CHAPTER 3

3 Hazard Identification and Risk Assessment

3.1 Overview:
The components of proactive OH&S management system identifies hazard, assessing risk and determination of control mechanisms. Though there is no general guidelines for the usage of terms for the practices like - HIRA, and decide Control mechanism in occupational health & safety management system (OH&S) however for consistency’s sake OHSAS 18001:2007 (Sousa, Almeida et al. 2012) defined terminologies will be used. Different terminologies from BS8800: 2004(namely hazard prevention), OHSAS 18001:2007(Risk assessment, hazard assessment are used in ILO-OHS: 2001 which deals the three processes separately and similar to OHSAS 18001:2007.Similarly HSG 65:1997 describes the entire process of controlling risk and health in three steps namely “risk assessment” , “risk control”, and “hazard identification”, which is the same as defined by OHSAS 18001:2007 (OHSAS 2007). On the other hand, BS 8800:2004 all the processes are combined under the term “risk assessment (British Standard 2004).

ILO-OHS: 2001, OHSAS 18001:2007 and BS8800: 2004, defines hazard as impairment to human with respect to ill health or injury or amalgamation of those two. However under HSG 65:1997 the possibility to cause harm to plant, environment, property or the product (Health Safety Executive 2013) is termed as hazard. There is a difference in the definition of terminologies like “incident” and “accident”. There is some variation in the guidelines and standards (Saldaña, Herrero et al. 2003, Hughes and Ferrett 2013).

As per OHSAS 18001:2007; HSG 65:1997, ILO-OHS: 2001 and BS 8800:2004, defines “incident” discriminately as events causing no harm, and “ accident” as
which causes ill health, injury or fatality. OHSAS 18001:2007 has replaced the term “acceptable risk” with “tolerable risk” (Özgen 2012).

While S.D., P., Kampmann J., Tengborg, Eskesen, Veichert T.H.: 2004 in guidelines for tunneling risk management: International Tunneling Association (ITA), Working Group No.2 follows a middle way in between BS 8800:2004 and OHSAS 18001:2007, it combines identification of hazard and assessment of risk processes under the term of risk assessment and mitigation (Özgen 2012). The organizations need to recognize, implement and sustain the processes of “Risk assessment” “Hazard identification”, and “determining controls” for general understanding of the hazards caused due to its workplace activities in workplace, and being positive that any risks pertaining from the hazard is reduced to or is at a tolerable level (Asbury and Ball 2016).

The items of instituting, executing and adopting effective process of HIRA process (Hester and Harrison 1998) are achieved mainly by:

- Adopting processes measures to identify hazard and risk assessment,
- Hazards are classified as per the activity or place,
- Evaluate the threats related to common hazards by assessing and defining the levels of risk as per their acceptability,
- Evaluating the tolerable risk control mechanisms, which are important and conforms legitimately to other necessities and the requirements, which are necessary as per OH&S objectives and policy
Figure 1: Outline of the identification of hazard and assessment of risk process (Adopted from OHSAS 18002:2008)

This addresses the execution of controls, observing and review. So, the “implementation of controls” and “review monitoring” procedures displayed in Figure 1 are those key processes of the organization’s OH&S management system and are hence performed accordingly (Lu, Yao et al. 2005).

3.2 Qualitative Hazard Identification

3.2.1 Past Accident Analysis

In the area of safety it very challenging to execute controlled tests in a cost efficient and harmless manner unlike other specializations of science and engineering where it is easy to conduct cost effective tests to obtain results (Badawy 1995). Therefore, past accident analysis becomes a crucial tool for documentation of the origins, result and various hazardous factors that led to the mishaps and hence to evade the recurrence of accident in the future (Badawy 1995). Past accident analysis provides instrumental result which can help to mitigate unavoidable mishaps (Aini, Fakhru'l-Razi et al. 2005). Past accident
analysis helps in identifying various hazards (Vinnem, Aven et al. 2006). The contributing factors will be known by evaluating previous incidences or near misses or accident incidents (Sagberg 1999). Careful analysis of previous accidents can help in outlaying the unsafe and safe condition of the working site and as a result will help in developing corrective measures for evading so (Reason 2016).

Accident analysis is the process to determine the route of an accident or succession of accidents by assessment of all sorts of evidence through past records interviews, on-site inspection, etc. so as to analyze further episodes of same kind (Behrent 2010). After a mishap occurs, all related important facts that may have contributed to the occurrence and understanding of the accident is gathered by an accident analysis team (Larsen and Kines 2002). After the completion of the forensic process or at least if a wrong idea of the cause of the mishap is drawn, the facts are put together to give a bigger and better view of the actual scenario (Schofield, Noond et al. 2002). The suitable information can be drawn from the history of the accident, conclusions can be drawn about causative factors. Then the counter measures for dodging these mishaps are formulated and they are recorded for future references (Green 1995).

