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Risk assessment and its management for environmental pollution in oil refinery using FMEA approach

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ABSTRACT
The main goal of petrochemical industries is to produce petrochemical and chemical products as well as by-products of oil and oil derivatives along with natural gas, which have the potential to cause adverse effects on the environment due to the activities and processes. This study was conducted with the aim of investigating the environmental, safety and health risks in the gas condensate storage tanks in an oil refining company. In order to prevent accidents in process industries and considering the increasing development in all aspects of these industries, it is necessary to identify the risks in the processes and evaluate their risk management. In this study, in order to assess quantitative risk, the FMEA method was developed to provide an approach with high user power, followed by management of risks that can be understood by all personnel, so that, its results can be used to analyze incidents. The results showed that the bowtie method provides a complete, and understandable graphic structure of the incident scenarios along with all the components of the incident and a good connection with the components of a management system. Research implications were to facilitate the implementation of the bowtie method, hence, the active bowtie software was introduced and some of its features were examined. It was also a case study on the LPG unit of the refinery. The results showed the existence of a purposeful and at the same time, adaptable management. In addition, the most important petrochemical risks included air pollution, reduction of water quality and jeopardizing the public health of the region. Therefore, in order to reduce or eliminate the risks and factors that cause environmental risks, it is suggested that the inspection and monitoring periods, according to the identified risks, should be among the most important goals of the management plans.

Keywords: Environmental risk assessment, Bowtie diagram, Fault tree, Event tree, FMEA.
Article type: Research Article.

INTRODUCTION
Nowadays, the products of oil industry are so intertwined with the daily life of people that in practice, life without using them is unimaginable. Anyway, in this industry, potential environmental hazards caused by oil activities threaten neighborhoods and habitats nearby or close to them. Therefore, it is necessary to use evaluation methods in order to reduce the risks and adverse consequences caused by them. The results of these evaluations can be used for management and decision-making regarding the control and reduction of risks and their consequences without worry. The environment around dangerous facilities, planning for emergency situations, acceptable risk level, inspection and maintenance policies in industrial facilities and other cases are provided (Bhatia *et al.* 2019; Taleb-Berrouane & Pasman 2022; Mobaseri *et al.* 2022; Wari *et al.* 2023). The liquefied gas production unit is

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one of the most important process production units of refinery, whose duty is to purify gases sent from other units, and finally, after their purification, products such as ethane (which is mainly sent to petrochemicals) and a part of it to the consumed fuel side of the refinery is guided, propane and butane are the other two products of this unit, which by combining propane and butane with different percentages in the seasons of the year forms a product called LPG. In the LPG production unit, a large amount of flammable gases are produced and kept under pressure. The release of the contents of these tanks can lead to consequences such as the explosion of boiling liquid vapor and fiery explosions and the dispersion of toxic materials (Wang *et al.* 2022). Many works (Landucci *et al.* 2016; Mkrtchyan *et al.* 2022) have been done in the field of risk assessment, which are mentioned below in the field of research. Landucci *et al.* (2016) have conducted a risk assessment of industrial sites using the process of hierarchical analysis with the help of geographic information system. In their study, an attempt has been made to rank the risks by identifying the major risks in a number of uses in the region and using the semi-quantitative risk calculation method as well as determining appropriate intervals. Then, the overall risk, which is the result of the accumulation of all risks in each user, is determined by giving the relative weight of each risk in the risk number, followed by simulating it by the GIS software. In their study, they have shown the role of BT update in dynamic risk analysis. They have also used reliable physical models to investigate the impact of real-time changes in physical parameters on the probability of occurrence. They have shown that these physical models provide a deeper insight into the risk behavior of the process by incorporating physical parameters into the failure of distribution functions. This article does not have a case study and its results can be used for dynamic risk analysis. Liu *et al.* (2023) presented the risk analysis of the gas sweetening unit using the LOPA and Bow tie methods have been carried out in a case study of gas refineries in South Pars, the Persian Gulf. They investigated the LOPA method in bow-tie for different scenarios in the gas sweetening unit and analyzed the results. Finally, they have come to the conclusion that most of the errors that lead to accidents are of human origin, while the system and equipment errors account for a small percentage. The role of HSE training and culture building is very prominent and a huge void is felt in this field. Sethi & Chutima (2022) using dynamic risk investigated the Texas refinery incidents and showed that the employment of dynamic risk is a powerful learning tool with predictive capabilities. This tool is highly dependent on the accident and the information is close to destruction. The degree of accuracy of this method strongly depends on the accuracy of the input data. By examining previous incidents using dynamic risk in a case study, it was found that most of the incidents were predictable and could be prevented. Ayden *et al.* (2022) used the Bow tie method in the safety management system. It has been shown that the Bow tie method is an ideal method for structured assessment and interface of risks. It clearly shows the relationship between control measures and procurement of the management system, and finally, can be used for quality assessment and control of all types of risk.

MATERIALS AND METHODS

The working method is that we have selected five main components of the LPG units and implemented various scenarios corresponding to these units. After the preliminary investigations carried out in the studied units, a pattern has been drawn in the form of Fig. 1 to carry out the research steps. Investigation of the studied unit and collection of basic information: necessary data and information were collected through direct observations, interviews with experts, review of documents and operational maps, etc. In the present work, the number of five components of LPG unit has been selected according to Table 1 and static and dynamic risk discussion has been done on them. It is necessary to explain that each of these components are related to each other.

Table 1. The examined components of the LPG unit.

1	**Gas compressor system- TC-501A/B CDU O/H Gas Compressor System**
2	Liquid gas unit feeding compressor- TC-502A/B LPG Feed Gas Comp. System
3	Stabilizer tower TV-504 Straight Run Stabilizer Tower
4	Absorption tower V-506 Absorber V-506
5	Caustic washing system unit LPG(LPG Caustic Wash System)

Before reviewing the risk analysis of all components, we will first familiarize ourselves with the equipment available in these units, which are presented in the form of Table 2.

Description of the investigated components of the liquid gas (LPG) purification unit

The gases above the crude oil distillation unit (CDU) enter the TV-501 container after separating the liquid in it and enter the TC-501 compressor, where the gas operating pressure is from 1.9 kg cm^{-2} to 8.8 kg cm^{-2}, and after cooling the gas in the TE-501 heat exchanger, it enters the TV-502 container to separate the remaining liquids from the gas. After separation, the resulting gas enters the TC-502 compressor and the pressure of output from the compressor increases up to 14.4 kg cm^{-2}. After leaving the compressor, the resulting gases enter the high pressure vessel of TV-503.

