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# An overview of Risk Management and Assessment Methods in Industrial Units

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## Abstract

There are several methods of risk assessment in the world, which are usually used to identify, control and reduce the consequences of risks. According to several cases such as the purpose and level of use and the type of available information, risk assessors usually use one of the most appropriate risk assessment methods. In this research, the theory of risk assessment and management methods is presented first. Then, based on the mathematical model and the introduction of the bowtie risk management method, and by reviewing the previous works, their performance has been checked. Finally, the performance of the HAZOP method for risk management of an industrial example is presented.

**Keywords**: Risk management, Industry Unit, Safety, HAZOP

## 1. Introduction

Today, risk management is widely used to ensure the safety of systems and reduce unwanted incidents. In risk management, after performing risk assessment and prioritizing them, planning is done to eliminate risks or reduce the intensity of their effect and the probability of their occurrence (Leo et al., 2019; de Araújo Lima, 2020; Manab and Aziz, 2019; Corallo et al., 2020; Valinejad and Rahmani, 2018). In process industries, in the design phase, it is tried to prevent risks based on their identification in the design phase, or to eliminate the source of the risk from the very beginning, or to control its corresponding effect by applying a control measure. In Chevreau et al., (2006) have dealt with the

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environmental risk management of the oil product pipeline using the bow tie method. This study was carried out with the aim of evaluating and managing the environmental risk of oil products pipeline with an approximate length of 273 kilometers. For this purpose, the environmental risk has been evaluated with the method of indexing system. In this regard, hazard identification and risk assessment have been done by analyzing two indicators of total hazards and effects and determining the risk score based on the relative risk model of the indexing method. Then, using Arc GIS 9.3 software, the risk score was zoned in three risk levels: high (0.08-0.26), medium (0.26-0.44) and low (0.62-0.44) along the pipeline route and in order to manage risk. The environment has been used by the Bow-Tie method. The results of this study indicate that 7% of the pipeline route has high risk potential (risk score range 0.08 to 0.26). The most effective risk factors were the design features (soil movement potential) and the destruction potential of third factors. In order to reduce and control the identified risks, management solutions in the form of a bow tie model have been presented. Among the suggested preventive and control measures are the creation of a warning system, appropriate response to calls, use of holding equipment, quick interruption of the flow inside the pipe, emptying of the products inside the pipe, quick notification and recovery and Restoration of damaged areas mentioned.

In Lu et al., (2015) have investigated the organization of learning processes about risks using the bowtie (BT) method. showed that the BT method is useful in every stage of risk management. The case study was about a company that has a long history of using failure trees. They have shown the success of using the BT method in that company. The obtained results can help in the implementation of the Aramis method in industrial plants, because it allows manufacturers to know what they want about risk. In Ferdous et al., (2013) have obtained a comprehensive risk calculation method for natural gas pipes by combining the risk matrix with the bow-tie model. The study case is gas pipes that pass under water. In this work, it has been shown that a comprehensive risk assessment method has been achieved by combining the BT method and the risk matrix. This method can be fruitful for the management of pipelines in identifying the risk factor and evaluating its results and prevent many possible accidents. In Xiaole and Sam Mannan (2010) have obtained an innovative method of analyzing the safety system and the risks caused by uncertainty using the BOW-TIE diagram. Their research attempts to consider operator expertise to overcome missing data and to combine fuzzy set and evidence theory to assess uncertainties. Uncertainty in input data and model adequacy for BT analysis is still a major concern and may mislead the decision-making process. To deal with uncertainty and reduce risk, theory-based and FUZZY-BASED methods have been developed along with sensitivity analysis technique for BOW-TIE analysis, which is a new method for dynamic risk assessment.

In Roozitalab (2021) have developed and applied dynamic risk assessment in oil, gas and chemical industries. In this work, a comprehensive method is introduced based on the framework of mathematical models, as well as decision-making based on cost-benefit analysis. They have integrated stochastic modeling and dynamic modeling for risk assessment. A case study is on an offshore site in a surface control unit for oil/gas separation. The results on the case study provide significant insight for further inspection interval optimization. The preset control valve is known as the most important component of the scenario. In Mehrzad Ebrahemzadih et al, (2014) have assessed and managed risk using the FMEA method in Steel Industries. He compared the FMEA method with other evaluation methods and showed that the FMEA method identifies more risks than other techniques and gives better results as an output. Therefore, for risk analysis in steel industry, FMEA method has been introduced as the best method for risk analysis. In Ivanov and Dolgui (2021) have investigated the FMEA method in industrial radiography risk analysis. In order to avoid the irreparable effects of industrial radiographic rays, the risk assessment of this risk must be done. The evaluation shows that increasing failure detection capability is a practical and feasible approach to reduce risk in most failure modes of industrial radiography devices. They have suggested the necessary measures to reduce RPN in the FMEA method Fell and Hartford (2018), as the effective way in quantitative risk analysis.

## 2 Method

### *2.1 Bow Tie Method*

The bow tie method is one of the useful methods in the field of quality risk management, whose initial idea was presented at the University of Queensland, Australia, by Hazen in 1979, and without a doubt, the multinational company Royal Dutch Shell is the first company to fully implement this method (Lezzi et al., 2018; Analouei et al, 2020; Trindade et al., 2020). All its structures have been established and after that this method has been widely developed all over the world, according to the records and experiences presented, it shows that this method can be used in the management of all risks and for all risks. The bow tie method creates a more realistic understanding of the relationship between the factors that are effective in the occurrence of risks, the resulting consequences and the obstacles that can prevent the occurrence of an accident at each stage. The figure below shows the general schematic of the bow tie method.


**Figure 1:** Schematic of the bow tie method

In this method, the necessary documentation is done by creating a bow tie diagram for a specific process. Based on this, the ultimate goal is to control safety, health and environmental risks, and as a result, the first step is to identify risks. This process should be done continuously. The second measure is risk assessment and decision regarding the necessary measures to control the risks. The main difference between this method and other methods is from this stage that we have to answer the question that if it happens, one knows and becomes aware of the consequences of the incident and how these consequences can be controlled. Prevent more damages and losses. The interesting point in this method is that at this stage, the question is constantly raised, what we should do to prevent the occurrence of accidents and their consequences (Sivapragasam and Arumugaprabu, 2019; Ding et al., 2020). Another interesting point is that by drawing a bow tie diagram for a specific process, all the people working on the site, especially the people involved in the relevant process, are fully aware of their duties in relation to a specific risk and how the accident occurred and its consequences. They know well the responsibilities and what should do (Omidvar et al., 2022). In this way, in a specific process, the process designer knows how to include the necessary measures related to a risk in the design, and then the people responsible for their duties know how to carry out implementation, repair and maintenance.

When the risks are identified, we can use the bow tie diagram method to better evaluate the risk using a specific framework and even to show the effective control of the risks. Normally, the extended diagrams of this method are used. The advantages of the bowtie method for risk analysis are as follows: It covers all processes; It is simple and applicable; The cost is very low; It is understandable for everyone; Its output is in the form of a diagram and can be installed in office spaces; In addition to HSE risks, it also deals with credit risks of the organization.