Accident analysis refers to the investigation of accidents by collecting all sorts of information through interviews, on-site inspections and past records, etc. to determine the causes of an accident or chain of accidents to avoid the additional incidents (Sorooshian, Teyfouri et al. 2014). After an accident, the accident investigation is begun to assemble all the conceivable important realities that add to comprehend the mishance (Banić). On the way reference of finishing the scientific procedure or at least delivering some results, the facts are put together to draw a conclusion (Dewey 1958). Consistency and plausibility are checked and reconstructed from the history of the accident (Lowe 1987). Causation and contributing factors can be drawn if the accident history is sufficiently informative (Lowe 1987). The improvement of counter-measures sometimes is
wanted or proposals must be issued for anticipating further mishaps of the same kind. These conclusions are archived and recorded for future (Spiers 1986).

Understanding and awareness of things that went wrong, and perhaps may go wrong again can be predicted from the analysis of past accidents (Reason 2016). The past occurrences encounters are interpreted into cautious measures; later on an association can counteract episodes and the requirement for suppressive activities at time of need (Rothblum 1992). Acquaintance from these episodes are required for comparing and the frameworks and own circumstance and empowers us to build an investigation assessment and minimize time to organize the activities (Ganz 2006).

Though, after an occurrence is happened in an activity or process, promptly the circumstances changes. The time to consider (Brockhoff 1967), when the knowledgeable personnel is being there, based on the past accidents, can take optimal and immediate actions to lessen the damages caused by the accidents. Experienced personnel like him can also prevent the accidents that can initiate an incident in the future, by identifying the hazards (Crowl and Louvar 2001).

3.2.2 Preliminary hazard analysis

3.2.2.1 Overview:
Before starting a job the methods which are practiced, where the risks involved and hazards are discussed and the way outs are provided is called the Preliminary hazard analysis (Harms-Ringdahl 2003). After evaluating the possibilities and the consequence of foremost hazards, the risks allied are estimated and is solved prior to the consequences cause harm (LaGrega, Buckingham et al. 2010).

The following are some of the fundamental points taking into account the preliminary hazard investigation and the qualities of the preliminary hazard analysis:
• Expert opinion and questionnaire based on brainstorming to identify types of hazards and provide a risk ranking, helps in prioritizing recommendations to reduce risks (Thaheem and De Marco 2014).

• Basically it is performed by a group of people who have proficient about the kind of action being referred to. Field inspections and verification of documents are on priority analyzing available system (Hassan 1981).

• Define activity or process

• High level analysis of activity or process

• Qualitative hazard analysis will be carried out based on available procedure.

• Corrective measures will remain in place minimizing level of hazard and continuing process further. (Renn, Burns et al. 1992).

• The effectiveness of assessment depends on the involved team and their experience and also if they have been involved in same activity or process earlier(Robinson and Sellschopp 2002).

3.2.2.2 Detailed procedure:
Steps for carrying out a preliminary hazard analysis are as follows:

3.2.2.2.1 Define the action or arrangement of interest.

Define clearly and particularly the restrictions of the framework or action for which preparatory hazard information are required (Ferrier and Haque 2003).Define the accident classifications of interest and the accident severity classes.

Recognize the issues of interest that the risk evaluation will take in consideration like environmental issues, health and security concerns and so forth. Stipulate risk and its severity classes of the incident which is utilized to organize assets for risk control (Covello, Sandman et al. 1988).
3.2.2.2 Conduct audit.

Recognize the related area of the major hazards that will result in unwanted consequences. Besides, identify the alternatives or design criteria that could dispense with the associated risk (Frenkel, Hommel et al. 2005).

3.2.2.3 Use the outcomes in drawing a basic conclusion.

Audit the corrective and preventive measures and its benefits that are proposed. The common format used for primary hazard analysis is as Table 2.

Table 2: Primary Hazard Analysis worksheet

<table>
<thead>
<tr>
<th>Example Primary Hazard Analysis Worksheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area: _________________________________</td>
</tr>
<tr>
<td>:____________________________________</td>
</tr>
<tr>
<td>Drawing Number:__________________________</td>
</tr>
<tr>
<td>Team Member:____________________________</td>
</tr>
<tr>
<td>Hazard: Potential Accident</td>
</tr>
<tr>
<td>Curse</td>
</tr>
<tr>
<td></td>
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3.2.2.3 Advantages of PHA:

- Makes sure that the system is protected
- Carrying out in early stage of the design and therefore, changes are less expensive
- Reduces the number of changes thus decreases the design time
3.2.2.4 Disadvantages of PHA:

- The analyst must recognize the hazards.
- The consequences of the hazards in a pertinent process are not easily predicted.

