CHAPTER 2

LITERATURE REVIEW

2.1 OVER VIEW OF RISK ASSESSMENT

An inclusive literature survey was conducted on qualitative and quantitative risk assessment software used for risk assessment modelling, establishing risk acceptance criteria for various countries, failure frequency analysis and applications of QRA in oil and gas facilities.

Based on the literature survey the following papers were reviewed and classified based on the area of work:

- Hazard identification techniques used in oil and gas industries : 24 papers
- Quantitative risk assessment related research work: 97 papers
- Consequence analysis and its modelling : 45 papers
- Failure frequency analysis and modelling : 37 papers

The key papers which are directly related to the research work area are reviewed thoroughly and gaps identified.

A Risk Assessment study is a minimum requirement for oil and gas facility installations in many countries as a matter of legislation. The underlying problems in QRA, however, include subjectivity in hazard identification, oversimplification of release models, assumptions in environmental conditions, uncertainties in technical failure mechanisms and failure rates and deficiencies in consequence modelling [10].

2.2 QRA METHODOLOGY

A Risk Assessment is defined as a mathematical function of the probability and consequence of an accident [43]. The aim of risk assessment is to identify potential accidents, analyse the causation and evaluate the effects of the risk control or reduction measures. Risk assessment can be broadly classified as qualitative and quantitative.

In the early 1980s, TNO (assigned by the Dutch Government) composed a series of "Colored Books" on how to carry out risk assessments [61]. The models for calculating the consequences of fires, explosions and release of toxic gases into the environment and exposing living matter were developed. The TNO Purple Book frequencies are over optimistic by a factor of almost $10e^{-2}$. However it is accepted by risk analysts [20].

In 1990, the Layer of Protection Analysis was introduced in the United States as a simplified risk assessment tool for process industries. LOPA can be used as an effective tool in the entire range of underwriting of petrochemical risks in cases of property insurance [63]. This technique invented by the American Institute of Chemical Engineers, USA, gives credit for the highly reliable safety systems used in modern Oil & Gas installations and motivates others to go in for the highly reliable process safety / instrumentation systems. The Oil and Gas industry is exposed to major risks like fire, explosions and oil spills by virtue of its nature and operation.

The CPQRA method [63] to measure risk, aims to combine the Incident Frequency and Consequence Estimates. An understanding of different risk measures is important when using CPQRA and quantitative risk assessments as a risk management tool [19]. On the other hand, LOPA and FMEA are the tools classified as semi-quantitative analysis tools. In QRA studies, initial hazard identifications are carried out by qualitative tools to find frequency of failures. But, when estimating risks, qualitative likelihood are used.

QRA methodologies in use today include the World Bank guideline, the Purple Book, and the CCPS Guidelines [11] [12] [13]. The NFPA-USA produce a standard on production, storage and handling of liquefied natural gas which provides failure rates of components related to LNG storage tanks, pipelines, compressors, heat exchangers and other transfer equipment [83]. The standard provides the radiant heat flux, thermal radiation dose and blast over pressure damage criteria. Individual risk and societal risk tolerability criteria are given in this standard, but these criteria are not vetted for public review. Event Frequencies and Equipment Failure Rates are a continuous problem for risk assessment studies in LNG facilities [82]. The uncertainties are mainly due to facility design, material of construction and failure modes of vessel and components amongst other things. The HSE failure rates are more pessimistic in nature when compared to other databases. Establishing suitable failure rates should be reviewed carefully due to a lack of consistency in failure data in LNG facilities and their components.

2.3 QRA TYPICAL FLOW CHART

The general methodology is followed in a systematic QRA procedure as shown in Figure 2.1. This is a typical flow diagram that includes stages of risk assessment adopted by many oil and gas organisations and leading risk consultants around the world [7].

Safety and risk assessment studies are increasingly used to manage the activities involving hazardous materials. Frequency estimation is the methodology used for estimation of the number of occurrences of a scenario in a year.