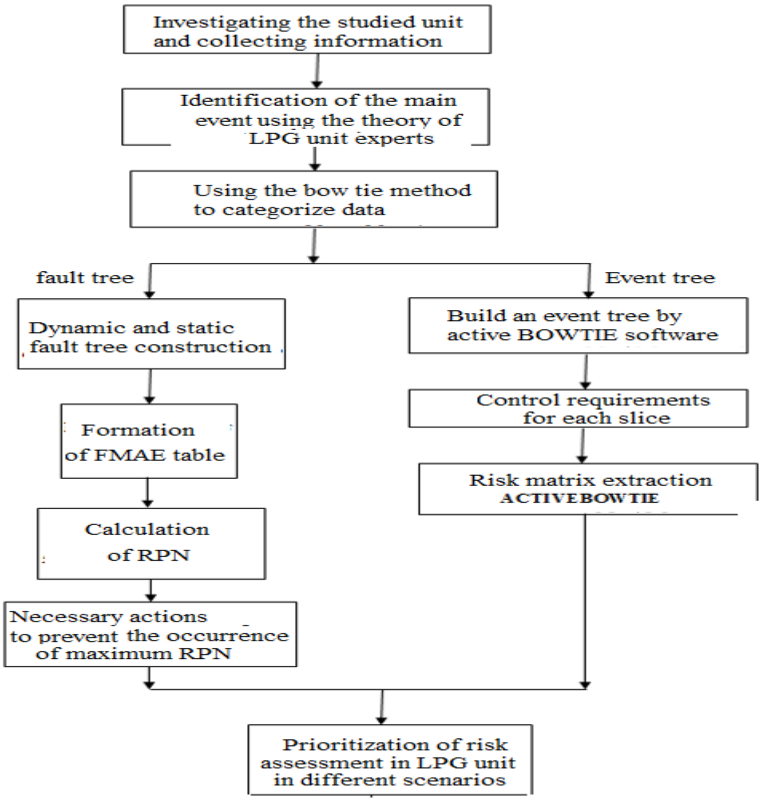

Fig. 1. Graphical representation of the stages of research.

The liquefied hydrocarbons at the bottom of the container are directed to the TV-504 stabilization tower by the TP-502 pump. The feed temperature of this tower is increased by TE-502 converter before entering. The working pressure of this tower is about 18 kg cm^{-2}. Its main purpose is to separate the LSRN present in the feed. On the other hand, light hydrocarbons such as ethane, propane, and butane are separated from the top. Along with these light hydrocarbons, there are H_2S compounds, which are directed to the caustic washing part before continuing the route. The caustic washing section consists of two containers including TV-508 with caustic about 18% and TV-509 filled with water. So that, light hydrocarbons first enter the caustic container to remove H_2S compounds, and then to prevent the transfer of possible caustic particles. In the flow, it passes to other parts of the water container and then it is directed towards the separation towers of ethane, propane and butane. Due to the possibility of propane in the very light hydrocarbon streams separated from different parts of this unit (fixing tower, de-ethanizing tower and de-propanizing tower), it is directed to the absorption tower for washing. In this tower, the gas flow enters from the bottom of the tower and a part of the LSRG product enters from the top of the tower, then they come into contact with each other. Finally, the liquid flow is directed to the first part, and the gas flow, which will mainly contain ethane, is directed to the refinery fuel or as feed to the olefin unit in petrochemicals.

Description of the investigated components of the liquid gas (LPG) purification unit (Calvo *et al.* 2020). In this analysis method, the risk matrix is used to categorize different scenarios. The basis of the work is to determine how many safety barriers are available to prevent, control or mitigate identified scenarios and the quality of these barriers. There are four key objectives for using the Bow tie when managing major risks:

1. Providing general information about the framework of the important parts of the risk.

2. Showing the interdependence between different stages in the overall framework.
3. Exhibiting how to use the process in each analysis.
4. Ensuring the common understanding of all members to do team work when an accident occurs.

Table 2. Naming of equipment available in LPG units

CDU	Crude Distillation Unit
FAL	Flow Alarm Low
FI	Flow Indicator
FRC	Flow Recorder Control
FT	Flow Transmitter
LAH	Level Alarm High
LAL	Level Alarm Low
LALL	Level Alarm Low
LGT	Level Glass Transmitter
LIAH	Level Indicator Alarm High
LICAH	Level Indicator Control Alarm High
LPG UNIT	Liquefied Petroleum Gas Unit
LRC	Level Recorder Control
LRCAH	Level Recorder Control Alarm High
LRCAL	Level Recorder Control Alarm Low
LSH	Level Switch High
LSL	Level Switch Low
LSLL	Level Switch Low
PAH	Pressure Alarm High
PAL	Pressure Alarm Low
PI	Pressure Indicator
PRC	Pressure Recorder Control
PRCV	Pressure Recorder Control Valve
PT	Pressure Transmitter
SV	Safety Valve
TAH	Temperature Alarm High
TE	Total Exchanger
TH	Total Heater
TI	Temperature Indicator
TP	Total Pump
TRC	Temperature Recorder Control
TC	Total Compressor
TT	Tank
TT	Temperature Transmitter
TV	Vessel

RESULTS

In the present work, the static and dynamic risk analysis of LPG refinery unit was investigated. The LPG unit is one of the important and strategic units of the refinery and the discussion on risk analysis is one of the necessities.

Gas compressor system

The risk analysis of the gas compressor system of the LPG unit using the FMEA method is shown in Table 3. The method of collecting this data was obtained using experienced experts of the LPG unit.
Fig. 2 exhibits the fault tree diagram for the gas compressor.

All RPN of IE cuts are calculated by equation 1 (Fu *et al.* 2022; Ivančan & Lisjak 2021).

$$\begin{aligned}
RPN_{IE01} &= RPN_{BE01} + RPN_{BE02} \\
RPN_{IE02} &= RPN_{BE03} \\
RPN_{IE03} &= RPN_{BE04} \\
RPN_{IE04} &= RPN_{BE05} + RPN_{BE06} + RPN_{BE07} + RPN_{BE08} \\
RPN_{IE05} &= RPN_{BE09} + RPN_{BE10} + RPN_{BE11} \\
RPN_{IE06} &= RPN_{BE12} \\
RPN_{IE07} &= RPN_{BE13} + RPN_{BE14}
\end{aligned} \quad \textbf{(1)}$$

In Fig. 3, IE05 is a dynamic risk as it is written by PAND gate and its explanation is that when the cooling system fails, the cooling system pump fails and due to the round-the-clock operation of the pump, there is a possibility that the pump's bearings and rotation system are faulty. So the pump's fault causes the cooling system to malfunction and subsequently causes the temperature of the gas compressor to increase. However, the opposite of this procedure means that the failure of the cooling system results in the failure of the pump. It is not true and is not considered a defect for the pump. Fig. 3 shows the probability tree diagram of each situation using the FMEA method.

Table 3. Risk analysis for gas compressor system

Parts	Failure cases	Causes of failure	Probability of occurrence	Effects	Effect intensity factor	Control	RPN
CDU O/H Gas Compressor System **TE01**	1. Low current or no current (IE01)	1. Stop flow from CDU unit (BE01)	**6**	Lack of current in TC-501A/B which causes compressor damage. (C01)	**8**	**5**	**240**
		2. Fault of TC-501 A/B(BE02)	**4**	A small flow reaches the suction drum of the LPG gas feed compressor	**2**	**2**	**16**
	2. More current (IE02)	1. Additional current from the CDU unit (BE03)	**4**	Possible high pressure in TV-501 A/B	**7**	**5**	**140**
	3. Reverse or opposite flow	1. Return flow from 3/4-05-P141-F1101V to TC-501 A/B chamber (BE04)	**4**	It will damage the T-C 501 A/B compressor	**1**	**2**	**8**
	(IE04)high pressure .4	1. Excess current from CDU unit to TV-501 (BE05)	**4**	More current enters the TV-501 and results in high pressure in the tank	**7**	**5**	**140**
		2. Fault of TC-501 A/B. (BE06)	**4**	More current enters the TV-501 and results in high pressure in the tank	**6**	**7**	**168**
		3. Due to negligence of the operator, VD04 is closed (BE07)	**4**	The possibility of increased pressure	**7**	**5**	**140**
		4. It starts working by blocking the TC-501 A/B output (BE08)	**4**	Critical damage TC-501 A/B	**7**	**5**	**140**
	5. High temperature **(IE05)**	1. Failure of the water supply pump for the cooling system Reason: Unauthorized vibrations and high current ampere and pump failure (BE09)	**7**	High temperature in gas feed to TV-502 leads to reduced efficiency of TC-502 A/B.	**1**	**2**	**14**
		2. fault detection in the bearings and as a result the temperature of the bearing chamber increases and the pump fails (BE10)					
		TE-501 (BE11) cooling system failure					
	6. Lack of surface **(IE06)**	1. The output valve of TV-515 to TV-103 has been opened due to the negligence of the operator.	**7**	The possibility of feeding the passing gas through the TV-102 leads to a process error.	**4**	**8**	**224**
	7. High level **(IE07)**	1. Carrying high current to TV-501 A/B through CDU gas feed flow line (BE13)	**7**	By causing serious damage to the TC 501 A/B compressor.	**7**	**6**	**294**
		2. The lower valve of TV-515 is not opened due to the negligence of the operator. (BE14)	**7**	It creates abnormal process conditions	**6**	**6**	**252**