3.2.3 What if analysis

What–If Analysis is an organized conceptualizing method of defining the action that can go wrong and assessing the probability and consequence of those circumstances (Tichy, Tushman et al. 1979). The competent assessors of an audit team genuinely identify the problem in a process or activity. Each individual from the audit group joins in finding what can turn out badly based on their previous accident of past similar circumstances (Wang, Chen et al. 2011).

With the help of Piping and Instrument Diagram (P&ID) or operating procedure, the group surveys the process (Venkatasubramanian, Zhao et al. 2000). Operating and maintenance personnel are usually included by the team members, operating engineers, design engineers, specific skilled personnel as safety and necessary personnel. At every step in the process or procedure, What-If questions are asked and consequently answers are developed. After that the review team works to get an approval on every question and answer (Clampitt 2009). A listing of recommendations is developed from the answers, identifying the requirement for additional revision or action. Along with the recommendations, the list of questions and answers, become the major components of the hazard assessment report (Kletz 1999). To lessen the chances of ignoring the probable problems, moving to proposals are done in anticipation of the greater part of the potential risks are perceived (Organization 2002).

When staffs are experienced the What-If Analysis technique becomes more effective and easy procedure. No specific devices or strategies are required (Huber 1984). The people with a preparation of little risk investigation can take part in a full and significant way. This can be practiced whenever interested like
at the time of debugging, at the time of construction, amid maintenance or amid operations. The consequences of the study can be applied quickly and are immediately available (Kranzlmüller 2000). This is factual if the review team members also maintain or operate the system being assessed.

3.2.4 Hazard and Operability Study (HAZOP)

3.2.4.1 Introduction:

A Hazard and Operability (HAZOP) study is an accurate and organized assessment of hazard associated to an existing operation (Wang and Ruxton 1997). It enquires how the plant or system deflects from the design stop and forms risk for equipment, personnel and operability problems. HAZOP have been used with great success within multiple construction, chemical and the petroleum industry to obtain safer, more efficient and more reliable plants.

To analyze this chemical processes, the HAZOP method was principally created.

3.2.4.2 History of HAZOP

The report of HAZOP involves systematic as well as organized work of a operation or existing or preset to establish (Cagno, Caron et al. 2002) and assess problems which may indicate peril to equipment or personnel or might disrupt an effective operation.

This method was formerly developed to examine process systems of chemicals, but it was later extended (Toola 1992) to various systems from software to complex systems. This subjective technique has its roots on guide words being performed by a multidisciplinary group (Kennedy and Kirwan 1998) in meetings.
3.2.4.3 When to execute:

The study of HAZOP should be taken up as soon as possible during early phase of designing to have an impact on the design. But then to go forward with HAZOP we require a completed design. At the time of when design is completed, we check HAZOP (Taylor 2007).

The report of HAZOP might as well be considered on an already established facility to determine any changes that needs to be done in order to reduce risk and operability (Bahr 2014).

Studies of HAZOP might also be extended further which includes:

- At the conception stage of design when outlines are readily accessible.
- At the time when finalized instrumentation and piping diagrams are ready
- At the time of installation and construction to make sure that suggestions are implemented (Meyer 1988).
- At the time of commissioning
- During regular operations so that emergency and operational procedures of plant are timely reviewed and modified as necessary (Kyriakdis, 2003).

3.2.4.4 Background of HAZOP:

- HAZOP was constituted in 1963 by ICI based on techniques of “critical examination”
- HAZOP guidelines was the first lead from Chemical Industries Association Ltd and ICI, 1977 (Rossing, Lind et al. 2010)B.
- HAZAN and HAZOP - Assessment and identification of hazards in the process industry (Malfatti 1809).

3.2.4.5 Guidelines and Standards:

- HAZOP - Best practices guidelines for the chemical and process industries (Crawley and Tyler 2015).

3.2.4.6 Various forms of HAZOP:

• Process HAZOP: This form of HAZOP was formerly developed to evaluate process and plant mechanisms.
• Human HAZOP: It includes particular special HAZOPs which focus on human mistakes rather than any breakdown in operation.
• Procedure HAZOP: Safer Operation Study often denoted as SAFOP which reviews the operational or procedural sequences
• Software HAZOP: It is a form of HAZOP that help identify the errors during the software development.

3.2.4.7 Team Members

• Member of HAZOP team;
• Basically, a plant process team would have:
  • Electrical/Instrument Engineer
  • Process Engineer
  • Project Engineer
  • Manger for Commissioning
  • Safety Engineer
• On basis of the actual operations, the team may constitute:
  • Suppliers Representative
  • Maintenance Engineer
  • Operating Team Leader
  • Any other experts as required
3.2.5 Process HAZOP:

Necessary Conditions: To facilitate HAZOP study, we need following information to be readily available:

- PFD (Process Flow Diagrams)
- MSDS (Material Safety Data Sheet)
- Temporary instruction for operation
- Layout of a design
- Instrumentation and piping diagrams
- Data of equipment, Start up and procedures for emergency shutting down equipment.