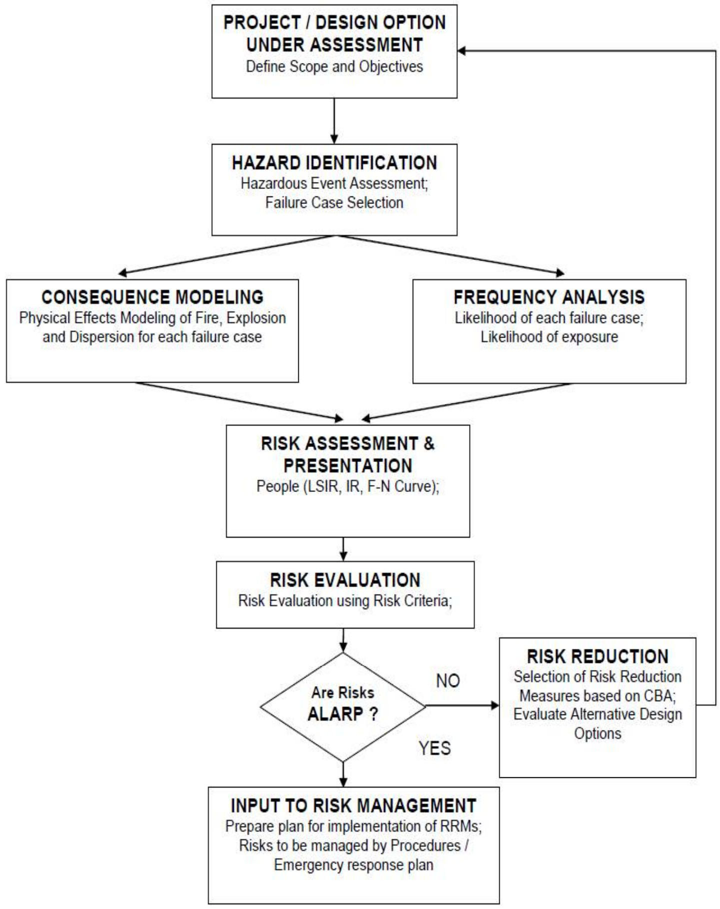

Figure.2.1: Typical Methodology adopted in QRA.

Estimates may be obtained from generic historical data or from failure sequence models. In 1988 the offshore failure database, OREDA, was established after the Piper Alpha Offshore Explosion. The HSE, UK, published a report for Onshore / Offshore Installations [38].

2.4 HAZARD IDENTIFICATION TECHNIQUES ADOPTED IN QRA

Safety in the design of Oil and Gas, Petrochemical and Offshore Plants relies on the application of various codes of design which are based upon the wide experience and knowledge of experts and specialists in the industry. Hazard identification is a fundamental step in safety management systems. Hazard means anything which has the potential to cause harm, ill health, injury or damage to assets [62]. As explained earlier, the safety of a plant is determined during the design stage, so it is of great importance to identify the hazards as early as possible during the design phase so that safety is 'designed' in to all processes.

Although risk assessments are carried out by Oil and Gas industries at different stages of the plant life cycle, hazard identification is the fundamental step in risk assessment. There are many techniques adopted by industries to identify hazards. If the hazards are not identified, then the risk cannot be assessed comprehensively. The unidentified hazard may cause a fault, leading to an accident and or loss at any time. So it is very important that all the hazards are to be identified as early as possible. HAZID and HAZOP studies [4] are hazard identification techniques that can be applied at various phases of project development, including during front end engineering and design phase, as a part of detailed design phase and plant operation phase or any modification or alteration of the plant.

Hazard identification and evaluation [48] of major hazards are vital in any Safety Management Systems [48]. New Oil and Gas facility projects and in some cases modifications of existing Oil and Gas facilities, call for some element of change and the degree of change is often considerable. The procedure has to identify the hazards systematically arising from normal and abnormal operation of the facility. It is important to recognize that experience expressed in codes, among other things, is limited by the extent of existing knowledge. Therefore, hazard identification should be conducted through employee interview and pipeline hazard identification studies. Interviews should be conducted either on a one to one basis, or in groups [66].

Many techniques are available such as experience, engineering codes and standards, checklists, hazard index, what-if analysis, Hazard and Operability (HAZOP) study, Failure Modes and Effect Analysis (FMEA), Preliminary Hazard Analysis (PHA), Fire and Explosion Index, Mond Index, Hazard Identification (HAZID), Construction Hazard Identification (HAZCON), Electrical Hazard and Operability (SAFOP) and many other such standards and guides. Each hazard identification technique has its own advantages and limitations, which is why the Oil and Gas industry has adopted various techniques and methodologies at different stages of the life-cycle at each facility. Although Checklists are considered to be a generic approach, they are widely used in the Chemical and Process Industries [62].

One weakness of the HAZID technique is to develop a checklist for each installation [25]. Conventional HAZID techniques do not capture all the hazardous scenarios, as they deviate from normal expectations and can lead to unwanted events. This, then, calls for a structured hazard identification technique such as HAZOP in addition to HAZID for installations such as flammable gas facilities.

LOPA is increasingly used for recent developments as a semi-quantitative tool to assess the hazards and risk from each scenario of Oil and Gas facilities. This is despite the fact that LOPA should be used after the HAZOP study has been completed, as the HAZOP study provides input to the LOPA analyst about the list of scenarios to be considered for further risk assessment. At such stage a Risk Assessment Matrix (RAM) is usually combined with a HAZOP worksheet to provide a more detailed or accurate risk assessment level.

The HAZOP study [33] is immensely popular for identification of hazards, as a qualitative technique, for process facilities but is also used as a semi quantitative analysis technique applied to upstream Oil and Gas operations such as offshore drilling operations [15]. The Fire and Explosion Index, and Mond indices consider the type of materials used, quantity of materials used, operating conditions and the type of operation. The values of indices used prioritise or provide relative risk comparison only. It does not provide the actual risk. These indices are a guide for further risk assessment studies to be carried out for the plant.