As shown in Fig. 3, the IE04 cut has a high probability compared to other cuts, so necessary measures should be taken to prevent the possibility of high pressure. Also, for the rest of the cuts, prioritization should be done based on the probability of occurrence. The necessary measures to prevent IE04 from being cut are as shown in Table 4.

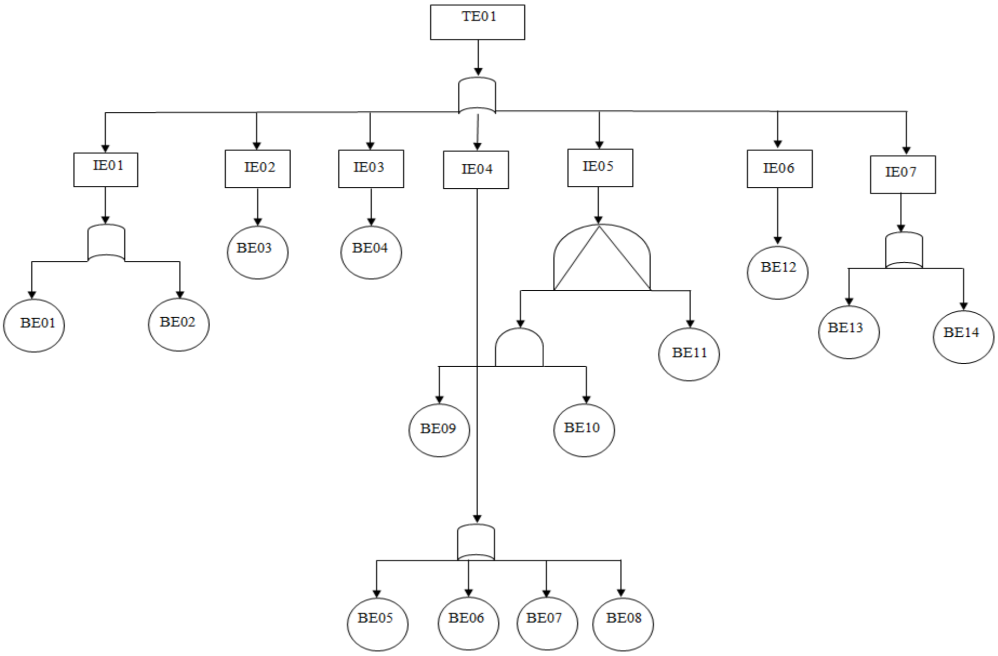

Fig. 2. Fault tree diagram for gas compressor.

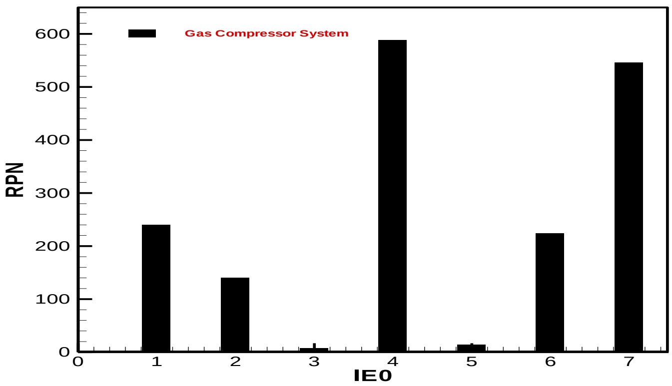

Fig. 3. Bar diagram of the probability of the fault tree using the FMEA method.

Table 4. Necessary arrangements for risk management IE04.

1. Installing SV-501 on TV501 A/B
2. Turn on SV506
3. Turn on PI-517
4. Installing SV 502 A/B in the output of TC 501 A/B

Table 5 presents the event tree for the gas compressor system. All the information entered into the software is based on the theory of experienced experts of the LPG refinery unit. This diagram was drawn by BOW-TIE PRO software.

LPG unit feeding compressor

The data related to the risk analysis using the FMEA method for the LPG unit feeding compressor are depicted in Table 6. Fig. 4 illustrates the fault tree diagram for the feed compressor.

Table 5. Risk matrix for gas compressor system.

R	E	A	P	Threat/Consequence	Event	Hazard Name
D4	C2	E3	D3	More current enters the TV-501 and results in high pressure in the tank	Gas compressor system malfunction	Compressor system
C4	A0	C4	F3	TB-501 A/B Lack of current causing compressor damage	Gas compressor system malfunction	Compressor system
C4	B2	C3	D2	TC-501 A/B compressor damage	Gas compressor system malfunction	Compressor system
B4	A2	D2	B2	The possibility of feeding gas passing through TV-102 leads to a process error	Gas compressor system malfunction	Compressor system
D4	D3	C3	E2	Creating abnormal process conditions	Gas compressor system malfunction	Compressor system
D4	B2	D3	E3	A small flow reaches the suction drum of the LPG feed compressor	Gas compressor system malfunction	Compressor system
D4	B2	D2	C2	High temperature in gas feed in TV502 Cause the efficiency reduction of TC-502 A/B	Gas compressor system malfunction	Compressor system
D4	B2	E3	D2	Too much pressure in TV-515	Gas compressor system malfunction	Compressor system
D3	B3	B3	C3	High pressure in TV-501 A/B	Gas compressor system malfunction	Compressor system

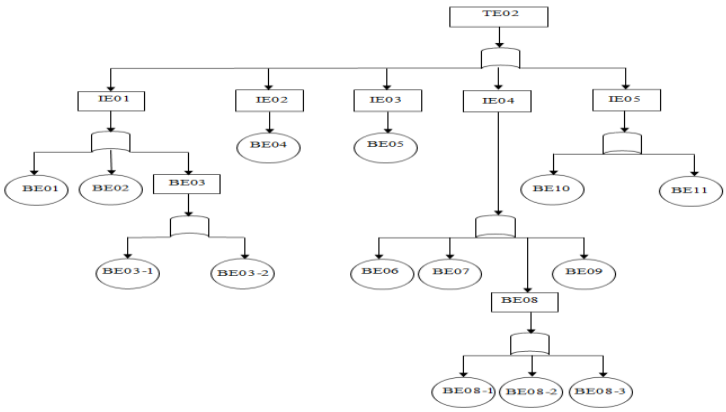

Fig. 4. Fault tree diagram for feed compressor.