3.2.5.1 Procedure:

- The system has to be divided into various sections like storage, reactors.
- A node of study has to be chosen which might be line, pump, vessel, operating instructions
- Purpose of the design needs to be described
- Particular parameter of process is selected.
- Guide word is applied
- The causes are determined
- Assess problems or consequences
- Suggestion for actions on time, reason, responsibility
- Information record
- The procedure from Step 2 has to be repeated

3.2.5.2 Operational Modes:
The following operational modes of the plant need to be considered for individual node:

- Regular Operations
- Reduction in throughput of a operation
- Normal Start up procedure
- Normal Shutdown
- Shutdown in case of emergency
- Commissioning
- Any operating modes that needs special attention

3.2.5.3 HAZOP recording

The findings are recorded during the meeting(s) using a HAZOP work-sheet, either by filling in paper copies, or by using a computer connected to a projector (recommended).

3.2.5.4 Worksheet entries

A. Node

The design/process intentions are evaluated in a process at specific location called a node.

Heat exchangers, Separators, Interconnecting pipes with equipment, Scrubbers, Pumps, and Compressors are few examples.

B. Design Intent

The outline expectation is a depiction of how the procedure is relied upon to carry on at the hub/node; this is subjectively portrayed as an action (example: encourage, response, sedimentation) and/or quantitatively in the process parameters, similar to temperature, stream rate, weight, creation, and so forth (Tribus and McIrvine 1971).

C. Deviation

An approach of heading off from process targets is called deviation.
D. Parameter

It is the significant factor for certain conditions. (E.g. weight, temperature, synthesis).

E. Guideword

It is to make the creative energy of a deviation of the process/outline plan. The most regularly utilized arrangement of assistant words is: no, all the more, less, and in addition, a portion of, other than, and reverse (Alesina and Weder 1999). Also, guidewords like too soon, past the point of no return, rather than, are utilized; the last essentially for bunch like procedures (Buxton 2010).

F. Cause

It is the clarification why the deviation could happen. A few causes might be distinguished for one deviation. It is regularly prescribed to begin with some of the causes that may bring about the most exceedingly terrible conceivable outcome (Hayek 1932).

G. Consequence

In case if a consequences occurs, it is the outcome of the deviation. Outcomes may both involve process risks and operability issues, similar to plant close down or lessened nature of the item (Jespen 2016).

A few results may take after from one cause and, thusly, one outcome may include few other causes.

H. Safeguard

It is to moderate the event occurrence and consequences. There are five types of safeguards in which

- Deviation is identified (e.g., human operator detection, and alarms and detectors)
• Recompense for the deviation (e.g., if there should arise an occurrence of packing a programmed control framework diminishes the food to a vessel (Hines 1966). These are regularly incorporated into part of the procedure control)
• Occurring of deviation is prevented (e.g., blankets of an idle gas in stockpiles of combustible material)
• Deviation is further prevented from escalation Mitigate the procedure from risky divergence (e.g., Process safety valves (PSV) and vent frameworks)

3.2.5.5 Process parameters

3.2.5.5.1 Parameters:
Flow, Pressure, Temperature, Level, Composition, pH, Viscosity, Speed, Voltage, Frequency, Addition, Mixing, Separations, Reaction, Time, Control, Sampling, Inspection, Maintenance

3.2.5.5.2 Guide Words:
None, More of, As Well As, Other than, Less, A part of etc.

3.2.5.6 HAZOP Procedure

The system about HAZOP will be the examination from claiming a surviving or illustrated operation (work) technique on risk assessment and reasons for operational issues, technical issues & human errors (Cameron and Raman 2005). To give a chance to be connected with every one successions of operations.

• Best suited for accurate assessments, but can also be used for common preliminary assessments
• Adaptable approach with admiration to utilization of guide-words. Breaking down of operation process to suitable steps
• Characterize intention for every venture.
• Constitute limit states else as accepted procedure HAZOP.
• Relegate guide-words should proposition and limit states to every venture.

3.2.5.6.1 Advantages:
• Systematic examination
• Can be assigned to every sequences of operations
• Multidisciplinary studies
• Considers operational procedures
• Covers all safety as well as operating conditions
• The Solutions to most of all problems that are identifiable are indicated
• Covers all human errors
• The Study can be conducted by independent personnel.
• All the results are then recorded

3.2.5.6.2 Disadvantages:
• Methodical examination
• Utilizes operational experience
• Considers operational procedures

3.2.6 FMECA
FMECA inclines to be favored over FMEA in space as well as in North Atlantic Treaty Organization (NATO) military uses.

3.2.6.1 Application and Benefits of FMECA:

1. It is a documented technique can be used to ensure the proper design and safely completion of job. It is being in used to assess potential failure in a system, mode of failure and its impact during operation.