Recursive Operability Analysis (ROA) is usually performed to identify the possible accident sequences [48]. It has been shown that modifications made as a result of ROA studies [62] have had a positive impact on accident prevention rates. LOPA was introduced in the 1990s in the USA as a simple risk assessment tool. It examines the functioning of safety measures in a process section given initiating events which may progressively upset the plant [36]. However, any unidentified hazards negate the risk assessment process as risks cannot be assessed for those hazards, and control measures cannot be developed and implemented. Therefore, operators who are involved in the process are not aware of the hazards in first place.

Other techniques such as Logic Diagrams, What-If and Checklists can be used as qualitative risk assessment techniques [75]. Job Safety Analysis (JSA) is also qualitative but is more process driven as it analyses a job step by step.

Hazard identification is the first step of any risk assessment study. In this the various sources of hazards or loss of containment scenario are discovered and the various mechanisms of release and consequences of the release [19] are pointed out. The Safety Audit is another tool that can identify the hazards in a plant or installation including its condition of operation and maintenance.

2.5 QUALITATIVE AND QUANTITATIVE TOOLS

The following table 2.1 shows the various Qualitative and Quantitative tools used in process safety analysis [46]:

Table.2.1 Qualitative and Quantitative tools

QUALITATIVE	QUANTITATIVE
Checklist	Fault tree analysis
Site survey	Event tree analysis
Site inspection	Probabilistic risk assessment
Safety audit	Quantitative risk assessment
Site observation	
HAZID	
What if	
HAZOP	

For this research, a HAZID checklist was developed and applied to the selected flammable gas facilities. Being a process plant, the operational hazards were identified using a HAZOP study. Based on the hazard identification and HAZOP study, the Maximum Credible Loss Scenarios (MCLS) were selected. Hazards were identified in the LPG handling facility and its inventories (such as quantity used, composition, operating temperature and pressure of the process, storage condition etc.). The site visits were conducted during which flow diagrams were verified, and process and instrumentation diagrams checked during discussions with plant operators and managers. The HAZID study provided the escape of flammable gas which could cause fires and explosions in given scenarios. Based on the nature of hazard and consequences of such hazard, the significant hazards were identified. The selected hazards incident scenarios were taken to further modelling.

2.6 CONSEQUENCE MODELLING / ANALYSIS

Consequence analysis is an integral part of risk assessment which includes various outcome cases such as fire, explosion, toxic release or combination of these events. Based on the outcome cases they are explained below.

JET FIRE

A Jet Fire is a turbulent diffusion flame resulting from the combustion of material continuously released with some significant momentum. Jet fires can arise from releases of gases, flashing liquid (two phase) and pure liquid inventories. Furthermore, an ignited pressurised release of a gaseous material may give rise to a jet fire.

It is possible for the high heat generated during Jet Fires to flux the containing vessels which, in turn, may lead to structural failures causing further escalations. The impact distance of jet fire depends on the material composition, release rate, direction and ambient wind conditions.

POOL FIRE

A pool fire is a turbulent diffusion fire burning above a horizontal pool where the material has zero or low initial momentum. Pool fires may be static (e.g. where the pool is contained) or 'running' where a spillage from non-pressurized liquid storage will result in a liquid pool being formed. Ignition of the vapours emanating from the liquid can lead to a pool fire which is a turbulent diffusion flame. For hydrocarbons such as condensate, the vapour will emanate readily from a spillage and will be easily ignited. For heavier hydrocarbons, such as lube oil or fuel oil, little vapour emanation occurs unless the fuel is heated leading to ignition of a spillage.

FLASH FIRE

If the fluid vapours from the isolatable section are not ignited, then the fluid will evaporate. Any released vapors will spread out in the direction of the wind. If the vapour cloud is released in an open space in absence of significant confinement or obstruction and ignites before being dispersed below the Lower Flammability Limit (LFL) of the flammable material, a flash fire is likely to occur. It is assumed that all persons present in an ignited flammable cloud will be seriously, if not lethally injured. Outside the flash fire envelope, no fatal injuries are to be expected. In consequence analysis, the size of the cloud determined by the LFL indicates the area that may be affected by the flash fire.

VAPOUR CLOUD EXPLOSION

A Vapor Cloud Explosion (VCE) results from the ignition of a flammable mixture of vapour in which flame accelerates to sufficiently high velocities to produce significant overpressure [77]. An explosion may occur when a large amount of flammable material is released in a space with significant confinement or obstruction and ignited before being dispersed below the LFL. The blast wave following these incidents can be lethal.

The following main types of explosion can be distinguished:

- Confined explosions where the vapour cloud is largely confined;
- Unconfined explosions where the vapour cloud is largely unconfined, typically on an onshore installation, but there are sufficient obstacles to generate turbulence and start the build-up of pressure.