Fig. 5 illustrates the probability tree diagram of each situation using the FMEA method. All RPN of IE cuts are calculated by equation 2 (Ahumada *et al.* 2019; Chin *et al.* 2020).

$$\begin{aligned} RPN_{IE01} &= RPN_{BE01} + RPN_{BE02} + RPN_{BE03} \\ RPN_{BE03} &= RPN_{BE03-1} + RPN_{BE03-2} \\ RPN_{IE04} &= RPN_{BE06} + RPN_{BE07} + RPN_{BE08} + RPN_{BE09} \\ RPN_{BE08} &= RPN_{BE08-1} + RPN_{BE08-2} + RPN_{BE08-3} \\ RPN_{IE05} &= RPN_{BE10} + RPN_{BE11} \end{aligned} \quad (2)$$

Table 6. Review of the FMEA method for the feeding compressor.

parts	**Fault** cases	Cause of **Fault**	The probability of occurrence of the cause	causes	Coefficient of intensity of effects	control	RPN
2.LPG FEED GAS COMP.SYSTEM TE02	1. No current or low current	**Fault TC 501-A/B BE01**	**5**	Less current to the TC-502A/B will cause compressor damage	**3**	**2**	**30**
		Fault TC 502-A/B BE02	**7**	Less current to Drum Receiver Pressure TV-503, however no significant consequence	**2**	**1**	**14**
		Fault TP501-A/B BE03	**7**	Less current into the Drum TV501 high pressure receiver, however, is of no significant consequence.	**2**	**1**	**14**
			6	A higher liquid level in the TV 502-B results in liquid transfer to the compressor.	**3**	**2**	**18**
	2. More / high flow More/High Flow EI02	LICAH 502V cannot be opened **BE04**	**7**	The lower liquid level in TV-502 leads to low pressure on the suction side of TP 501 A/B and the possibility of cavitation phenomenon.	**3**	**3**	**63**
	3. Reverse or wrong flow **EI03**	Reverse flow from 3/4-05-P141-F1101V to TC-502 A/B **BE05**	**1**	Damage to the TC-502 A / B compressor is possible	**2**	**1**	**2**
	4. High pressure **EI04**	**.1 Fault TC-502-A/B BE06**	**4**	It is possible that the TV-502 tank has more than the allowed pressure.	**7**	**3**	**84**
		2. TP-501-A/B starts up when output is blocked. **BE07**	**7**	There is a possibility of damage to the TP-501A/B.	**3**	**3**	**63**
		3. LICAH 502V cannot be closed **BE08**	**4**	1. There is a possibility of damage to TP-501A/B.	**2**	**2**	**116**
			4	2. Gasket breakage may occur due to excessive pressure and cause hydrocarbon leakage into the EI	**7**	**3**	
			4	3. The higher liquid level in TV502 B will lead to liquid transfer to the TC-50A / B compressor, which will cause serious damage to the compressor	**2**	**2**	
		4. TC-502-A/B starts up when output is blocked. **BE09**	**4**	Critical damage TC-502 A/B	**7**	**3**	**84**
	5. High level height **EI05**	1. Defect of TP 501 A/B **BE10**	**7**	A higher liquid level in the TV502 will result in liquid transfer to the TC-502A/B compressor, resulting in serious damage to the compressor	**7**	**3**	**147**

		2. LICAH 502V cannot be closed **BE11**	**5**	The lower liquid level in TV-502 leads to low pressure on the suction side of TP 501 A/B and the possibility of cavitation phenomenon	**5**	**3**	**75**

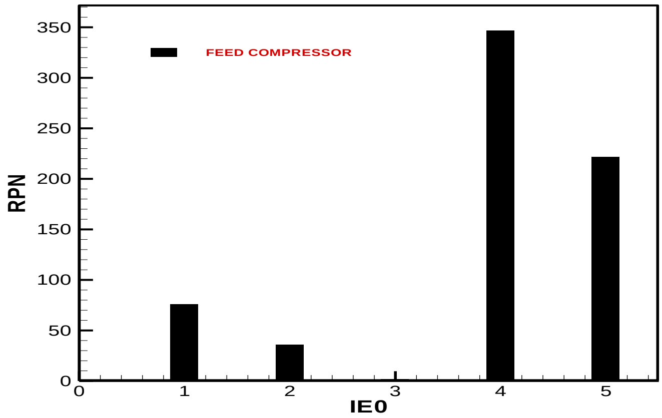

Fig. 5. Bar diagram of the probability of the fault tree using the FMEA method.

As illustrated in Fig. 5, the IE04 cut has a high probability compared to other cuts, so necessary measures should be taken to prevent the possibility of high pressure. The necessary measures to prevent the possibility of IE04 cutting are as depicted in Table 7.

Table 7. Necessary measures to prevent the possibility of IE04 occurrence.

1. Installing SV504 on TV502
2. Turning on PI-512,553
3. Turning on LICAH 502
4. Turning on LSH 517
5. Installing SV-502 A/B in TC-502 A/B outlet

Also, for the rest of the cuts, prioritization should be done based on the probability of occurrence.

Stabilizer system

Fig. 6 illustrates the fault tree diagram for the stabilization system. Also, the probability of all IE cuts are calculated by equation 3 (Mandych *et al*. 2022; Lee *et al.* 2019).

$$\begin{aligned}
&RPN_{EI01} = RPN_{BE01} + RPN_{BE02} + RPN_{BE03} + RPN_{BE04} + RPN_{BE05} + RPN_{BE06} \\
&RPN_{BE01} = RPN_{BE01-1} + RPN_{BE01-2} \\
&RPN_{BE02} = RPN_{BE02-1} + RPN_{BE02-2} \\
&RPN_{EI02} = RPN_{BE07} \\
&RPN_{BE07} = RPN_{BE07-1} + RPN_{BE07-2} \\
&RPN_{EI03} = RPN_{BE08} + RPN_{BE09} + RPN_{BE10} + RPN_{BE11} + RPN_{BE12} + RPN_{BE13} \\
&RPN_{EI04} = RPN_{BE14} + RPN_{BE15} + RPN_{BE16} + RPN_{BE17} + RPN_{BE18} + RPN_{BE19} \\
&RPN_{BE16} = RPN_{BE16-1} + RPN_{BE16-2} \\
&RPN_{EI05} = RPN_{BE20} + RPN_{BE21} + RPN_{BE22} \\
&RPN_{EI06} = RPN_{BE23} + RPN_{BE24} \\
&RPN_{EI07} = RPN_{BE25}
\end{aligned} \qquad \textbf{(3)}$$

Table 8 depicts the risk matrix of the supply compressor failure scenario for the LPG unit.

Table 8. Risk matrix of feeding compressor failure using BOWTIE-PRO.