### *2.2 Risk management process*

One of the key points for system management is the risk management process, which is summarized in the table 1.

Table 1: Risk management process

| | |
|---|---|
| Are people, people's environment and people's property at risk? | Identification |
| What are the causes and consequences?<br>What is the probability of losing control?<br>What is the risk? | Evaluation |
| Can the causes be eliminated?<br>What things are necessary for control?<br>How effective are the controls? | Control |
| Can the consequences and potential effects be reduced?<br>What restoration measures are required?<br>Is the ability to recover appropriate and sufficient? | Recovery |

The Figure 2 shows the risk management process in a BT diagram.

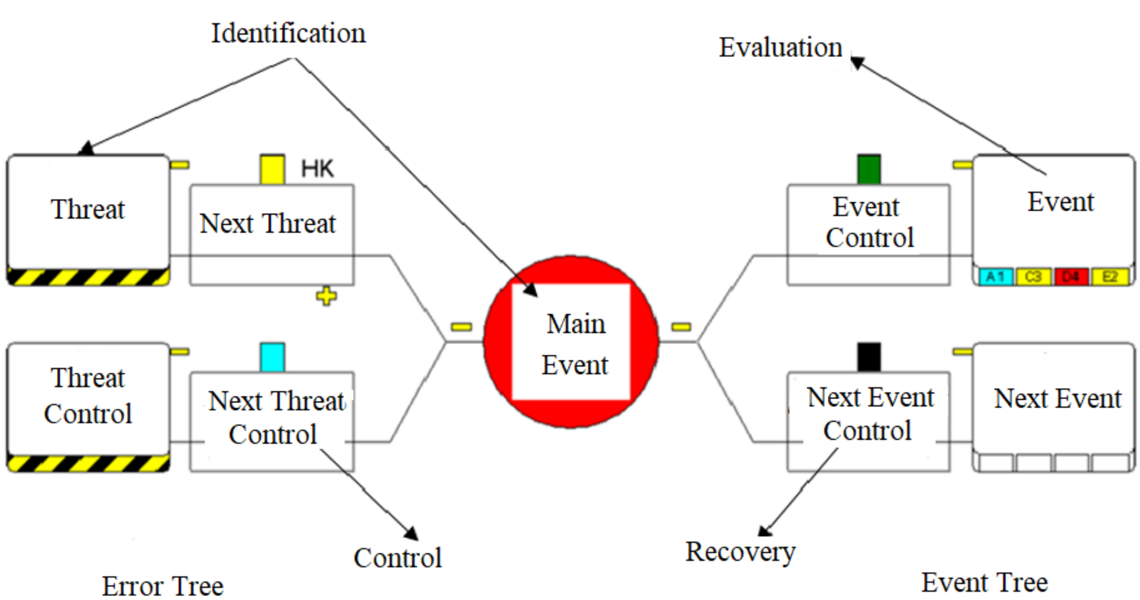


**Figure 2:** Bow-Tie Risk Management Process

### *2.3 Risk matrix*

One of the main methods of risk assessment is through the risk matrix. The software has an adjustable risk matrix that is very useful in risk analysis. The risk matrix in the software consists of parts according to the figure 3, the continuation of each of which is explained separately.

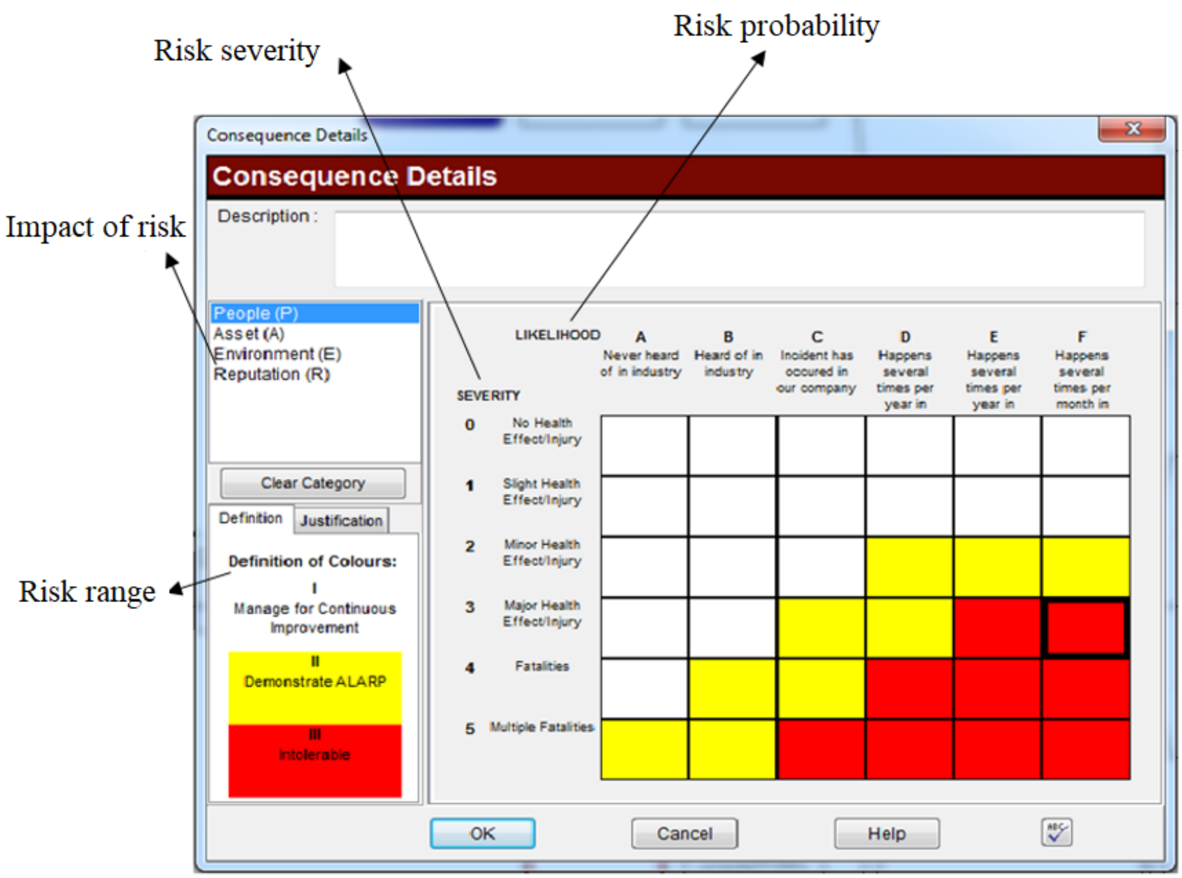


**Figure 3:** The constituent parts of the risk matrix

### *2.3.1 The effect of risk on different parts*

Different parts include the effects of risk on people, asset, environment and credit. People: which include life risks and damage to body parts, such as breathing problems, amputation, etc. Property and assets: Risks that lead to financial loss for the complex, such as damage to the working device, damage to the piping system, etc. Environment: Risks that cause damage to the environment, such as air, water pollution, etc., which cause disruption of the ecosystem in the environment. Credit: often known as credit risk, the risk of losing the company's credit and reputation, in lost revenue; An increase in operating costs, capital or adjustments, or destruction of stock value. Unwanted events that are commonly associated with credit risk include ethics, safety, security, sustainability, quality, and innovation. Credit risk can be a matter of company trust (Fiorentini, 2021; Aliabadi et al., 2022).