TOXIC RELEASE

If the toxic gas releases vapour from the isolatable section, it will spread out in the direction of the wind. As the gas cloud moves downwind, gravity can cause some of the vapor to travel upwind to its release point. Further downwind, as the cloud becomes more diluted and its density approaches that of air, it begins behaving like a neutrally buoyant gas. A gas that has a molecular weight greater than that of air will form a heavy gas cloud if enough gas is released. Gases that are lighter than air at room temperature, but are stored in a cryogenic (low temperature) state, can also form heavy gas clouds. The two-phase mixture that escapes into the atmosphere may behave like a heavy gas cloud.

BLEVE

BLEVE - Boiling Liquid Expanding Vapour Cloud Explosion. Any sudden catastrophic failure of a vessel containing superheated liquid or liquefied gas may result in BLEVE. Large quantities of pressurised fluids released suddenly into the atmosphere, where such fluid expands more than 300 to 400 times in volume, will result in this type of effect.

Any external fire or other such structural failure of the containing vessel will result in BLEVE. Most commonly LPG storage tank failures result in BLEVE [26]. Any pressurised cryogenic fluid flammable tanks may also result in this type of explosion. The results create overpressure, fire ball and fragmentations from storage tanks and heat radiation flux to the surrounding structures.

COMBINATION OF EVENTS

Where necessary, events are combined to give the overall risk. For example, the combined effects of a VCE and/or flash fire followed by a jet fire or BLEVE are calculated by superimposing the effect areas for each consequence and then removing any double-counting of the risk.

2.7 QRA SOFTWARES

The widely used and reputed software PHAST 6.51 and SAFETI Micro V 6.51 [65] were developed by DNV, UK, and used for risk evaluation. Various sophisticated models approved by the EPA,USA and the Netherlands Disaster Prevention committee are an estimation of damage distances arising due to fire, explosion and toxic gas dispersion. The selection of suitable software and parameters for consequence modelling is crucial for risk estimation.

2.8 FREQUENCY ANALYSIS

Frequency analysis is an attempt to assess how an accident scenario likely to occur. It is based on and attempts to assess the type of failure and components/parts in the system. Usually the component failure frequencies are derived from generic, historical failure databases, failure experiences or any failure prediction statistical methods. The leak frequency data and various failure hole sizes are assumed based on the scenarios of the study requirement. The generic or historical failure frequency is used for estimating the scenario frequency in order to assess the risk of the particular scenarios.

2.8.1 FAILURE ANALYSIS TECHNIQUES

The theoretical modelling or techniques that are used to find failure data are listed below:

- Fault Tree Analysis;

- Event Tree Analysis;
- Layer of Protection Analysis;
- Fuzzy Fault Tree Analysis;
- Bayesian Network;
- Modification factor with basic frequency data / historical data.

Fault trees are graphical methods that attempt to define how the failure of individual subsystems could lead to total failure of the system. Fault trees are developed normally by acyclic graphs and model the subsystem with appropriate gates that are used to fit into the graph. Fault trees are computed quantitatively as well as qualitatively. Qualitative analysis is an attempt to discover how the failure occurred to the system, while the quantitative method of fault tree analysis is an attempt to discover how to compute and generate failure frequencies and find the failure frequency of the event.

A) EVENT TREE ANALYSIS

An Event Tree was generated based on the ignition, safety and protection of layer available in the system and their success and failure for the various incident outcomes [42]. The fault tree and event trees were combined to establish the frequency of the incident outcome case frequency.

B) LAYER OF PROTECTION ANALYSIS

Layer of protection analysis is another technique used to analyses the protection layer in the oil and gas industry. This technique is an evaluation of frequency for potential incidents and probability of failure of the protection layer. It is a semi quantitative risk technique and simple to compare with a comprehensive quantitative risk assessment. This tool is a measure of the initiating cause frequency and independent protection layer probability of failure.

C) FUZZY FAULT TREE ANALYSIS

Fuzzy fault tree analysis is another technique used by experts to derive the top event probability. In conventional fault tree analysis, the failure probability of a system is established based on actual failure data or historical failure data of sub-system components [76]. But the specific component data for sub-systems are scarce. For this reason the risk values are more subjective. Due to lack of failure data incorporating expert opinion into the assessment, the failure data enhances the risk results reliability. Fuzzy set theory attempts to incorporate expert opinion into fuzzy numbers and calculate failure probabilities [5].

D) MODIFICATION FACTOR WITH FAILURE DATA

Due to the incompleteness of the generic failure data, risk analysts use modification factors to evaluate the local specific failure data. Reliability studies help to integrate the modification factors with generic or historical data to derive reliable failure data [27].

Inferences on Frequency Analysis is a concept of risk assessment, the steps involved in the risk assessment and advantages & limitations of such analysis [75]. Potential calculation differences that can provide the solution to improve transferability are described. This paper describes the hardware failure and their effects on the system, and the Safety Instrumentation Systems (SIS) that are applied for safety critical systems [29]. The Fuzzy Logic methodology is used to assess the failure for the LNG carrier system instead of conventional probabilistic risk assessment methods. A description of the methods to calculate risks for installations and risks connected with transportation is also included. This method is to determine risks and identify the most cost effective methods of risk reduction of chemical plant process safety during the whole life cycle of a plant [15].