2. It helps identifying probable failure and their causes before it could be converted critical. It is helpful in evaluation of changes made in design or
other operational procedures within time and helps maintaining safety at work place.

3. It helps in orderly evaluation of process or system which keeps maintaining proactive safety culture at work place.

3.2.6.2 Limitations FMECA:

While identifying hazard, it may not be comprehensive due to which assessment will be limited. It is used as top down tool in which FTA is comparatively best. In top down tool, FMEA identify the major failure although in the case of bottom up analysis it is slightly better than FTA. Assessment of risk value may be reversed because risk ranking are ordinal scale and its multiplication is not defined in ordinal numbers.

3.2.7 Job Safety Analysis:

Job Safety Analysis (JSA), which is also called Job Hazard Analysis, is an effective tool for hazard identification and risk assessment applicable in all industries but most effective in construction industry. At work place where working environment changes constantly and workers moves throughout of day. It is very difficult to identify hazard and risk at work place and to address this type of problem and evaluate risk, (Azadeh, Fam et al. 2008).

JSA is one of the most effective way which helps in minimizing accidents, injuries at workplace. It is tool for training, investigating near misses and accidents (Reese 2011).

A process or activity will be selected to start JSA and potential hazard will be identified. All the way, each and every step will be considered for analysis. After JSA completed, it will be ensured that work had planned properly and ensured safety of workers at workplace(Phoya 2012).

Steps in involved in JSA:
I. List out steps involve in JSA

The moment work activity decided and understanding of work is clear, the work activity need to divide into various parts or steps. These activity or sub-activity is not just specific to the job but also suitable for the work areas. When there are changes in work areas, possibly there is a need to change the sub activity or steps involved.

II. Identification of hazards associated with each step.

Hazard identification in an activity or process is key elements of JSA. Each sub activity will have associated hazard and could lead to failure. Therefore, it will be recommended that how an activity or process, people, material and environment can lead to different hazards. Assessment of activity and identifying hazards are by the following

- From past accidents analysis
- Legal requirements
- Instruction given by manufacturer
- Surrounding work near to the specified work areas.

III. Determine controls for each hazard.

All identified hazard in an activity or sub activity will be having a control by which risk level of hazard can be minimized.

IV. Discuss the JSA with your workers.

Completing all these three steps, JSA will be framed to reduce the risk level at work place. The same information has to share with the workers or employee involved so that any adverse action can be avoided. Before
starting the work, JSA review will be done by crew members and ensured that everyone familiar how to do the job. Review of JSA will be done once the same task extended for another day.

3.2.8 Fault tree analysis

3.2.8.1 History
The Beginning Years (1961 – 1970)

- Watson & Mearns (1961), built up the strategy for the Air Force for assessment of the Minuteman Launch Control System.
- Dave Haasl (1963) of Boeing as a critical framework safety investigation device.
- The first specialized papers on FTA were introduced at the primary System Safety Conference, held in Seattle, June 1965  Boeing started utilizing FTA on the configuration and assessment of business air ship, around 1966
- Boeing built up a 12-stage issue tree reenactment program, and an issue tree plotting program on a Cal comp move plotter
- Adopted by the Aerospace business (air ship and weapons)

The Early Years (1971 – 1980)

- Adopted by the Nuclear Power industry
- Power industry upgraded codes and calculations

The Mid Years (1981 – 1990)

- Usage began getting to be global, essentially by means of the Nuclear Power industry
- More assessment calculations and codes were produced
- A vast number of specialized papers were composed on the subject (codes and calculations)
- Usage of FTA in the product (security) group
- Adopted by the Chemical business

The Present (2000)

- Continued use on numerous frameworks in numerous nations
- High quality flaw tree Commercial codes built up that works on PC's

3.2.8.2 Overview:

Fault Tree Analysis (FTA) is an innovative technique which is commonly used to recognize the events which may occur in order to realize a desired or undesired result. The technique uses a deductive approach to event analysis as it moves from the general to the specific. FTA provides great utility in its ability to distinguish between those events which must occur and those that simply can occur in order for the top event to occur. The information charted on a fault tree provides a qualitative analysis by demonstrating how specific events will affect an outcome (Ramzali, Lavasani et al. 2015). The basic strategy includes the utilizing a mix of generally basic rationale gates (AND, OR, NOT) to build a disappointment model. The Top Event recurrence or likelihood, is figured from information identifying with less complex or more fundamental Activity. An essential hypothesis in FTA is that all framework disappointments are paired in nature, i.e. a segment or administrator either performs effectively or fizzes totally (Purba, Sony Tjahyani et al. 2015). Construction of Fault Trees

For undertaking the procedures of FTA, 5 steps are involved

- Description of system, including system boundary.
- Identification of Hazard, and determination of top event.
- Construction of fault tree.
- Subjective assessment and examination of the fault tree.