### *2.3.2 Risk Range*

The risk range consists of three parts, the white color represents the acceptable range where the effects of the risk can be ignored. The yellow color indicates the medium risk, in this range, the best and most practical thing to do in the current situation should be done. Most accidents are caused by not paying enough attention to the dangers that are in the middle zone. Therefore, it is recommended that the risks in this area should be taken into consideration as well as the above risks. The red color indicates the range of unacceptable risk, in which corrective measures should be prioritized. Finally, the severity of the risk effect and the probability of risk occurrence, which are fully explained in the FMEA method. In this work, dynamic and static risk analysis is performed using fault tree analysis. Also, by using FMEA method, we have carried out a quantitative risk analysis and finally, using BOWTIE PRO software, we have drawn a bowtie diagram of risk analysis and extracted the risk matrix, and discussed their results on the LPG unit of Refinery.

## 3 Results

The bow tie model was proposed to unify and interrelate a broad group of cause-effect models. Traditional models such as event tree and fault tree are tied together, and the vertex event in the fault tree is the primary event of the event tree. Bowtie vision was originally created to strengthen the safety management system. The theory that can be found behind bow tie view is the Swiss cheese model. This approach is often used to identify hazards and develop a documented hazard list, which establishes a link between hazard barriers and operational system and existing procedures that are used to reduce the hazard or reduce the frequency of occurrence or reduce the potential for consequences (Roozitalab and Majidi, 2017). The bow tie model serves as a lens to focus on the causes of an event and examine how they translate into consequences. This method is used to prevent, control and reduce unwanted events by developing a logical relationship to these causes and consequences. The bow tie diagram consists of the following five main components: • Main (Base) Event (BE) • Failure tree (FT) • Top event (TE) • Event Tree (ET) • Outlet event (OE). Main (basic) Event: It is an event that leads to an accident or has the potential to become an accident. Failure Event: Fault or error is a translation of the word Fault, where the word Fault is considered "defect" in the use of hardware and "malfunction" in the use of software. System modeling and analysis with the help of the failure tree was first proposed in 1962 in Bell Laboratory under the supervision of the US Air Force, and today it is one of the most widely used methods in the field of modeling system failure states, evaluating, diagnosing and locating system failure in a wide range of Engineering disciplines have been used. A failure tree is a diagram, a hierarchy that is drawn as an inference from the functional structure of a system, and in which all possible ways for system failure (including causes and adverse factors) are depicted. This model can be evaluated in both quantitative and qualitative ways. In this model, the highest element represents the occurrence of an adverse event (an event that is considered critical and dangerous from the point of view of reliability and safety) in the system and the lowest element represents the basic events (these events are usually the failure of the components of a system at the most basic possible level). Fault tree analysis is one of the most widely used methods in quantitative safety and reliability analysis. A fault tree is a graphical expression of the composition of the main faults that cause the main unpleasant event to occur. With the help of the crash tree, all possible ways for the main event to occur are systematically deduced. This method is based on three assumptions:

1- All events are binary.
2- The events are statically independent from each other.
3- The relationship between events is expressed by logical Boolean gates (such as AND, OR, etc.).

Damage tree analysis is done in two stages. In the first step, a qualitative analysis is carried out and minimum shear sets related to the main event are identified. Then, quantitative calculations are performed based on the probability of failure of each event and the probability of the main event is determined. Static fault tree analysis is analyzed with AND, OR gates (Figure 4).

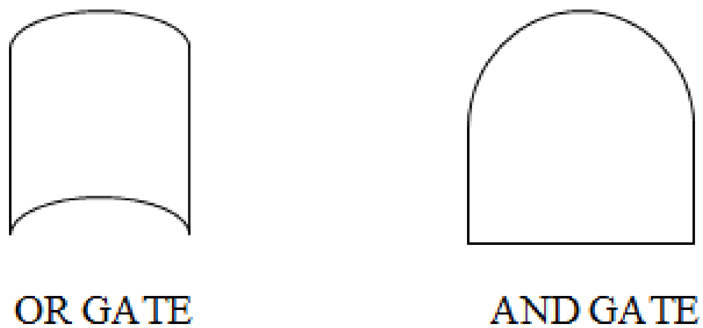


**Figure 4:** Schematic of AND, OR gates

Examining the dynamic behavior of system failure mechanisms such as sequence dependent events, spare parts and dynamic redundancy management and prioritization of failure events is not possible with static gates. To overcome this problem, the concept of dynamic fault tree analysis has been introduced. The gates used in the dynamic fault tree are:
PAND: If all the inputs connected to it fail in order from left to right, the output of the gate, it will be bad.
SEQ: This gate forces all its inputs to decay in the specified order.
SPARE: This gate dynamically models spare and main parts and its output will be defective when the number of spare parts or main parts is less than the desired minimum value.
FDEP: In this gate, there is an input enabler and some other dependent events. Dependent events are functionally dependent on the activator. When the trigger acts, other dependent events will also be forced to occur. These gates are shown in the figure 5.