R	E	A	P	Threat/Consequence	Event	Hazard Name
C3	A1	B1	B2	Serious damage TC-502 A/B	Feeding compressor failure	Feed compressor
D3	A0	C3	B3	The possibility of damage to TP-501A/B	Feeding compressor failure	Feed compressor
C3	B5	D3	C4	Less current to TC-502A/B and damages the compressor	Feeding compressor failure	Feed compressor
B2	A1	C2	D4	Higher liquid level in TV-502 B It leads to the transfer of liquid to the compressor	Feeding compressor failure	Feed compressor
C3	A1	B3	B3	Higher liquid level in TV-502-B leading to the transfer of liquid to the compressor TC-502A / B which causes severe damage to the compressor	Feeding compressor failure	Feed compressor
D4	A2	C4	B3	Lower liquid level in TV-502 and leading to low pressure on the suction side TP 501 A/B and cavitation phenomenon is likely to occur	Feeding compressor failure	Feed compressor
D1	D4	C2	C3	A gasket failure may result from overpressure and cause hydrocarbon leakage into the EI	Feeding compressor failure	Feed compressor
E3	A2	A3	B3	It is possible that the TV-502 tank has more than the allowed pressure	Feeding compressor failure	Feed compressor

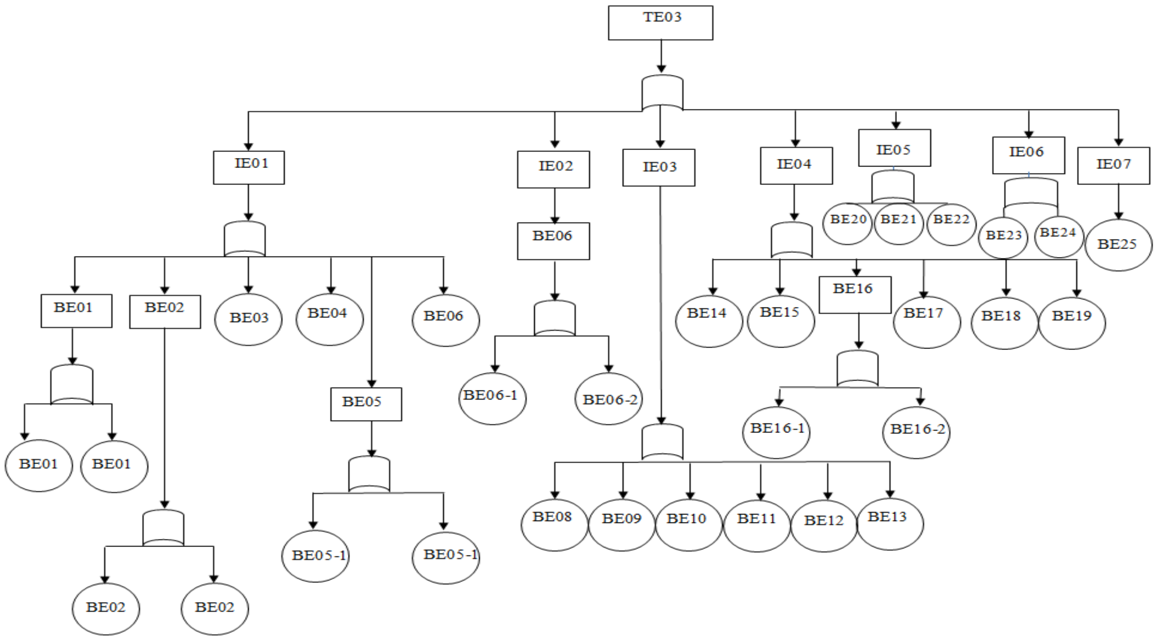

Fig. 6. Fault tree diagram for stabilizer system.

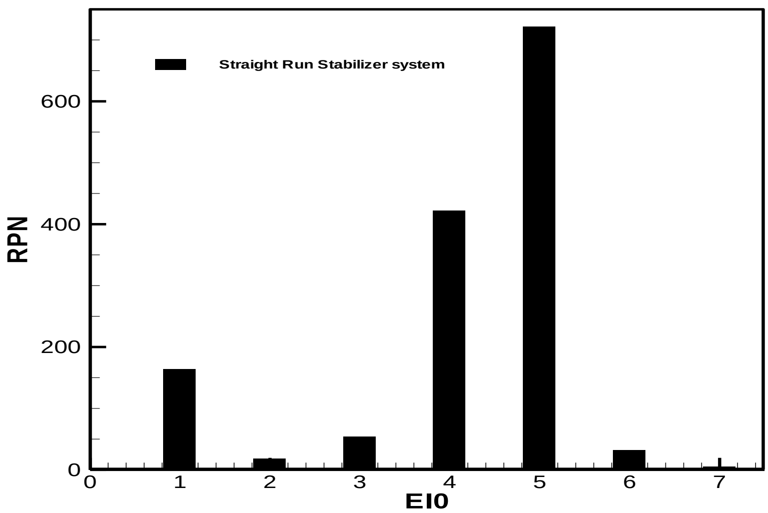

Fig. 7. Bar chart of RPN for different cuts.

As shown in Fig. 7, cut 5 has a higher RPN than others, therefore, when controlling and reducing risk, it has the first priority for the stabilization system in the LPG unit, and the rest of the cuts are prioritized according to the maximum RPN. The necessary measures to reduce the probability of EI05 cutting are shown in Table 9.

Table 9. Necessary measures to prevent the possibility of cutting EI05.

1. Installing LRCAL 505
2. Installation of LRC-504 to control low fluid level in TV-504

The following Fig. 8 illustrates the fault tree diagram for the above scenario.
Table 10 presents the event tree diagram using BOW-TIE PRO software.

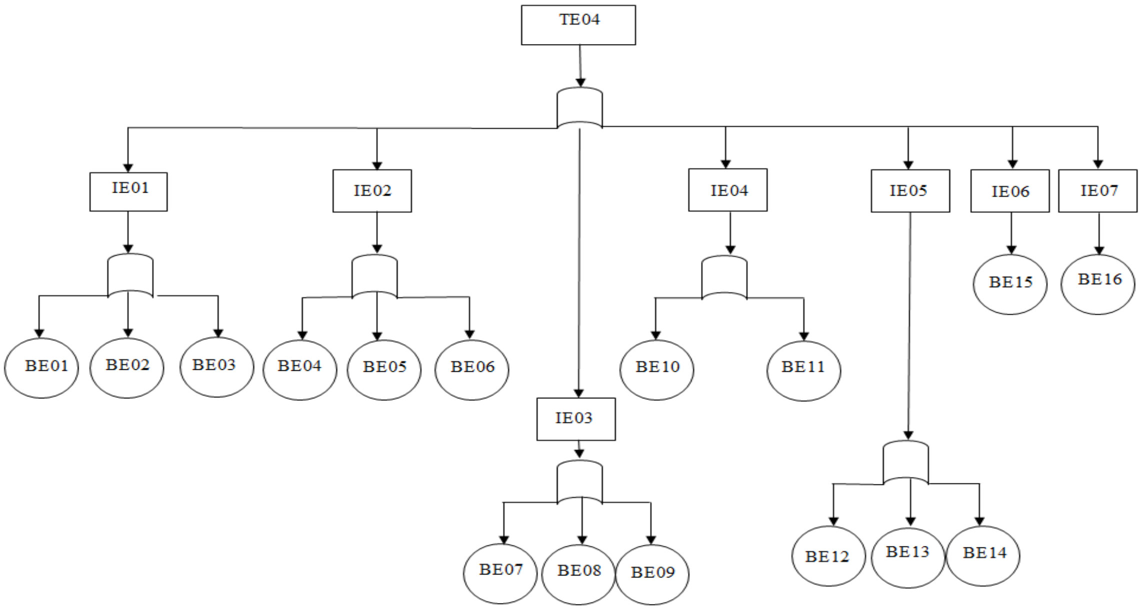

Fig. 8. Diagram of the fault tree related to the absorber V506.

Table 10. Event tree risk matrix using BOWTIE-PRO software.