**Step One: System description:**

A key step in FTA is that a knowledge of the causes of Untimely events is conceivable only by a thorough idea of how the system works (McNelles, Zeng et al. 2016). The initial stage is basically open and it’s the responsibility of the individual building the fault tree (the analyst), where boundaries and data needs can be found out (Matuzas and Contini 2015). A portion of the data that might be required are process description, hazardous materials, specifications of equipment’s, operating and maintenance procedures, so on (Makajic-Nikolic, Petrovic et al. 2016).

**Step Two: Hazard identification**

Various activities for example, site reviews, checklist, HAZOP studies and examination of incidents can be utilized to find out top events (Lower, Magott et al. 2016). Top events are generally very major incidents for example, fire, equipment failure, other incident and huge explosions.

**Step three: Fault tree construction**

There are no such rules what events and gates to be used in fault tree construction. Fault tree show how a specific event occurs by logic diagrams.

A specific undesired outcome is selected and it becomes the event. The causes of the event are identified with their logical link, then an analyst asks queries as “How it can happen?” and “what are the causes which led this event to occur?”. The queries continues till the analyst is fully clarified that the model which was failed describes the process under the study (Liu, Yang et al. 2015). Moreover, the process of queries could continue and issues coming outside the boundary of study are not mentioned. As a result, definition of boundary is essential for the success of fault tree analysis(Lavasani, Ramzali et al. 2015).
Fault trees which are made manually are comprehensively subjective and may be incomplete, but, allows the analyst reviewing the system, some errors that may occur in a fault tree are:

- Rapid building of a branch of a tree without deliberately processing level by level along the entire fault tree (Komal 2015).
- Omission of a fundamental failure framework or cause, or a wrong supposition of irrelevant contribution.
- Incorrect blends of probability and frequency into logic gates.
- Improper balance between equipment sort causes and human blunders.
- Non-recognition of dependence of events.

**Step Four: Qualitative examination of structure**

The structure of the fault tree can be qualitatively analyzed after being built, to understand the mechanisms. The things which are highlighted are, the subjective significance of occasions, safeguards effectiveness and the helplessness to regular mode failures (Kabir, Walker et al. 2016). Inspection becomes difficult for more complex fault trees and to tackle this more simplified way as Boolean analysis must be applied. For defining the top events in terms of a summation of all lower events, fault trees has to be converted into equivalent Boolean expression (Ju 2016). This expression is expanded with the help of laws of Boolean algebra, until the top event as the sum of minimal cuts sets.

When a single event affects the basic events, common failures are caused which are independent in fault tree (Huang, Fan et al. 2016). The common causes are maintenance error miscalibrating all sensors and power failure disabling several electrical safely systems. For instance, if there is a power failure in any of the two branches of a fault tree attached by an AND gate, and the gate by gate method is followed, the final result will have an error (Huang, Fan et al. 2016). Boolean analysis addresses this problem by identifying the errors. However, there are other
elements also which are not included could result in common failure, for example, Common manufacture, common location and so on (Deng, Wang et al. 2015).

**Step Five: Quantitative evaluation of fault tree**

The top event frequency can be calculated once the last structure of fault tree has been resolved and a recurrence has doled out to each of the essential events. The gate by gate technique is being followed up to the top event. Before calculating the gate output, all inputs must be defined. Before continuing to the more elevated level, all lower gates must be computed. In OR gates, addition occurs and in AND gates, multiplication occurs (Choi and Chang 2016). A number of additional studies possible once a fault tree has been calculated which includes, uncertainty and Sensitivity analysis. Uncertainty analysis gives us a measure of the error bounds of the top event whereas Sensitivity analysis is utilized to decide the affectability of the top event recurrence (Cheshmikhani and Zarandi 2015). The various minimal cut sets are ranked by Importance analysis in order of their contribution to the failure frequency.

<table>
<thead>
<tr>
<th>Name of Gate</th>
<th>Classic FTA Symbol</th>
<th>Causal relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>![OR Symbol]</td>
<td>If both inputs are &quot;No,&quot; then the output is &quot;No.&quot;</td>
</tr>
<tr>
<td>AND</td>
<td>![AND Symbol]</td>
<td>Output is &quot;Yes&quot; when both inputs are &quot;Yes.&quot; Otherwise, &quot;No.&quot;</td>
</tr>
<tr>
<td>Inhibit</td>
<td>![Inhibit Symbol]</td>
<td>If all input occurs along with an additional conditional event occur, then output will occur.</td>
</tr>
<tr>
<td>Name of Gate</td>
<td>Classic FTA Symbol</td>
<td>Causal relation</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Voting OR (k\text{-out-of-}n)</td>
<td><img src="image" alt="Symbol" /></td>
<td>The yield event happens if (k) or a greater amount of the information (Input) events happen.</td>
</tr>
<tr>
<td>XOR</td>
<td><img src="image" alt="Symbol" /></td>
<td>If both inputs are either “false” or “true”, then the output is false.</td>
</tr>
<tr>
<td>Dependency AND</td>
<td>In FTA it is not used.</td>
<td>If all the inputs are “true” and the inputs are dependent upon each other, then the output is true.</td>
</tr>
<tr>
<td>Priority AND</td>
<td><img src="image" alt="Symbol" /></td>
<td>If all the input occurs in a particular grouping, then only the output occurs.</td>
</tr>
</tbody>
</table>