It reveals that the assumption of frequency is an inconsistent method as major accidents are still occurring in the oil and gas industry. Most of the frequency data are very old, from around 1970, and are derived mainly from military installations, nuclear fields and from process industries. However, these values are still helpful for risk analysts given that there is no absolute value of frequency.

Generic and historical frequency databases are not available for chemical process industries. The failure definitions vary from database to database and there is no method to derive a common frequency across industries and organisations [49]. Bayes approach, however, is helpful as it incorporates specific local plant operation or maintenance data into failure data, and it can be used with generic database values. But using these tools and data needs specialised knowledge to apply these frequency value estimations. Bayes theorem defines how to update the probability distribution of the frequency of specific local values with general or historical database values [35].

Fault Tree and Event Tree Analysis is used to construct bow-tie analysis to identify the various causes of basic events and how top events lead to different hazardous outcomes. Gas pipeline failure frequencies are provided by the European Gas Association Incident Data Group (EGIG) and based on operational experience of 1.5 million kilometers per year. The data provided by the Department of Transport (DOT) and British Gas Transport Company are higher in order compare to the EGIG values [89]. Estimation of failure frequency is based on data from a generic database from EGIG for cross country pipeline safety assessments [47]. These failure frequencies are used in order to assess the various hazardous event outcome frequencies.

Risk assessment is to be carried out for all natural gas transport systems. Failure rate assumption of pipelines varies by many factors. Failure rate of pipeline for different scenarios are evaluated based on historical values and modified empirical formulae [30]. EGIG values are taken as a base generic value for further estimation. Cascading failure predicting techniques can be useful to find solutions for very complex systems of natural gas networks.

A few major oil and gas industry companies establish proprietary failure databases whereas other authorities and analysts depend on public general or historical failure rates [59]. These rates are generic in nature and using these values to carry out risk assessments can lead to non-reliable results where validity is very difficult to establish. The Purple Book by the Dutch competent authority, FRED managed by the HSE-UK (the British competent authority), AMINAL from Belgium and API from US provide failure rates for many types of equipment [34]. These frequency values are based on data available at the time of compilation and are developed with expert judgement.

The Italian association of LPG collected data about failures of small LPG tanks. Experimental results showed higher failure rates compared with the data provided by the Dutch authorities, API and HSE-UK. At the same time the frequency failure rates were low for LPG operations due to high safety standards of operation by experience [59]. Historical or generic failure rates are obsolete in some cases. The Fault Tree Analysis technique is used to evaluate the failure rate of chlorine pressure vessel failures, but there is a lack of historical data [34]. Different failure modes of pressure vessels are considered, such as instantaneous failure, failure of largest connection to vessel, complete release of vessel content in 10 min and leakage from holes amongst other things.

Risk Assessments are conducted to make facilities safer, acquire legal permission or approval for the facility, and land use planning and to enhance the emergency preparedness and response [34]. Because human factors and management effectiveness are difficult to quantify, they contribute to failure rates. A standard approach therefore is to improve knowledge and improve identification of scenarios which is why the Bayesian Belief Network and decision theory are being rapidly adopted in this area. Total Scenario Frequency has to be established based on the basic equipment failure frequency, ignition probability, weather probability and wind direction probability [73]. The final scenario outcome depends on initiating event frequency and probability of intermediate events.

Many of the failure rates established by the HSE are two decades old, and need to be updated in order to use them for modern planning and quantified risk assessment studies [16]. Although FRED was found in the 1990s to support fire risk assessors modify the generic failure rates, overall it failed due to specific site conditions rendering the data inappropriate. Component failure rates are further classified as mechanical, electrical, bulk transport and movable storage amongst other things.

CONCAWE and UKOPA are further organisations that developed failure databases for pipelines and made them available for public reference. Their failure rates were synthesized by using fault tree techniques, generic data adjusted by modifiers and opinions from experts in order to alter the generic or historical failure data. Changes in failure rates need particular attention, as minor changes can have large impacts to the overall risk. Each scenario needs to be studied carefully as it may affect, for example, land use planning where a leak is close or large in extent. The modified assumptions of frequency failure rates must be calculated sensitively as they affect the overall Risk Contours.

Generic failure data are available for the chemical process industry, nuclear industry and offshore installations. But these values are non-specific and mostly provide point estimates [1]. Expert opinions or Delphi methods are used to generate local plant specific failure rates which can be used to update figures and data. Generally, the generic or historic databases do not provide mean or median values. These failure rates provides only point estimates.