R	E	A	P	Threat/Consequence	Event	Hazard Name
F4	E3	E4	D 4	Lower Hydrocarbon Level in TV-504 Causing to Process Upset in TV-504 Operation and Possible Damage to TP-505 and TH-501	Straight Run Stabilizer system	Stabilizer system
C2	D3	C3	B3	Lower Vapor Stream From TV-504 Causing Level Decreases in TV-505 and Possible TP-504 A/B Damage	Straight Run Stabilizer system	Stabilizer system
B3	C3	A1	A 2	There is a possibility of high pressure on the thrust side of TP502-A/B, causing damage to the gasket and hydrocarbon leaking into the EI.	Straight Run Stabilizer system	Stabilizer system
D2	C2	B2	A 2	The inhibitor current upstream of the TV-504 is interrupted, causing possible corrosion.	Straight Run Stabilizer system	Stabilizer system
C2	C3	D3	E3	Reverse current may overflow from the TP-504 into the containment system	Straight Run Stabilizer system	Stabilizer system
D3	C3	B3	A 3	Reverse flow from the TP-504 overhead to the reflux flow line may result in ram phenomena during pump start-up.	Straight Run Stabilizer system	Stabilizer system
D3	B2	B3	B3	The high temperature of the flow in the absorbing tank of TV-506 increases the absorption pressure in TV-506 and ultimately causes the reduction of products.	Straight Run Stabilizer system	Stabilizer system
C4	B3	C3	C3	The lower level of the TV-505 reflex drum causes possible damage to the TP-503A / B, TP-504 A / B.	Straight Run Stabilizer system	Stabilizer system
D3	C3	B3	A 3	Higher liquid level in TV-504 will cause escape (flooding) in TV-504 operation	Straight Run Stabilizer system	Stabilizer system

D4	A1	C3	B3	The higher liquid level in TV-505 causes the liquid to move to the next section.	Straight Run Stabilizer system	Stabilize r system
D4	A3	C3	B3	Excessive pressure of TV-505 will lead to cracking of the tank.	Straight Run Stabilizer system	Stabilize r system
D4	B3	C3	B3	More pressure in the TV-505 leads to over-pressure of the TV-505	Straight Run Stabilizer system	Stabilize r system
E3	D3	C3	B3	Low pressure in the TV-504 steering system leading to process failure	Straight Run Stabilizer system	Stabilize r system
D3	D4	C4	B4	Stopping the flow of reflex TV-504 causes exit from the process.	Straight Run Stabilizer system	Stabilize r system
D3	C3	C3	B3	Failure of the water supply system pump for cooling	Straight Run Stabilizer system	Stabilize r system
C4	E4	D3	C3	The hydrocarbon passes through the water supply system or the drinking water system and leads to the possible release of the hydrocarbon into the atmosphere.	Straight Run Stabilizer system	Stabilize r system
C4	B4	B3	A 4	The reduction of hydrocarbon level in TV-505 causes process escape in TV-504 operation	Straight Run Stabilizer system	Stabilize r system

V506 Absorber

Data related to the risk analysis of the V506 absorber system are presented in Table 11.

Table 11. Risk analysis related data for the V506 absorber system.

Parts	**Fault** cases	Cause of **Fault**	Probability of occurrence of the cause	causes	Coefficient of intensity of effects	Control	**RPN**
absorber V506ABSORBER TV506 (TE04)	1. No current or low currentEI01 1.	**Fault TP508 1 (BE01) A/B**	**5**	1. The possibility of liquid overflow from the storage tank TV506	**2**	**1**	**10**
			5	2. The possibility of fluid entering the gas inlet line and the possibility of damage to the gas inlet line.	**3**	**2**	**30**
		Fault 2 TP506 BE02	**5**	1. The possibility of high temperature in TV506 and creating liquid vapor and reducing the amount of flow	**2**	**1**	**10**
			5	2. The possibility of gas flow in the opposite direction and gas entering TE508 in the output process and the possibility of damage	**3**	**2**	**30**
		Fault 3 TP 507 BE03	**4**	1. The possibility of high temperature in TV506 and creating liquid vapor and reducing the amount of flow	**3**	**1**	**12**
	2. Reverse flow or opposite direction **EI02**	**Fault TP508 1 (BE04) A/B**	**5**	1. The possibility of liquid overflow from the storage tank TV506	**2**	**1**	**10**
			5	2. The possibility of fluid entering the gas inlet line and the possibility of damage to the gas inlet line.	**3**	**2**	**30**

		Fault 2 TP506 BE05	**5**	1. The possibility of high temperature in TV506 and creating liquid vapor and reducing the amount of flow	**2**	**1**	**10**
			5	2. The possibility of gas flow in the opposite direction and gas entering TE508 in the output process and the possibility of damage	**3**	**2**	**30**
		Fault 3 TP 507 BE06	**4**	1. The possibility of high temperature in TV506 and creating liquid vapor and reducing the amount of flow	**2**	**2**	**16**
	3. Low pressure **EI03**	**1.** Low flow of fluid upstream **BE07**	**7**	1. Low pressure in TV507 and causes overflow in TC503A/B, which causes damage to the compressor.	**4**	**3**	**84**
		2. Fault in TV507 BE08	**6**	1. Low flow in the suction of TC-503A/B, which reduces the pressure in the suction of the header compressor.	**3**	**2**	**36**
		3. PRC-506V cannot be closed. **BE09**	**5**	Over pressure in the TV 505 will result in over pressure of the TV-505.	**2**	**1**	**10**
	4. High pressure **EI04**	**1. Fault in TC503A/B BE10**	**3**	1. No feed fluid reaches the H2 unit	**2**	**2**	**12**
			4	2. The possibility of excessive pressure in TV507	**2**	**2**	**16**
		2. PRC-507 A-V cannot be opened. BE11	**4**	More current in TC-503 A/B, causing higher performance of TC-503 A/B and lower output to H2 unit and sudden increase in pressure of TV-507	**5**	**3**	**60**
	5. High temperature **EI05**	**1. Fault TE508CW BE12**	**6**	The possibility of high temperature in TV506 and causing liquid vapor and low current	**2**	**2**	**24**
		2. Fault TE509 CW BE13	**6**	The possibility of high temperature in TV506 and causing liquid vapor and low current	**2**	**2**	**24**
		3. Fire around TV506 **BE14**	**6**	High pressure in TV506 leads to overpressure in TV507.	**4**	**6**	**144**
	6. Less fluid level **EI06**	1. FRC505-V cannot be closed **BE15**	**4**	Low current in TP508 suction and possible damage	**2**	**2**	**16**
	7 more surface of fluid levels **EI07**	**.1 Fault TP508 A/B (BE16)**	**5**	1. The possibility of liquid overflow from the storage tank TV506	**2**	**1**	**10**
				2. The possibility of fluid entering the gas inlet line and the possibility of damage to the gas inlet line			

The probability of all cuts in this scenario using the FMEA method is in the form of the following equation (Fu *et al.* 2022).

$$
\begin{aligned}
RPN_{EI01} &= RPN_{BE01} + RPN_{BE02} + RPN_{BE03} \\
RPN_{BE01} &= RPN_{BE01-1} + RPN_{BE01-2} \\
RPN_{BE02} &= RPN_{BE02-1} + RPN_{BE02-2} \\
RPN_{EI02} &= RPN_{BE04} + RPN_{BE05} + RPN_{BE06} \\
RPN_{BE04} &= RPN_{BE04-1} + RPN_{BE04-2} \\
RPN_{BE05} &= RPN_{BE05-1} + RPN_{BE05-2} \\
RPN_{EI03} &= RPN_{BE07} + RPN_{BE08} + RPN_{BE09} \\
RPN_{EI04} &= RPN_{BE10} + RPN_{BE11} \\
RPN_{BE10} &= RPN_{BE10-1} + RPN_{BE10-2}
\end{aligned}
\quad (4)
$$

$$RPN_{EI05} = RPN_{BE12} + RPN_{BE13} + RPN_{BE14}$$
$$RPN_{EI06} = RPN_{BE15}$$
$$RPN_{EI07} = RPN_{BE16}$$

Fig. 9 shows the bar graph of the RPN value for each slice.