### 3.2.9 Event Tree Examination

#### 3.2.9.1 Overview

- It is a type of risk assessment that depends upon binary logic. In this tree examination an event either is being or being not taking place or a constituent is or is not diminished.
- It is used in recognizing as well as analyzing the consequences take place from a failure or unwanted event. It is a forward bottom-up approach (Ayav and Sözer).
- It is a dominant tool that will categorize all features of a system that includes a chance of taking place later on, when the initiating event is to
be applied to extensive range of systems such as nuclear power plants, chemical industries etc.

- An event tree begins through initiating event, with pivoted events in between as well as ends with Accident situation. Probabilities of Events are acknowledged for each and every situation

Initiating Event:

- Collapse or unwanted event that initiates the start of an accident series.
- Fire, Explosion or a release of a hazardous substance are the examples of initiating event

Pivotal events-

- These are the mediator events between IE as well as the final accident.
- These are the (Failure/success) events of design safety techniques
- Fire alarm works, Sprinkler system, Fire detection system are some examples of Pivotal events

Accident scenario –

- Series of events that are eventually result in an accident.
- The sequence of event usually starts with initiating event as well as is followed by one or more pivotal events that leads to unwanted circumstances

3.2.9.2 Steps that are involved in event tree examination

- Recognize the Initiating event
- Recognize the commas well ass, which are assigning with the primary event like as automatic ty systems, alarms on operator actions.
- Create the event tree starting with the initiating event as well as proceeding through collapse of the safety functions.
- Build the resulting accident sequence.
• Recognize the substantial elements which are to be linked

3.2.9.3 Advantages of Event Tree Examination

• It unites the hardware, software, environment, as well as human interface
• It allows probability evaluation
• Business-related software is available
• Can be performed on various levels of details
• No need to look forward to end events
• Comparatively easy to learn as well as implement

3.2.9.4 Disadvantage of Event Tree Examination:

• Addresses only one initiating event at a time
• Success or failure probabilities are very difficult to discover
• an analyst is needed with practical training as well as experience
• The initiating challenge must be recognized by the analyst

3.2.10 Cause-Consequence Analysis (CCA):

It is a method used for analyzing consequence of chain or any activity. It can be used independently and for individual and also it is helpful for other analysis methods (Ylijoki-Sørensen, Boldsen et al. 2014).

By this method, unwanted events, their consequence and probabilities gets identified. It can be done by merging or combining two different tree events together. In this methods, it examine the primary event and its follow or intermediate events might lead to any failure(Reinholds, Bartkevics et al. 2015). The primary event and follow events cause and probabilities analyzed by top to down tree and it describes failures in this tree only which normally called as fault
trees. Cause and consequence tree forms a chain which clarifies the relation between cause and consequence and probably leads to damages. CCA includes:

1. Identify damaged chain or event
2. Identify primary event
3. Identify follow up events
4. Recognize the consequence damage
5. Clarifies cause of failure events
6. Set up probabilities for the cause identified in primary and follow up events.

It is an effective tool which ensures the execution or operation of any activities for which consideration would have been taken in design phase. It is helpful in evaluating complex events which have many altered consequence even in primary events

3.2.11 Decision tree analysis

It is a tool used in tree - form graph or model of all decisions and their consequences. It includes the outcomes, cost & utility and represented in flow chart in which each branch represents the outcomes.

It has three nodes:

1. Decision nodes
2. Chance nodes
3. End nodes

It helps in identifying the causes of failure or consequence coming during operational safety. Once failure identify, suitable control measures remains in place.
Decision trees are as of now a standout amongst the most mainstream strategies utilized for data modeling of data or information displaying. Decision trees are ordinarily utilized as a part of operations examination, particularly in choice investigation, to recognize a methodology well on the way to achieve an objective. They have the edge of being reasonably straightforward, and have been appeared to perform well on an assortment of issues. Decision trees have numerous utilizations, for example, for instance, anticipating a likely result, helping with the examination of issues, and supporting in deciding.

3.2.12 Monte Carlo simulation

It is a mathematical technique in which risk assessment done in quantitative form. This technique is suitable for project management, finance, energy, oil & gas, environment, manufacturing and R& D sectors. It allows decision makers to set possible outcomes and their probabilities of occurrences at any point. A range of outcomes and their occurrences comes out of it and it helps in decision taking.