Failure frequency data estimates cover various plant components and equipment in chemical industries resulting in generic estimations of risk not particular to the specific industry [6]. The CCPS guidelines provide process safety incident databases. These database values are used and the variance of these values are obtained based on expert judgment which is helpful in the prediction of frequency assessments. The CCPS guidelines for quantitative risk analysis is used for making subsystem models, however, this value gives rough estimates only at best.

The FMECA and HAZOP integrated methodology is applied to study the risk of LNG regasification plants where as FMECA, by itself, is used to estimate the component failure modes in the plant and its appropriate effects. Many techniques are available to identify the hazards in the process industry, but not a single technique covers all the safety concerns [25]. FMECA considers individual components failure modes and assesses the failure rates. Even though the FMECA is used to assess failure rates for components it assumes human error as zero which is a shortcoming of this method. The effectiveness of the FMECA and HAZOP integrated methodology shall be established by the end of this study.

Fault Tree and Event Tree Analysis use basic failure frequencies from generic or historical databases but include uncertainty, so the Bayesian updating mechanism must be used to minimise the uncertainty [25]. Probability models are used in accident modelling and analysis in process industries - about 22 process accidents are considered [2]. Human reliability analysis is carried out using the Bayesian Belief Network, which classifies humans into five groups in order to assess the human error [51]. It is a very good tool that can be applied to predict human error and its usage is an increasing trend.

The SINTEF blowout database failure frequency for offshore flow out is considered for carrying out risk analysis of oil and gas drilling, based on the Deep Water Horizon case study [41]. The frequencies are calculated for exploration wells, wild cat wells, appraisal wells and development wells. Frequencies obtained are per well operation per well year.

The Bayesian Network model is widely used for safety, risk assessment and maintenance. This method predicts the probability of failure which leads to serious accidents in process industries. Bayesian Network is a flexible tool that can be used for frequency updating and frequency adapting for analysis of accident scenarios [56]. Bayesian Network is a graphical tool used in safety and risk analysis by experts. It is well suited for dynamic safety analysis. Bayesian Network analysis method also provides good results compared to bow-tie analysis as bow–tie considers only common cause failures [57]. However, due to generic or historic data, it is not able to identify the series of failures which could cause a blow out in a well, or predict human error or mechanical failure. In order to overcome these limitations it attempts to use the local failure data to update the failure frequency.

The Bow-tie and Bayesian Network methods can be applied for conducting risk assessments in drilling operations. However, the frequency data are very limited and consequently there is large uncertainty in the results [54]. It is therefore very important to estimate the frequency very carefully. In order to manage these uncertainties statistical tools are used to localise the data with generic data, and modification factors must be applied to estimate the appropriate frequency. Bayesians Network is a statistical tool used in risk and safety analysis where there is a data uncertainty. This tool has more flexibility and can be used for assessing the risks of complex oil and gas facilities.

The quantitative method consists of a probability assessment, a Consequences Analysis and a Risk Evaluation. The outcome of the qualitative method is a qualitative risk value, and for input for a quantitative method the outcomes are IR and SR. [31]. The target of the risk assessment is to identify potential accidents, analyses the causation, and evaluate the effects of the risk reduction measures. The qualitative and quantitative methods are two aspects of risk assessment. The selection of qualitative, quantitative or semi quantitative risk assessment depends on many factors such as the design stage, operational stage or expansion of the plant, legal requirement and usage of the results.

Quantitative risk assessments are carried out to find the risk as a number. The method identifies the risk from the hazards, and assesses the risk level using different models according to the risk involved. Quantitative tools such fault tree and event tree are used to quantify the risk. This method consists of probability and consequence analysis and risk evaluation. The results of QRA are normally presented as individual risk graphs or individual Risk Contours. QRAs can be a useful tools, for example in land use planning. QRAs are very important in risk management and are widely used in assessing risks of pipelines carrying natural gas and used to improve their safety level.

Databases such as E&P Forum, OGP, QRA datasheet, CONCAWE, Offshore reliability database (OREDA), European gas pipeline database (EGIG), VROM –purple handbook, and Failure data-F.P Lees are internationally available generic or historical databases [43] which are commonly used by risk analysts.

2.9 HISTORIC / GENERIC DATABASES

2.9.1 OGP (International Association of Oil and Gas Producers)

The International Association of Oil and Gas Producers has access to technical knowledge and experience from its members. The association collates and distils data from its experience and use this as a guideline for good practice. The OGP-434-1 data sheet presents frequencies of leaks from various oil and gas process equipment types. The following table lists the various equipment and release frequencies. The release frequencies are based on the data from the HSE hydrocarbon release database (HSE- HCRD 1992-2006). They are intended to be applied to process equipment on the topsides of offshore installations and on onshore facilities handling hydrocarbons, but are not restricted to releases of hydrocarbons. The data has been collected from facilities covering a range of ages, but reflects recent industry practices in terms of inspection, maintenance and risk control. The database is supported by a high level of documentation and has been subject to rigorous analysis by the originators. Table 2.2 shows OGP equipment descriptions and failure units.