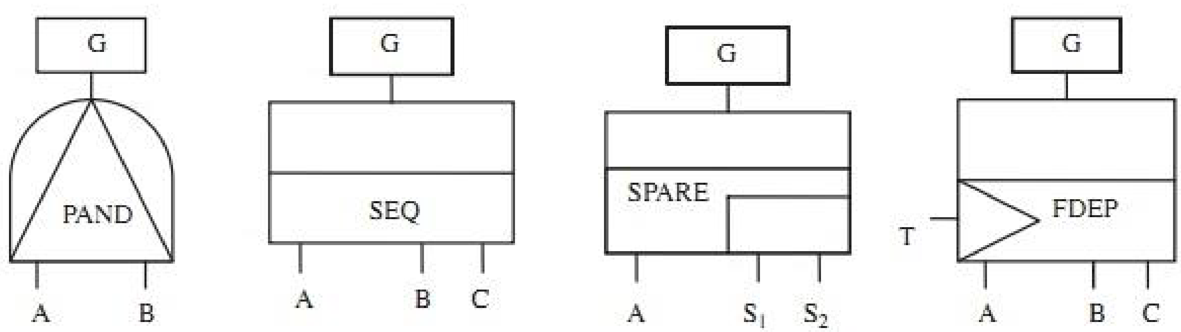


**Figure 5:** Gates used in dynamic fault tree analysis

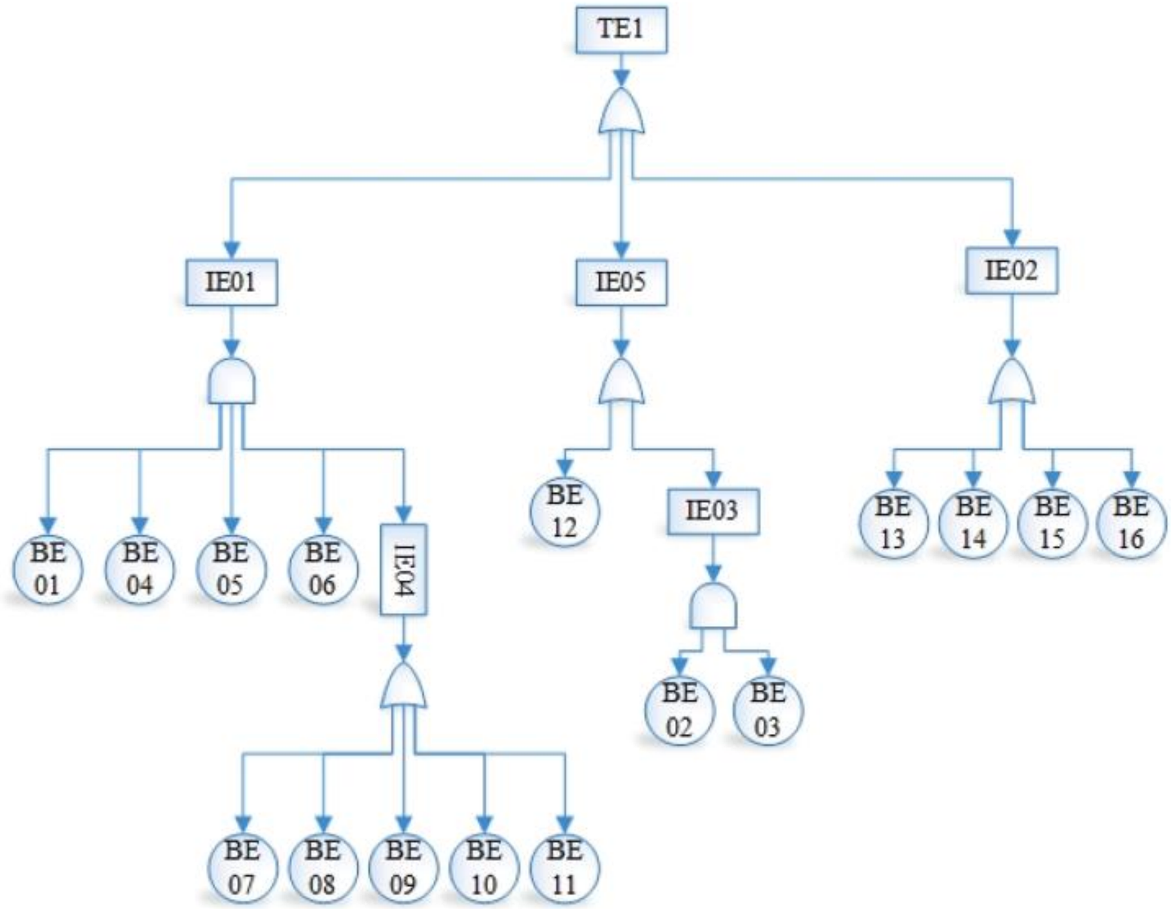


**Figure 6:** An example of a fault tree diagram

Top Event: A top event is an unwanted event or risk release at the end of the failure tree and at the beginning of the event tree. Such as electric shock, explosion, fall, structural defect, etc. Event Tree: Event tree, like fault tree analysis, is a tool in risk assessment that can be used qualitatively or quantitatively. If it is used qualitatively, it is a tool in the service of hazard identification, and if it is quantitative, it will be used in risk assessment. When the successful performance of a system is dependent on the determined performance of the relevant sub-systems, the event tree will be a suitable tool for analyzing these systems. This analysis is generally used for complex systems. Usually, each event tree starts with an initial incident and then this initial incident will lead to subsequent consequences, so for more qualitative analysis, these sequences can be made into an event tree model. The event tree analysis method is used to calculate the probability of various consequences that may occur in the event of an initial event. Unlike the fault tree, where the causes of a general adverse event are analyzed in detail, in the event tree, starting from an initiating event, an attempt is made to predict the sequence of events in order to discover possible safe or harmful situations. An example of an event tree is shown in Figure 7.

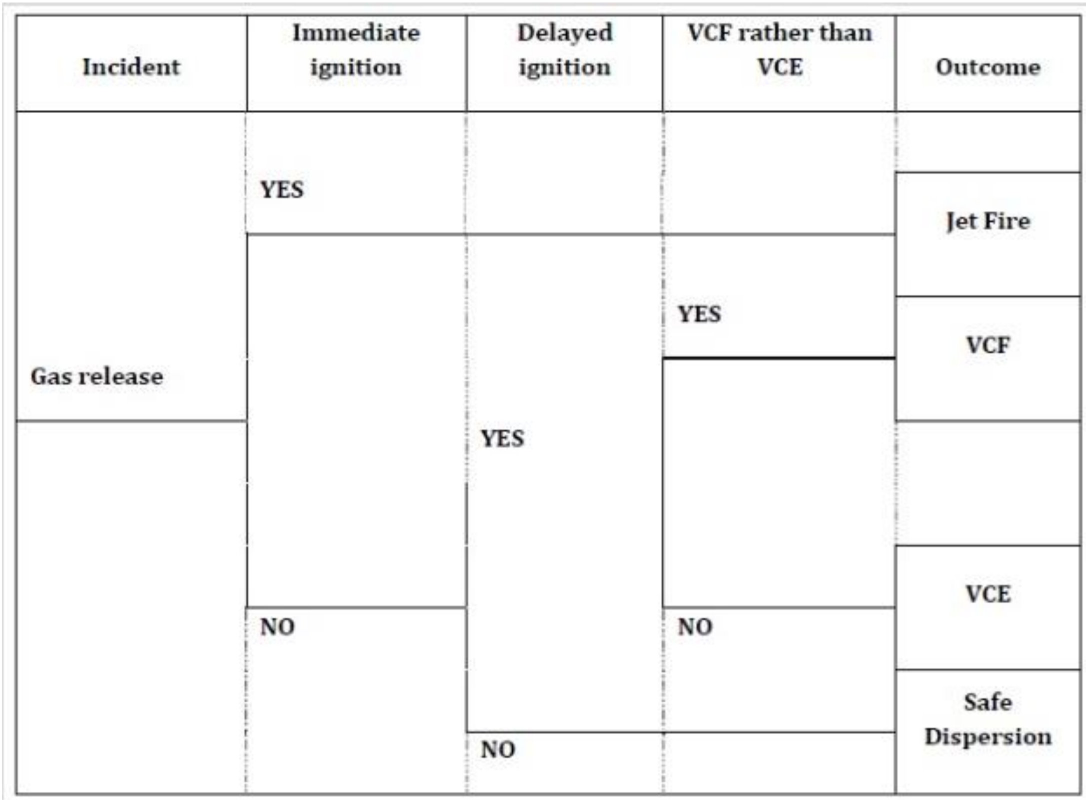


**Figure 7:** An example of an event tree related to gas release [3]

Outlet Event: The outlet event is the consequence of an event or a chain of events that occurs as a result of the release of risk. The consequences can have a range of results that are expressed in the risk matrix. For example, fire and explosion, injury to people, death and financial penalty, etc.