This technique was used by scientists during working on the atom bomb and during second world war it has been used in many physical and conceptual system.

Monte Carlo techniques are basically utilized as a part of three particular issue classes: enhancement, numerical reconciliation, and creating draws from likelihood dissemination.

The probabilistic way of incident frequencies and adverse behavior makes the Monte Carlo strategies a perfect tool for risk assessments.

3.2.13 Hazard Identification and Risk Assessment (HIRA):

Whenever we talk about hazard, we assume a source or situation which could able to harm and may turn into Ill health, loss of property, loss of environment and
injury etc. or amalgamation of these. Although, hazard identification is a process of recognizing the hazards that exists in any activity and defining its characteristics (Lees 2012). While risk is a result of any miss happening in which it signifies the likelihood of consequences of any hazard and severity of an injuries.

But when we take the considerations of risk assessment then we call it as process in which risk will be evaluated from the available hazard for the purpose of further control measure. There are numbers of standard which gives guidelines in which it is assume that work place hazard can be identified in any activities or sub activities and their associated risk can be determined (Kennedy and Kirwan 1998). The determined risk will be evaluated based on the risk matrix available for the further control.

OHSAS tells about the identification of risk in significant categories where it is required to classify the risk in a range where further control will be taken by special attentions or based on the control operating procedures (Labodová 2004). The identification of risk is the judgement made by the competent person and person involve in project management and those knows the trend of occurrences of any hazard or risk in past.

The OH&S hazard are the behavior of any process unit, activity, product and procedures which adverse as an impacts inline to the concern activity or process or procedures. Therefore, if impact noticed before and a suitable control applies at right time, the risk coming out from these activities or process will be under control or not able to touch its significant range.

Therefore, it is important for an organization to identify hazard in each and every process or activity and assessing its risk for suitable control measures. The control measure suggested should be impartial and should be applied without any interference.
Whenever risk assessment is done, it is always the combination or multiplication of likelihood of any hazard and its severity. In mathematical way, the risk can be calculated by

\[
\text{Risk (R)} = \text{Likelihood (L) of an event} \times \text{Severity (S) of any outcome}
\]

Where, Likelihood (L) is an occurrence of any event in a specified time or in specified circumstances while severity is a result or outcome from that event in terms of injury/health of people, properties damage, damage or adverse on environment or may be combination of these.

### 3.2.13.1 Purpose of HIRA

- Identification of the purposes which cause harm to employee
- Possibility of that cause of harm to the employee and its severity.
- An organization should able to plan, introduce necessary preventive measures controlling risk.

### 3.2.13.2 Planning for HIRA

a. It can be planned for a situation

- Where there is a significant hazard available
- Where control measures not adequate
- In which corrective and preventive measures are need to be implemented

b. An organization which is intended to improve safety management system

### 3.2.13.3 Process of HIRA

HIRA has certain steps to do at work site and they are as follows

- Identification of activity or sub activity hazards
- Assessing the risk related to each hazard (tolerable or non-tolerable)
- Control measure for risk categorized under non tolerable and its monitoring
- Verify adequate health and safety objective and action plan to reduce risk identified and follow up monitoring reduction of risk.
- Training needs identification for the adequate risk control measures and adequate control measures should be a part of operational control

Figure 2: Steps involve in HIRA
3.2.13.4 Assessment of probability and severity

Table 4: Probability Rating (PR)

<table>
<thead>
<tr>
<th>High (H)</th>
<th>When it occurs frequently or Chances approx. more than 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium (M)</td>
<td>When it occurs occasionally or Chances between 10% to 50%</td>
</tr>
<tr>
<td>Low (L)</td>
<td>When it has never occurred before or chances less than approximately 10%</td>
</tr>
</tbody>
</table>

Table 5: Severity Rating (SR)

<table>
<thead>
<tr>
<th>High = H</th>
<th>When it can lead to fatality or permanent disability Or when Property Loss is more than Rs 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium = M</td>
<td>When it can lead to temporary disability or doctor visit is required Or when Property Loss is more than Rs 10,000 but less than Rs 100,000</td>
</tr>
<tr>
<td>Low = L</td>
<td>When it can lead to First aid Injury Or when Property Loss is less than Rs 10,000</td>
</tr>
</tbody>
</table>

3.2.13.5 Risk Matrix:

Table 6: Risk analysis matrix

<table>
<thead>
<tr>
<th>Probability</th>
<th>H</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>H</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Severity

Table 7: Risk level

<table>
<thead>
<tr>
<th>Risk Level (RL)</th>
<th>Trivial</th>
<th>Tolerable</th>
<th>Moderate</th>
<th>Substantial</th>
<th>Intolerable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>