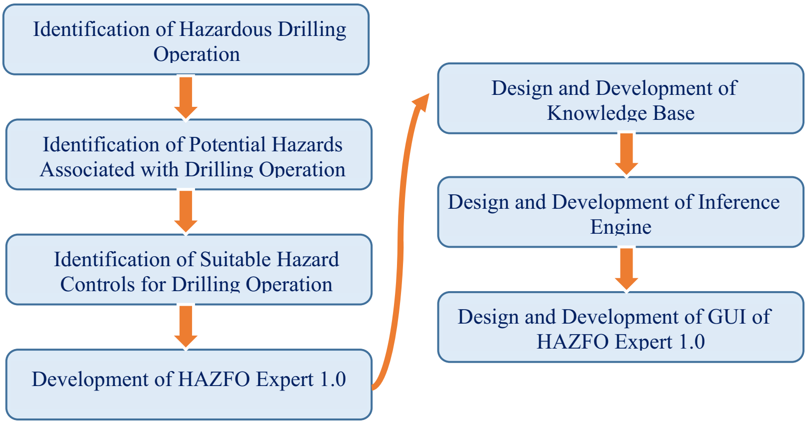


Figure 11.
Block diagram of HAZFO expert development process

of hazardous operation, characteristic of hazard, characteristic of hazard control, hazard control, experts' recommendation, international standard and regulation and report and documentation. The developed HAZFO Expert 1.0 aligns all identified hazard controls and measures according to the occupational health and safety standards and regulations. This KBDSS has a dynamic nature; therefore, it can be easily updated through HAZFO Expert 1.0 data insertion application which has been developed for the management of knowledge base of the developed system. The developed KBDSS will facilitate the drilling crew and safety professionals for the identification of potential hazards along with their suitable and most effective hazards controls and measures according to the safety and health standards and regulations at Malaysian, Saudi Arabian and Pakistani drilling domains.

Moreover, this system can be used as a pool of systematic knowledge and data for risk assessments and hazard reorganization, which will guide health and safety officials and practitioners to implement appropriate preventive measures for the reduction and elimination of potential hazard. Consequently, as few researchers have suggested that, due to the shear need of adequate hazard identification in particular addressing risks rising from the frontier conditions in drilling operation can be eliminated or controlled through pooling and comparing severity and hazardousness of drilling activities from different drilling fields, regions and affected industries by using multiple and effective hazard identification approaches (Asad *et al.*, 2014; Asad *et al.*, 2018a, 2018b, 2018c).

However, the developed HAZFO Expert 1.0 has been testified and evaluated by field experts. This developed system has been evaluated based on the decision-making potential, effectiveness of identified hazard controls, level of user satisfaction and performance of safety vestibule training among drilling crew at Malaysian, Pakistani and Saudi Arabian oil and gas industries in third research objective of this study. Moreover, the major application of this developed HAZFO Expert 1.0 is that it can be able to implement and execute at both onshore and offshore oil and gas industries for the identification of hazardous drilling operation, nature of hazardousness of potential hazard with their characteristics, suitable hazard controlling strategies according to the hierarchy of controls with characteristics and risk assessments (all operations) with international safety legislations. Also, HAZFO Expert 1.0 can be used for conducting detail risk assessments and job safety analysis prior to and after performing drilling activities for safe operation and enhancing the performance of drilling crew at oil and gas drilling sites in all targeted origins. Similarly, the developed KBDSS can be used for vestibule training activities of drilling crew for safe and secure drilling activities. Besides, this system can be implemented in educational institutes to train the drilling workforce prior to field work.

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