### *3.1 Bowtie diagram*

The fault tree is located on the left side of the diagram and starts with the vertex event and its branches diverge until it reaches the primary or intermediate causes, which are called root events, using logic gates and/or Takes. The right side of the diagram is dedicated to the expansion of the event tree, which starts with the vertex event as the initial event and continues by following the sequence of events to reach possible outcomes. Based on the combination of the event tree and the fault tree, all causes and consequences are linked to a vertex event that is clearly identified in the bow tie diagram.
Whenever a bowtie diagram is made, quantitative analysis can be followed by mathematical assumptions and functions. The bowtie method displays a complete scenario quantitatively and qualitatively. From a qualitative point of view, Bow tie diagram can be drawn both for quantitative risk analysis studies and for qualitative studies, in which there are differences in its drawing. In quantitative drawing, error tree and event tree are used to evaluate the quantitative risk of the incident scenario, a summary of how to implement it is stated above, but qualitative drawing is mostly used to clarify the incident scenario, risk management or incident analysis. It does not use and/or gates, and it can be considered as a simple form of the fault and event tree, which has increased the success of this diagram in understanding by non-experts and their familiarity with the incident scenarios around them. In the table below, we discuss the definition of risk and event method clearly exemplifies the logical

connection between the components of an incident scenario. It also helps to understand which possible combinations of initial events may lead to vertex events and to a particular outcome. Quantitative analysis can be done by determining the probabilities for the initial events of the fault tree and the probabilities of the safety barriers in the event tree. Bow tie diagrams are also used to describe preventive barriers that prevent the occurrence of a vertex event and protective barriers that reduce the severity of the consequences of a vertex event. These barriers can be divided into active and passive barriers. Active barriers are barriers that require an energy source or automatic or manual action to perform their function, and passive barriers are barriers that do not require an energy source to perform their expected function. And finally, we use the bow tie method in dynamic risk assessment for environments where breach data changes frequently. To assess quantitative risk in dynamic environments, we use the bow tie method, in which the probabilities of violation of the primary event obtained from the expansion of physical reliability models and the probabilities of violation of safety barriers periodically obtained by Bayesian argument It is used to calculate the probability of the event and the consequences of the incident scenario. Bow tie diagram can be drawn both for quantitative risk analysis studies and for qualitative studies, in which there are differences in its drawing. In quantitative drawing, error tree and event tree are used to evaluate the quantitative risk of the incident scenario, a summary of how to implement it is stated above, but qualitative drawing is mostly used to clarify the incident scenario, risk management or incident analysis. It does not use and/or gates, and it can be considered as a simple form of the fault and event tree, which has increased the success of this diagram in understanding by non-experts and their familiarity with the incident scenarios around them. In the table 2, we discuss the definition of risk and event

Table 2: Definition of risk and event

| Event | Threat |
|---|---|
| An event is an unwanted event or risk release that is placed at the end of a fault tree at the beginning of the event tree.<br>For example: electric shock, explosion, fall, structural failure | to the potential to cause harm, including illness, injury, damage to property and products or the environment, loss of product line or loss of reputation<br>For example: raised objects, toxic substances, noise |

### 3.1.1 The steps of making a qualitative bow-tie diagram

1. Risk identification (vertical event): a risk in the bow tie diagram consists of two items (risk and event)
2. Evaluation of threats (initial events): threats are placed at the farthest point on the left side of the diagram. A threat is something that can potentially cause the release of identified hazards such as high temperature, fatigue, environmental conditions, high voltage, etc.
3. Consequences evaluation: Consequences are placed at the farthest point on the right side of the bow tie diagram. A consequence is a chain of events that occurs as a result of the release of a risk. The consequences can have a range of results that are expressed in the risk matrix. Examples include fire and explosion, injury to people, death and property damage
4. Controls: Control is a protective measure and is placed in such a way that it prevents threats to release the risk. When the bow tie model is built, controllers are placed between threats and risks. All controls are to prevent threats and to control risk and reduce risk to ALARP level (Tolerable Risk). Examples are safety valves, process stop systems, basic process control systems.

5. Recovery controls (reducing): Recovery controls are placed between risk and consequences, recovery controls are organizational, functional and technical measures that eliminate and limit the chain of consequences that arise from the event. Examples of these controls are barriers containing materials, announcements and alarms, fire extinguishing systems.
6. Identify existing threats to controls: Renewal of controls are conditions that lead to increased risk by overriding or defeating a control. In the bowtie diagram, these threats are displayed outside the main diagram and in relation to the controls. Examples of these threats include unusual operational conditions, maintenance and repair conditions, and equipment testing, human errors, etc.
7. Identification of controls for the threat of controls: Controls for the threat of controls must be available to make sure that the controls do not fail. Examples of this control include procedures, instructions and personnel training.

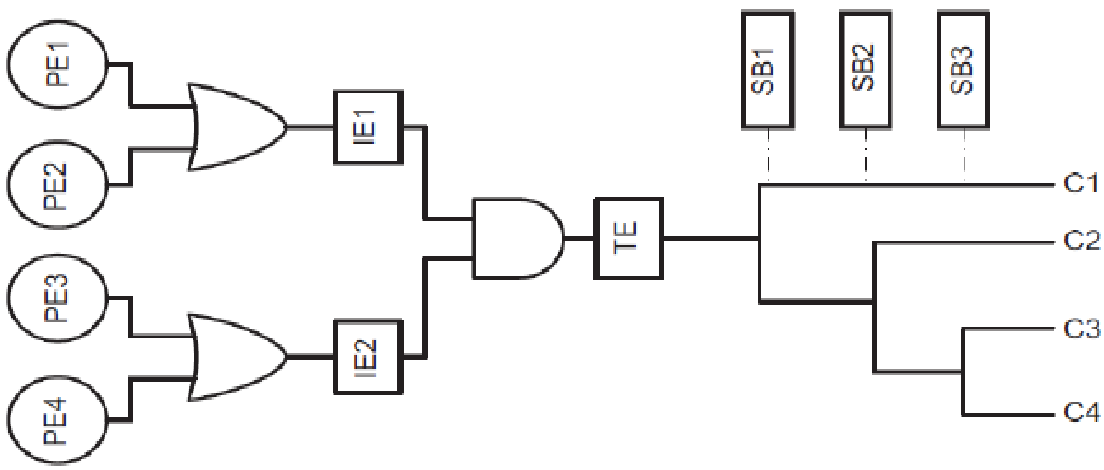


**Figure 8:** An example of a bow-tie diagram [3]

### *3.1.2 Risk Evaluation*

Today, the use of risk assessment methods in various industries is expanding, so that there are currently more than seventy different qualitative and quantitative risk assessment methods in the world. These methods are usually used to identify, control and reduce the consequences of risks. Most of the methods available in risk assessment are suitable methods for risk assessment and their results can be used for management and decision-making regarding the control and reduction of its consequences without worry. Each of the industries can benefit from the mentioned methods depending on their needs.