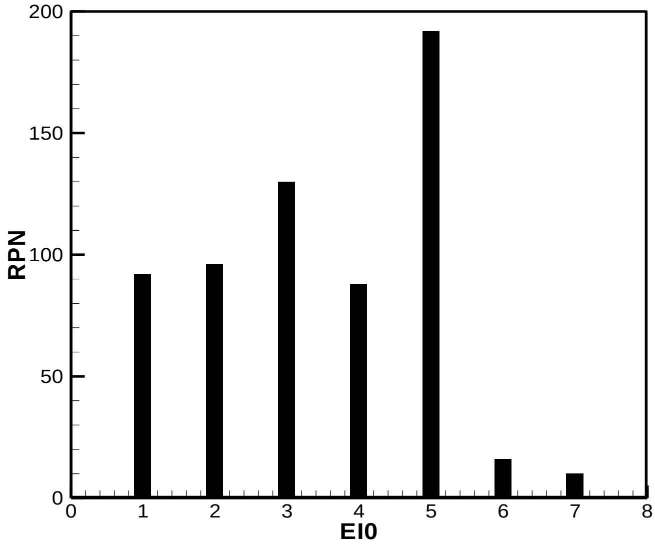

Fig. 9. Bar chart of RPN value for each slice.

As illustrated in Fig. 9, the cut EI05, i.e. high temperature, has the highest value in the V506 absorber risk analysis scenario. So, it is prioritized in the risk assessment and necessary measures, and the rest of the cuts should be examined in order of the maximum value of RPN. The necessary measures to prevent the possibility of cutting EI05 are as shown in Table 12.

Table 12. Necessary measures to prevent the possibility of cutting EI05

1. Installation of TT/TAH in the output line of TE-508
2. Installation of TT/TAH in the output line of TE-509
3. Installation of RELIEF VALVE in TV506

The following Table 13 shows the risk matrix for the V506 absorber scenario.

Table 13. Risk matrix output from BOWTIE software.

R	E	A	P	Consequence	Event	Name
A 0	C 1	C 3	B 1	Possible Gas Misdirected Flow Into TE-508 Process Outlet Line and Possible Hammering	Absorber V506	LPG UNIT
C 1	B 0	A 0	A 0	Possible Higher Temperature in TV-506 Liquid Stream and Product Loss	Absorber V506	LPG UNIT
A 0	A 0	B 1	A 0	Higher Liquid Level in Absorber Vessel TV-506 Causing Possible Liquid Carry Over Into Gas Inlet Lines and Possible Hammering In Gas Inlet Lines	Absorber V506	LPG UNIT
A 0	B 1	B 4	C 3	TP-508 Suction loose and Possible damage	Absorber V506	LPG UNIT
A 0	B 2	B 4	C 4	Higher Pressure in TV-506 leading to TV-506 Possible Over Pressure and BLEVE	Absorber V506	LPG UNIT
A 0	A 0	B 1	A 0	Possible Higher Temperature in TV-506 Liquid Stream and Product Loss	Absorber V506	LPG UNIT
			C 4	. Higher Liquid Level in Absorber Vessel TV-506 Causing Possible Flooding	Absorber V506	LPG UNIT

Fig. 10 is the diagram of the fault tree of the above scenario, and the quantitative calculation of the probabilities is done based on this Fig.

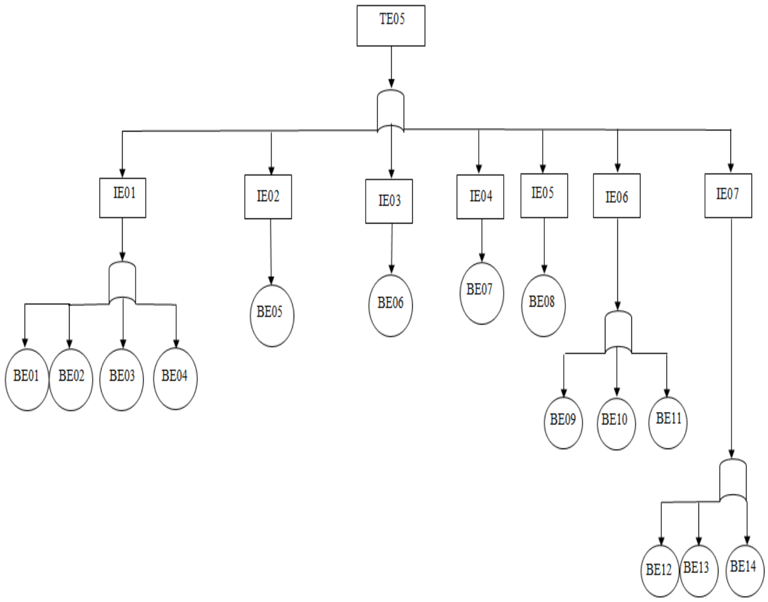

Fig. 10. Fault tree diagram for caustic washing system scenario.

The probability of all cuts in this scenario using the FMEA method is in the form of the following equation (Fu *et al.* 202)

$$\begin{aligned} RPN_{EI01} &= RPN_{BE01} + RPN_{BE02} + RPN_{BE03} + RPN_{BE04} \\ RPN_{EI02} &= RPN_{BE05} \\ RPN_{EI03} &= RPN_{BE06} \\ RPN_{EI04} &= RPN_{BE07} \\ RPN_{EI05} &= RPN_{BE08} \\ RPN_{EI06} &= RPN_{BE09} + RPN_{BE10} + RPN_{BE11} \\ RPN_{EI06} &= RPN_{BE12} + RPN_{BE13} + RPN_{BE14} \end{aligned} \tag{5}$$

LPG unit caustic washing system

Table 14 depicts the risk assessment scenario for caustic washing system of LPG unit.

Table 14. Risk assessment data for caustic washing system of LPG unit.

parts	**Fault** cases	cause of **Fault**	Probability of cause	causes	coefficient of effects intensity	control	**RPN**
4. V506 puller (ABSORBER V506) **TE04**	1. No current or low current EI01	1. **Fault** TP504 A/B (BE01)	**7**	1. Less hydrocarbon flow reaches TV508	**4**	**5**	**140**
		2. There should be no flow upstream of ISOMAX DEBUTANIZER (BE02)	**7**	1. Less hydrocarbon flow reaches TV508	**4**	**5**	**140**
		3. FRC-515-V cannot be closed (BE03)	**5**	1. There is a possibility of excessive pressure in TV508 and TV509, which causes their damage	**5**	**8**	**200**
		4. LCV-510 V cannot be closed (BE04)	**7**	1. It causes high liquid level in TV518	**4**	**5**	**140**
	2. Reverse flow or opposite	1. **Fault** TP504 A/B (BE05)	**2**	1. Possibility of gas return from TV-510	**2**	**1**	**4**