Table 2.3 shows an extract of leak frequencies for process pressure vessels for connection between diameters.

Table 2.4 shows frequencies for piping per meter and for all other equipment per item. (OGP historical failure database).

Table 2.5 shows the leak frequencies for Manual valves. (OGP historical failure database).

2.9.2 CCPS-LOPA FAILURE DATA

The Center for Chemical Process Safety–Layer of protection analysis guideline book provides failure rates or failure data for initiating event frequencies to calculate risk. As per the book, the following initiating events and its frequency ranges are compiled and shown in **Table 2.6**.

Table 2.2: Equipment types and units

S.No	Description	Unit
1	Steel Process pipes	Per meter year
2	Flanges	Per flange joint year
3	Manual valves	Per valve year
4	Actuated valves	Per valve year
5	Instrumented connections	Per instrument year
6	Process (pressure) vessel	Per vessel year
7	Pump-centrifugal	Per pump year
8	Pump-Reciprocating	Per pump year
9	Compressor-centrifugal	Per compressor year
10	Compressor-Reciprocating	Per compressor year
11	Heat Exchanger-Shell & tube , Shell side	Per exchanger years
12	Heat Exchanger-Shell & tube, Tube side	Per exchanger years
13	Heat Exchanger-Shell & tube, Plate	Per exchanger years
14	Heat Exchanger- Air cooled	Per exchanger years
15	Filter	Per filter years
16	Pig traps	Per pig trap years

Table 2.3: Process vessel failure frequency

Equipment Type: (6) Process (pressure) vessels

Definition:

Offshore: Includes all types of pressure vessel (horizontal/vertical absorber, knock-out drum, reboiler, scrubber, separator and stabiliser), but not the HCRD category "other", which are mainly hydrocyclones.
Onshore: Includes process vessels and columns, but not storage vessels.
The scope includes the vessel itself and any nozzles or inspection openings, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Pressure vessel release frequencies (per vessel year; connections 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	9.6E-04	3.9E-04	3.5E-04	1.8E-04
3 to 10	5.6E-04	2.0E-04	2.0E-04	1.4E-04
10 to 50	3.5E-04	1.0E-04	1.2E-04	1.2E-04
>50	2.8E-04	5.1E-05	7.9E-05	1.8E-04
TOTAL	2.2E-03	7.4E-04	7.4E-04	6.3E-04

Table 2.4: Piping failure frequency

(a) All piping release frequencies (per metre year) by pipe diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	9.0E-05	4.1E-05	3.7E-05	3.6E-05	3.6E-05	3.6E-05
3 to 10	3.8E-05	1.7E-05	1.6E-05	1.5E-05	1.5E-05	1.5E-05
10 to 50	2.7E-05	7.4E-06	6.7E-06	6.5E-06	6.5E-06	6.5E-06
50 to 150	0.0E+00	7.6E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
>150	0.0E+00	0.0E+00	5.9E-06	5.9E-06	5.9E-06	5.9E-06
TOTAL	1.5E-04	7.4E-05	6.7E-05	6.5E-05	6.5E-05	6.5E-05

Table 2.5: Manual valve frequency

(a) All manual valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	4.4E-05	6.6E-05	8.4E-05	9.8E-05	1.1E-04	1.3E-04
3 to 10	2.3E-05	3.4E-05	4.3E-05	5.0E-05	5.6E-05	6.4E-05
10 to 50	2.1E-05	1.8E-05	2.3E-05	2.7E-05	3.0E-05	3.4E-05
50 to 150	0.0E+00	1.1E-05	6.3E-06	7.3E-06	8.0E-06	9.3E-06
>150	0.0E+00	0.0E+00	7.8E-06	8.7E-06	9.5E-06	1.1E-05
TOTAL	8.8E-05	1.3E-04	1.7E-04	1.9E-04	2.1E-04	2.4E-04

Table 2.6: CCPS failure frequency and observed units

S.No	Description	Unit
1	Pressure vessel residual failure	Per year
2	Piping residual failure-100 m- Full breach	Per year
3	Piping leak (10% section)-100 m	Per year
4	Atmosphere tank failure	Per year
5	Gasket / packing blow out	Per year
6	Turbine /diesel engine over speed with casing breach	Per year
7	Third party intervention	Per year
8	Crane load drop	Per lift
9	Lightning strike	Per year
10	Safety valve opens spuriously	Per year
11	Cooling water failure	Per year
12	Pump seals failure	Per year
13	Unloading / loading hose failure	Per year
14	Instrument loop failure	Per year

15	Regulator failure	Per year
16	Small external fire	Per year
17	Large external fire	Per year
18	LOTO failure	Per opportunity per year
19	Operator failure	Per opportunity per year

2.9.3 OFFSHORE RELIABILITY DATA

OREDA (Offshore Reliability Data) was initially established by the Norwegian Petroleum Directorate, and later several oil companies joined and contributed by providing offshore equipment reliability data for safety studies. Failure data were collected based on equipment operational times, calendar times and the failure data lower value, upper value, mean and standard deviation. Table 2.7 gives an extract of an OREDA data sheet for compressor failures.