### *3.2 HAZOP Method*

HAZOP is a systematic method to identify risks that may cause a part of the equipment to malfunction or damage to personnel or the environment. This method is one of the most common process risk analysis techniques. This hazard identification technique begins with brainstorming and seeks to discover the causes and effects of potential hazards in processes. An experienced team can identify possible deviations with the help of this method and provide necessary solutions to prevent their adverse consequences. In general, the following goals are pursued in the HAZOP study:

Identifying the causes of all possible deviations from the desired performance.
Identifying places that have significant risk potential.
Identifying those design features that affect the probability of an event.
Ensuring that a systematic study is carried out on places that have the potential for danger.
Providing a mechanism to provide corrective suggestions in order to reduce the risk of accidents and increase the quality and efficiency of production.
Reducing direct and indirect costs caused by process safety and performance risks.

This method is qualitative and is used to identify very dangerous risks, and it also uses a team of experts in all sciences. This method is suitable for complex systems and examines the system hardware in a comprehensive way and the results are very detailed and accurate.

### *3.3 FTA Method*

In this method, an undesirable or critical situation is considered, then according to the environment and the performance of the system, all the ways that can cause the emergence of that unwanted and undesirable situation are searched. This model is a qualitative model and it can be implemented in a quantitative way.

### *3.4 Failure Mode and Effect analysis (FMEA) Method*

The FMEA method is one of the experienced, very useful and widely used methods for identifying, classifying and analyzing errors and evaluating the hazards and risks caused by them. With the help of this method, errors can be rooted and prevented from occurring. The FMEA has a history of 40 years. The use of FMEA was observed for the first time in the 1960s in the American aerospace industry for the construction of the Apollo 11 spacecraft in the American NASA, and then it was used in the 1970s and 1980s for nuclear institutions. In addition, it was also used for the automotive industry from 1977 onwards. Since 2000, this method is one of the most widely used risk assessment methods in all industries. In this work, this method is used for quantitative risk analysis. This method identifies and eliminates potential errors, problems and mistakes with engineering methods and analyzes the results semi-quantitatively to identify and rank the potential risks, causes and effects related to it. This method is actually an answer to the following questions:

- What kind of equipment can fail?
- How does failure happen?
- How many times will it be repeated?
- What will be the effects of this failure?
- What will be its safety, health and environmental consequences?

As seen in Figure 9, this method requires several steps.

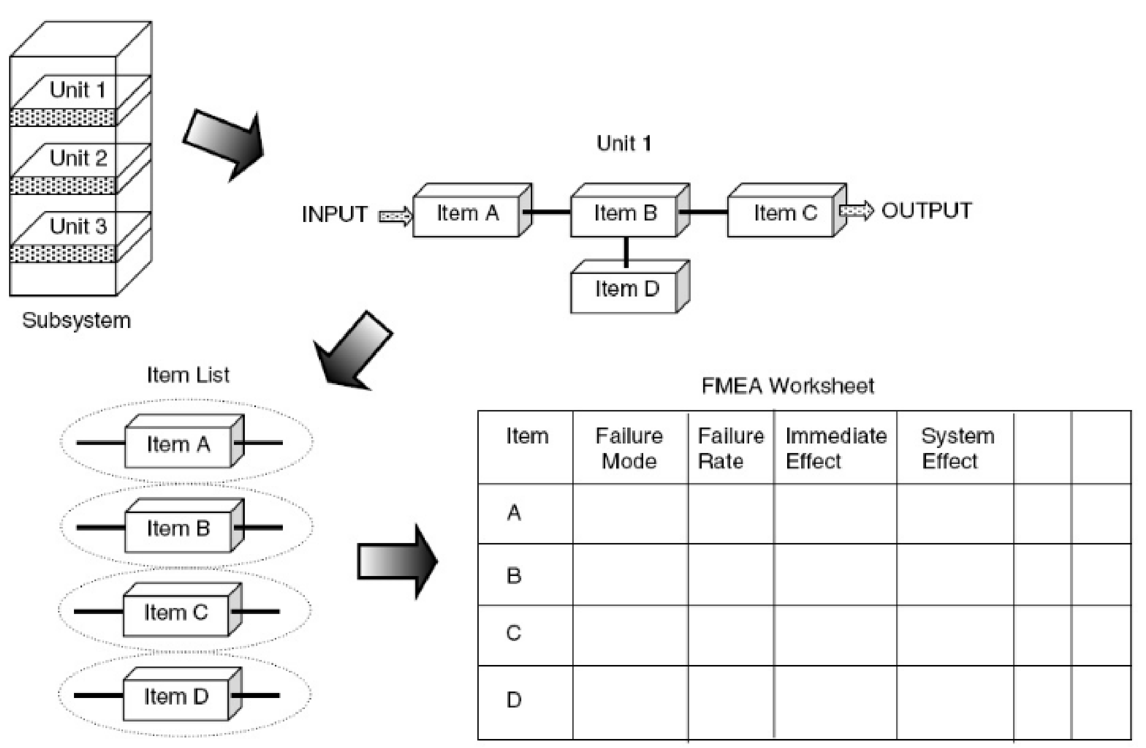


**Figure 9:** The method of checking failures in FMEA

First, accurate information about the process should be obtained, and then all the environmental, equipment, material, human risks and their effect on people, equipment, and the environment, etc., should be included in the FMEA worksheet, in risk assessment with the FMEA method, besides In these cases, the causes of the occurrence of each risk should also be recorded, and for the purpose of better evaluation, a column should be placed in the worksheet to explain the risks resulting from the implementation of control measures. Then, through the tables of this method and the RPN calculation formula, in addition to identifying the risks, it is possible to determine the level of risk. Checking the results of the identified risks is obtained by calculating the RPN number (Sharafat et al., 2021).

$$RPN = SEVERITY \times OCCURRENCE \times DETECTION \quad (1)$$

SEVERITY: The deterioration of the risk actually refers to the same effect that occurs as a result of the occurrence of the risk. (Determining the scale for risk severity indicators is often categorized in the range of 1 to 10). The table 3 shows how to assign numbers for each of the different situations.

OCCURRENCE: it specifies how often a cause or potential risk mechanism occurs. The probability of occurrence is measured on a scale of 1 to 10. Checking past records and documents is very useful. The table 4 shows how to assign a number for probability.

Detection: it probability is an assessment of the ability to identify a cause or mechanism of risk. In other words, detection probability is the ability to find out about the danger before it occurs. The following table 5, shows how to assign the number for the control.