	3. High pressure **(EI03)**	1. The lack of accuracy of the operator in opening the TV518 door when needed (BE06)	**4**	1. TV518 gas vapor is blocked and there is a possibility of excessive pressure in it	**5**	**9**	**180**
	4. Low temperature **(EI04)**	1. Low ambient temperature (BE07)	**9**	1. Causing solidification of caustic in TT-501, 502, 505, TV-508, 509	**4**	**9**	**324**
	5. High temperature **(EI05)**	1. Fire around TV-508,509 BE08	**4**	High pressure in TV-508,509 leads to overpressure.	**6**	**9**	**216**
	6 less fluid level **EI06**	1. Failure to manage the operator in opening TV508 when needed BE09	**5**	1. The leakage of hydrocarbon gases into the caustic system causes fire and explosion	**5**	**8**	**200**
		2. Failure to manage the operator in opening TV509 when needed BE10	**5**	1. The leakage of hydrocarbon gases into the caustic system causes fire and explosion	**5**	**8**	**200**
		3. Failure to manage the operator in opening TV518 when needed BE11	**5**	1. The leakage of hydrocarbon gases into the caustic system causes fire and explosion	**5**	**8**	**200**
	7 more fluid levels **EI07**	1. Lack of operator management to increase caustic fluid level in TV-508 BE12	**5**	1. More caustic flow in TV-509 leads to caustic distillation in TV-510 and causes corrosion.	**5**	**8**	**200**
		2. Failure to manage the operator to increase the water level in TV-509 BE13	**5**	1. Water with low caustic concentration enters TV-510 and causes corrosion.	**5**	**8**	**200**
		3. Failure to manage the operator to increase the caustic fluid level TT-501,502,505 BE14	**5**	1. Possibility of damage to TTS	**5**	**8**	**200**

Fig. 11 illustrates the column chart of RPN calculation in each slice.

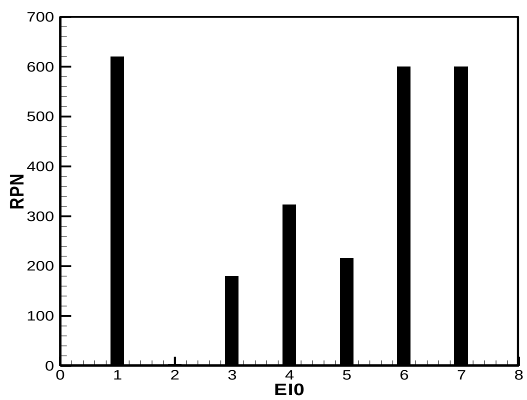

Fig. 11. Column chart of calculation of RPN value for each slice.

As depicted in Fig. 11, the EI01 cut has the highest RPN value. Therefore, in order to reduce the risk, it should be a priority. For the rest of the cuts, the prioritization of risk reduction is done in the order of the RPN value. For instance, the necessary measures to reduce the risk of cutting EI01, which is in the form of low flow or no flow, are presented in Table 15.

Table 15. Necessary measures to reduce the risk of cutting EI01.

1. Install FR 533
2. PRC-507-B-V Monument
3. Installing SV511
4. Installation of PRC-507-A-V

And finally, Table 16 gives the risk matrix of the above scenario using BOW-TIE software.

Table 16. Risk matrix table using BOWTIE software

R	E	A	P	Consequence	Event	Name
A 0	A 0	C 3	A 0	Caustic Solidification in TT-501,502,505,TV-508,509	Caustic washing	LPG UNIT
A 0	B 3	C 3	B 0	Hydrocarbon Flow to TV-508 ,However no Significant consequence	Caustic washing	LPG UNIT
A 0	B 1	D 4	B 2	Possible TV-508,TV-509 Over Pressure due to Outlet Blockage Leading to Possible TV-508,TV-509 Failure and Gasket Failure in Proper Lines	Caustic washing	LPG UNIT
A 0	A 1	C 3	A 0	TV-518 Gas Stream Blockage, Causing to Possible Over Pressure	Caustic washing	LPG UNIT
A 0	A 0	D 4	B 1	Higher Pressure in TV-508,509 leading to Possible Over Pressure	Caustic washing	LPG UNIT
B 2	D 4	D 4	C 3	Hydro carbon goes to Caustic system leading to Fire/ Explosion Hazards	Caustic washing	LPG UNIT
A 0	C 3	C 4	C 5	Gas goes to Caustic system leading to Fire/ Explosion Hazards	Caustic washing	LPG UNIT
A 0	A 1	C 4	C 3	Caustic Carry Over to TV-509 leading to Caustic Droplet in TV-510 Causing Possible Corrosion	Caustic washing	LPG UNIT
A 0	B 2	C 3	A 0	Water with Low Caustic Concentration Carry Over to TV-510 Causing Possible Corrosion	Caustic washing	LPG UNIT
A 1	B 2	D 4	C 4	Possible TT's Damage	Caustic washing	LPG UNIT
A 0	C 3	D 4	A 1	Higher Liquid Level in TV-518 and Caustic Carry Over to TV-517	Caustic washing	LPG UNIT

CONCLUSION

There are various methods for assessing environmental risks, each has its own strengths and weaknesses according to the environment and the sample under investigation. Choosing a method for risk assessment is a relative measure and it is not possible to definitely decide on the appropriateness of a method for risk assessment. By combining existing and new assessment methods, environmental risks in different environments can be significantly reduced and managed in order to achieve sustainable development. In this study, with the aim of evaluating and managing the risks of the oil refinery operation unit, the combination of hierarchical analysis process methods with EFMEA and TOPSIS was used in order to achieve an optimal method. At first, the risks related to the certain unit were identified through visiting and examining the unit and obtaining the opinions of experts, and then the environmental indicators, including five items of water, soil, air, sound, and resource consumption, were determined and the effects of risks on each of these indicators were evaluated, scored with expert opinions. Then, to enter the risks in the TOPSIS method, the priority number of the risks obtained from the EFMEA method, by the expert opinions of the previous step, were made into a matrix. Afterward, to weigh the matrix, the woman related to each risk that was obtained from the hierarchical analysis process was multiplied by the levels of the matrix and then the risks were prioritized. The result of this work was to identify the risks of excess load transferred to the burner and pollutants coming out of the chimney as important risks, and other risks were also identified in order of priority. Finally, for each of these risks, solutions were presented in order to reduce and manage these risks. The simultaneous employment of decision-making methods and risk assessment processes can help in the optimal management of risks. In this direction and in this study, two decision-making methods were used simultaneously in the two stages of the risk assessment and management process. Decision-making methods prevent the occurrence of human decision-making errors and try to manage and align them. In the process of risk assessment in this study, the intervention of arbitrary and disorderly human decisions has been prevented using these methods. The correct employment of decision-making methods in different stages of the risk assessment process can play an important role in the optimality and efficiency of the process. Paying attention to the safety issue in the LPG refinery unit is very important. In the present work, the risk analysis in the LPG unit of the refinery was analyzed quantitatively and qualitatively for the important and vital components of this unit for environmental risk assessment. First, the FMEA table was formed for each component and we calculated the RPN for each cut of the components using calculation methods. Then, using the fault tree analysis, the fault tree diagram was drawn for each component. 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. The advantages of applying the presented method in risk assessment of LPG tanks are preventive and reactive, providing control solutions, simple and applicable, low implementation cost, comprehensible for everyone, diagram output and installable in administrative units. Due to the existence of various risks in the LPG unit, a part of the system that needs basic attention for risk management is the caustic washing system unit, which was presented in the event tree using the BOW-TIE control systems software for this unit. It can also be seen that the FMEA method is a dynamic that can be updated at any moment according to different conditions.

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