Table 2.7: OREDA failure frequency spread sheets

Taxonomy no 1.1		Item Machinery Compressors									
Population	Installations	Aggregated time in service (10^6 hours)						No of demands			
131	38	Calendar time * 3.8235			Operational time † 2.4253			82472			
Failure mode		No of failures	Failure rate (per 10^6 hours).					Active rep.hrs	Repair (manhours)		
			Lower	Mean	Upper	SD	n/τ		Min	Mean	Max
Critical		**595***	**0.00**	**166.07**	**839.82**	**361.26**	**155.62**	**17.8**	**0.5**	**29.3**	**1818.0**
		595†	**0.08**	**268.58**	**1176.02**	**459.51**	**245.33**				
Abnormal instrument reading		3*	0.00	1.11	4.88	1.91	0.78	7.0	16.0	16.5	17.0
		3†	0.00	6.03	29.41	12.28	1.24				
Breakdown		5*	0.01	1.28	4.17	1.51	1.31	61.5	25.5	367.0	1481.0
		5†	0.00	6.20	34.23	17.26	2.06				
Erratic output		12*	0.00	6.00	29.41	12.36	3.14	32.2	3.0	56.8	580.0

2.9.4 PURPLE BOOK

The PURPLE BOOK QRA is a guideline for quantitative risk assessment. The CPR 18E Committee for the Prevention of Disaster prepared this report for calculation of risks for stationary installations and transport related activities in the

Netherlands. Failure frequencies are based on the COVO study from 1981 and other frequencies were calculated for the Dutch government over the following years. The loss of containment events are given in this report and shown below in Table 2.8.

Table 2.8: Purple book failure frequency and observed units

S.No	Description	Unit
1.	Stationery tanks and vessel Pressurized	Per year
2.	Stationery tanks and vessel, atmosphere	Per year
3.	Gas cylinders	Per year
4.	Pipes	Per meter per year
5.	Pumps	Per year
6.	Heat exchangers	Per year
7.	Pressure relief devices	Per year
8.	Warehouses	Per handling of packaging unit
9.	Storage of explosives	Per year
10	Road tanker	Per year
11	Tank wagons	Per year
12	Hose leak (Tanker / Wagons)	Per hr.
13	Ships	Per transshipment

2.9.5 EGIG

The European Gas Incident Data Group was formed by gas transmission operators in Europe in 1970. The European gas transmission system operators gather data on the unintentional release of gas in their transmission set ups with the aim to discover failure frequencies of pipelines and various causes of the failures. Table 2.9 shows the failure frequencies the EGIG database.

Table 2.9: EGIG failure frequency and observed units

S.No	Description	Unit
1.	Pipeline	Per 10^6 km.year
2.	Pipeline	Per 1000 km.year

2.10 RISK RESULTS AND PRESENTATION

The results of a QRA are normally presented as individual risk graphs or individual Risk Contours. Risks can be described in different ways: individual risk, societal risk, maximum individual risk, and average individual risk of exposed population, average individual risk of total population and average rate of death. Two popular measures are Individual Risk (IR) and Societal Risk (SR). The former is usually shown on a Risk Contours plot, while the latter is presented with a frequency-number (F-N) curve [62].

The Individual Risk looks at measures such as Individual Risk Contours, Individual Risk Profiles or Transects, Maximum Individual Risk, Average Individual Risk and Fatal Accident Rate (FAR). The Societal Risk looks at measures such as F-N Curve, Aggregate Risk, Arrogate Risk Index, and Equivalent Social Cost Index (ESC).

The Risk Criteria denote whether a specified risk is acceptable or unacceptable. The acceptable risk criterion is yet to be defined in the Indian industries, which lag behind other countries. Generally, the ALARP term is used to assess the risk level. From the incident scenario, the incident outcomes are developed using event tree analysis. From the incident outcome cases the impact zones are calculated (set of models used to find the amount and impact on people). In this analysis the frequency of each incident outcome is calculated based on Event Tree Analysis.

The QRA can be a useful tool, for example in land use planning. The safety of a plant or installation is determined to a large degree during the process, plant and installation design. It is therefore of great importance to consider the safety aspects early in the design phase [62]. The risk of complete chemical plant activity will include many accident scenarios and all possible weather conditions. The proposed method of quantitative risk assessment may be useful for risk management during the planning and building stages of a new pipelines and modification of a buried pipeline [88].

2.11 SUMMARY

The risk estimation plays an important role in decision making. But in this evaluation of risk the important component is frequency values. The failure frequency is assumed or selected based on historical or established databases. But these values are challengeable and subjective based on the risk assessment experts. The historical database value have limitations and effects the reliability estimated risk values or the risk contour. The failure frequency is to be enhanced based on the local environment and plant specific failure rates.