Table 3: The Severity coefficient

| **Description** | **Severity** | **Rank** |
|---|---|---|
| Deplorable deterioration such as the risk of death, complete destruction | Dangerous - no warning | ۱۰ |
| The deterioration is unfortunate but comes with a warning | Dangerous - with warning | ۹ |
| Deterioration is irreparable - inability to perform the main task | very high | ۸ |
| Severe deterioration such as the loss of a body part | high | ۷ |
| such as equipment fire | Average | ۶ |
| Aggravation is low, such as bruises and mild poisoning | low | ۵ |
| Aggravation is very low and most people feel it | Very low | ۴ |
| Like a minor gas leak that leaves minor effects | minor | ۳ |
| Like scratching your hand while turning | very minor | ۲ |
| No effect | Nothing | ۱ |

Table 4: Occurrence

| Rank | Probable risk rates | The probability of a hazard occurring |
|---|---|---|
| ۱۰ | 1 in 2 or more | Very high – the risk is almost unavoidable |
| ۹-۸ | Recurring risks 1 in 8 cases | High |
| ۷-۵ | 1 in eighty risks | Average |
| ۴-۲ | Relatively rare risks of 1 in 15,000 | Low |
| ۱ | Improbable risks | Rare |

Table 5: control parameters

| Rank | Discoverability | Criterion: the probability of discovering the danger |
|---|---|---|
| 10 | Absolutely nothing | There is no control or, if there is, it is unable to detect the potential hazard |
| 9 | Very insignificant | There is a very small chance that the hazard will be detected and detected with existing controls |
| 8 | Insignificant | There is a small chance that the risk will be detected and detected with existing controls |
| 7 | Very low | There is very little chance that the risk will be detected and exposed with existing controls |
| 6 | Low | It is unlikely that the hazard will be detected and detected with existing controls |
| 5 | Average | In half of the cases, it is likely that the potential hazard will be detected and revealed by existing controls |
| 4 | Relatively high | There is a relatively high probability that the potential hazard will be detected and detected by existing controls |
| 3 | High | There is a high probability that the potential risk will be detected and revealed by existing controls |
| 2 | Very high | There is a very high probability |
| 1 | Almost certain | The potential hazard will almost certainly be detected and detected with the controls in place. |

The Figure 10 shows the flowchart of all the steps of the FMEA method.

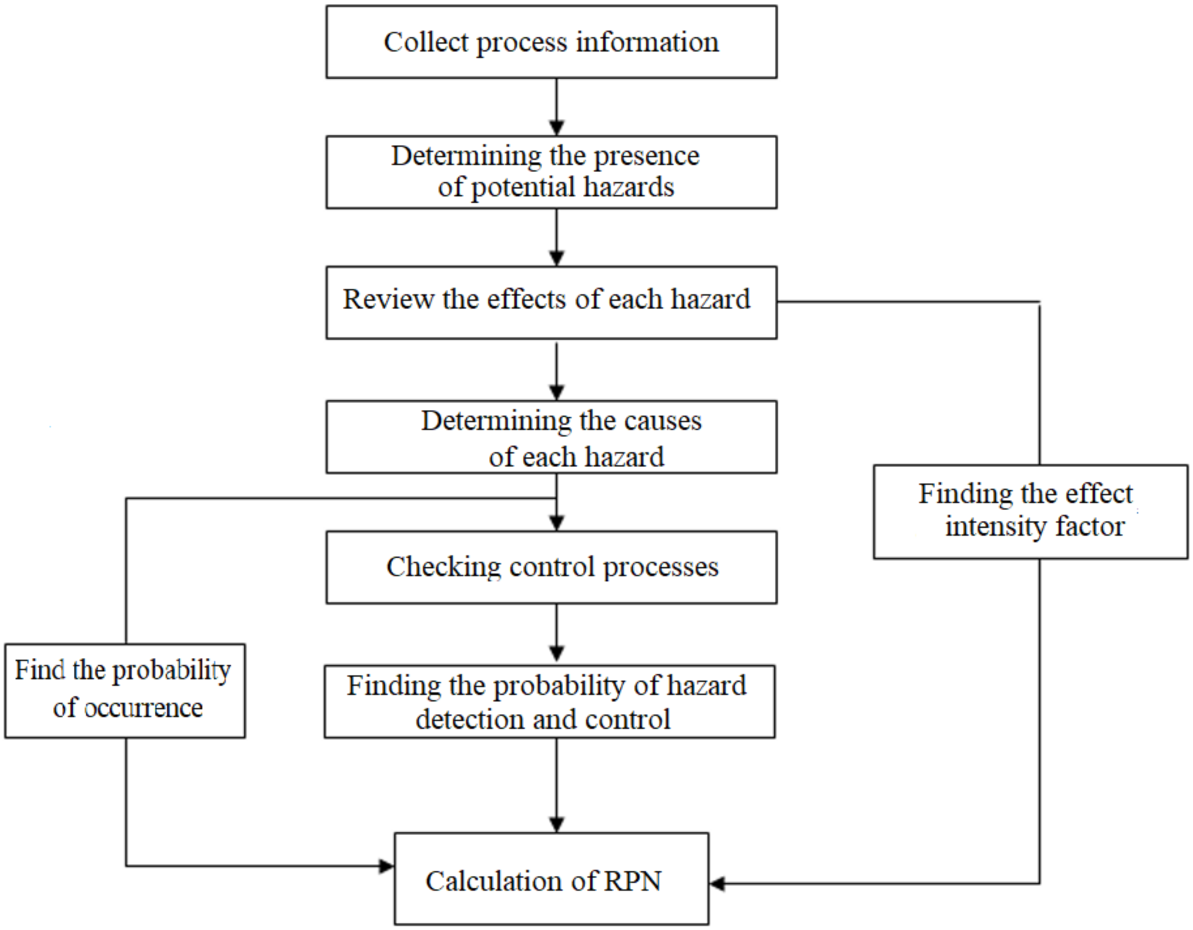


**Figure 10:** The steps of performing the FMEA method

### *3.5 HAZOP Method application*

To compare the bowtie method with the Hazop method, we consider one of the cuts in the absorbent scenario and compare them. Hazop method has already been investigated in the LPG unit of the refinery by TZORC. In the V506 absorber scenario, no-flow or low-flow cutting is considered. The table below shows the risk analysis provided for this node. As can be seen in the figure 11, only the risk matrix has been extracted and the explanations are very brief and specialized, which only people who are HSE experts can benefit from. This diagram is much more tangible and has more details compared to the result of Hazop. Therefore, the bow tie method of qualitative risk analysis is suitable for risk assessment in LPG unit.

Deviation: 6.1. No/Low Flow

| Causes | Consequences | Safeguards | Risk Matrix S | Risk Matrix L | Risk Matrix RR | Recommendations | Responsibility | Status |
|---|---|---|---|---|---|---|---|---|
| 6.1.1. TP-508 A/B Trip | 6.1.1.1. Higher Liquid Level in Absorber Vessel TV-506 Causing Possible Flooding | 6.1.1.1.1. Standby pump | 5 | C | 4 | 66. Provide Interface LT/ LAH on TV-506 | TZORC | |
| | 6.1.1.2. Higher Liquid Level in Absorber Vessel TV-506 Causing Possible Liquid Carry Over Into Gas Inlet Lines and Possible Hammering In Gas Inlet Lines | 6.1.1.2.1. Standby pump | 4 | C | 2 | 67. Provide Check Valve in Gas Inlet Line into TV-506 Close TO Vessel Body | TZORC | |
| 6.1.2. TP-506 Trip | 6.1.2.1. Possible Higher Temperature in TV-506 Liquid Stream and Product Loss | 6.1.2.1.1. FR-531<br>6.1.2.1.2. Standby pump | 5 | C | 4 | | | |
| | 6.1.2.2. Possible Gas Misdirected Flow Into TE-508 Process Outlet Line and Possible Hammering | 6.1.2.2.1. Standby pump | 4 | C | 2 | 71. Provide Check Valve in TE-508 Process Outlet Line into TV-506 Close TO Vessel Body | TZORC | |
| 6.1.3. TP-507 Trip | 6.1.3.1. SAME AS ABOVE | 6.1.3.1.1. FR-532 | 5 | C | 4 | 72. Provide Check Valve in TE-509 Process Outlet Line into TV-506 Close TO Vessel Body | TZORC | |

**Figure 11:** HAZOP output in risk analysis

### *3.5.1 Comparison of LPG unit components*

Equation 2 is the calculation of the overall probability of each component of the LPG unit [23].

$$\begin{aligned}
RPN_{TE01} &= RPN_{IE01} + RPN_{IE02} + RPN_{IE03} + RPN_{IE04} + RPN_{IE05} + RON_{IE06} + RPN_{IE07} \\
RPN_{TE02} &= RPN_{IE01} + RPN_{IE02} + RPN_{IE03} + RPN_{IE04} + RPN_{IE05} \\
RPN_{TE03} &= RPN_{IE01} + RPN_{IE02} + RPN_{IE03} + RPN_{IE04} + RPN_{IE05} + RON_{IE06} + RPN_{IE07} \\
RPN_{TE04} &= RPN_{IE01} + RPN_{IE02} + RPN_{IE03} + RPN_{IE04} + RPN_{IE05} + RON_{IE06} + RPN_{IE07} \\
RPN_{TE05} &= RPN_{IE01} + RPN_{IE02} + RPN_{IE03} + RPN_{IE04} + RPN_{IE05} + RON_{IE06} + RPN_{IE07}
\end{aligned} \tag{2}$$

The Table 6 shows the comparison of the probability of each unit according to the probability of occurrence. As can be seen from the table, the caustic washing system of the LPG unit has a higher RPN number than the other components of the LPG unit, so in the risk management of the LPG unit, this system should be given first priority and the rest of the unit components should be prioritized in order of probability number. And this is a very valuable result for risk assessment and reducing the probability of occurrence. Figure 12 shows the behavior of all scenarios in different slices.

Table 6: Overall probability for each component of the LPG unit

| Unit Name | TOTAL RPN |
|---|---|
| Gas compressor system | 1776 |
| LPG unit feed compressor | 710 |
| Stabilizer system | 1417 |
| Absorbent V506 | 624 |
| LPG unit caustic washing system | 2544 |

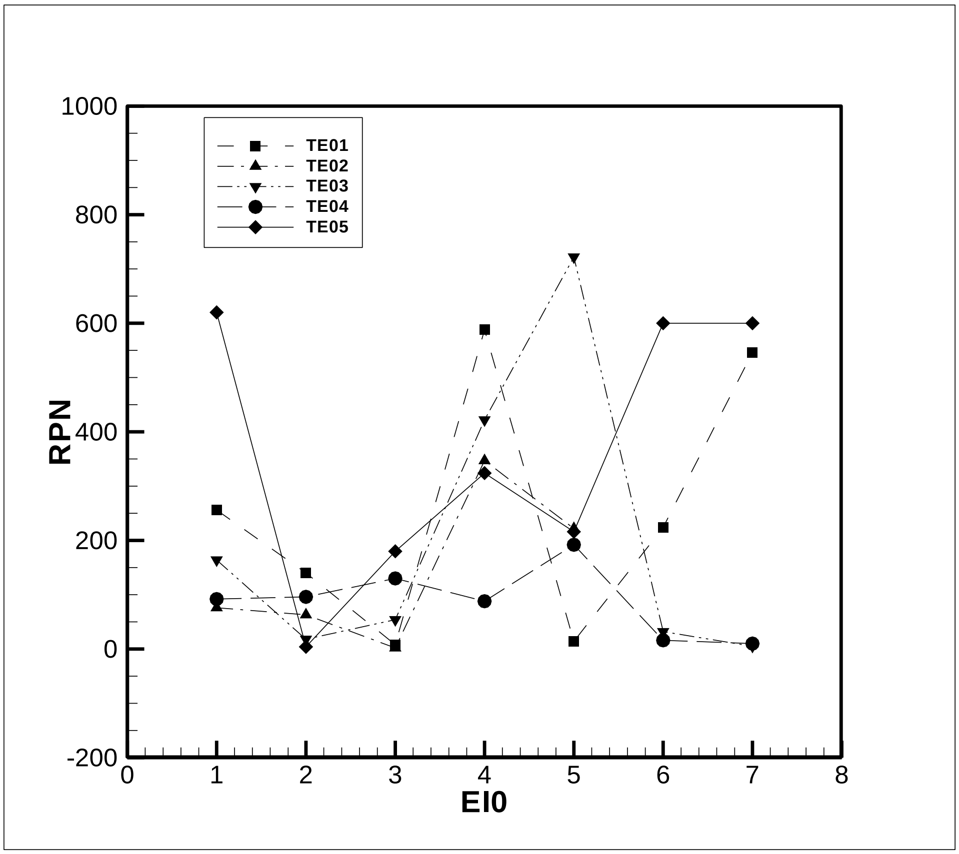


**Figure 12:** value of RPN according to different cuts for all components.

In the Figure 12, it is possible to check the components according to cuts, for example, according to the above figure, in the cut EI01, RPN TE05 has the highest value, so in this review, this cut except number 5 in the LPG unit is prioritized.

## 4. Conclusion

The results of this research are of great help to risk management in the unit and possible life and financial risks can be prevented. The purpose of quantitative risk assessment by HAZOP method. Calculating the value of the starting causes and the probability of the resulting consequences, as well as determining the starting and continuing scenarios until the resulting consequences. In the HAZOP diagram, the path of the accident was traced from the phase of the causes of the accident to the consequences of the accident. In this process, the importance of events and minimum cuts and different scenarios were determined, which can be used in the allocation of resources and facilities to reduce the occurrence of accidents and their consequences. Suggested works in line with the present work: (1) this method can be extended to all oil and gas industry units and (2) using the created error tree, the probability of each cut was also extracted

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