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Risk Analysis of Jet A-1 Tank Filling and Storage Processes at the Shorebase

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Abstract: Coastal Logistics Centers (CLS) provide logistics support to deep-sea drilling operations. Jet A-1 (helifuel), required for helicopters that transfer personnel to drilling ships, is filled into tanks from the tanker arriving at CLS and stored in open areas. Jet A-1 is a hazardous chemical with flammable and toxic effects and can also explode when exposed to flame. Risk analysis of this hazardous chemical is essential for CLS. This study aimed to determine the process hazards and risk analysis in the filling and storage operation of Jet A-1 from tankers to tanks. For this purpose, the preliminary hazard list and preliminary hazard analysis were performed. Then, a hazard and operability (HAZOP) study was carried out based on these analysis results. The HAZOP study identified Jet A-1 overflow from the tank as a high-risk event. Afterward, event tree analysis (ETA) was performed on the initial event of Jet A-1 spilling due to tank overflow. In ETA analysis, immediate ignition, delayed ignition, and explosion probabilities resulting from delayed ignition were calculated with the Center for Chemical Process Safety Module. The probability and frequency values of accident scenarios were calculated as $P = 0.0028$, $f = 1.736 \times 10^{-4}$ year^{-1} for jet fire, $P = 0.0225$, $f = 1.395 \times 10^{-3}$ year^{-1} for vapor cloud explosion, $P = 0.127$, $f = 7.874 \times 10^{-3}$ year^{-1} for flash fire, $P = 0.847$, $f = 0.0525$ year^{-1} for toxic release, respectively. It was determined that all accident scenario frequency values were above the legislation threshold value (10^{-4} year^{-1}). Design solutions and preventive measures have been proposed to reduce risks. The combination of risk analysis methods is effective in risk assessment studies.

Keywords: Jet A-1, fuel storage, preliminary hazard list, preliminary hazard analysis, hazard and operability, event tree analysis

1. Introduction

The production characteristics of petroleum products, fuels, and products such as crude oil, kerosene, and diesel pose dangers. This creates many risks, such as explosion, fire, and hazardous substance emissions in industrial facilities [1]. Fires and explosions in hydrocarbon fuel storage tanks have disturbed the oil and petrochemical industry in terms of costs, lawsuits, disputes, etc., at various levels over the years [2].

In the study by Chang and Lin [3], statistics showed that 90% of tank accidents occurred in the oil and petrochemical industry, including refineries. Most of the primary materials in the tanks where these accidents occurred were crude oil, kerosene, and petroleum products such as gasoline, diesel, and kerosene (jet fuels). The necessity of detailed risk analysis and assessment studies was demonstrated in order to prevent fire and explosion accidents and related injuries and deaths. A detailed risk assessment helps to predict how different energy sources, such as electrical, mechanical, and chemical, in the workplace affect tank safety and to develop control actions to reduce potential risks [2]. The chemical industry improves process safety and environmental protection with four main strategies: inherently safer design, risk assessment processes, use of instrumental safety systems, and safety management systems applications [4]. Risk assessment processes, one of these four main strategies, include many methods. Qualitative risk analysis methods such as PHL, PHA, and HAZOP contribute to identifying hazards in the system, unsafe process conditions, errors, and failures, as well as determining their causes, possible consequences, and preventive actions. Quantitative risk methods such as ETA determine the probabilities and frequencies of possible accident scenarios based on the sequence of success and failure events triggered by the initiating event. By using different risk assessment methods together, hazards and risks can be identified and evaluated step by step, qualitatively and quantitatively, in more detail with each methodology [5].

It has been observed that risk analysis studies are carried out offshore through various risk analysis tools, and the number of these studies has increased recently. In the study by Roed et al. [6], BBNs, and the HCL framework, the application of the HCL framework to the offshore oil and gas industry was explained. Abimbola et al. [7] analyzed that the exploration and production of oil and gas involve the drilling of wells using either one or a combination of three drilling techniques based on drilling fluid density: conventional overbalanced drilling, managed pressure drilling, and underbalanced drilling. Based on Bowtie analysis and real-time barriers, failure probability assessment of offshore drilling operations involving subsurface Blowout Preventers, a dynamic safety assessment approach, was presented. Bijay et al. [8] stated that the drilling process for oil was a hazardous operation; hence, safety was one of the major concerns and was often measured in terms of risk. The importance of real-time monitoring of safety barrier performances and quantitatively

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showing the effect of deterioration of barrier performance on kick consequence probabilities was revealed. Rozuhan et al. [9] proposed an integrated probability model that combined human and system reliabilities and utilized a Bayesian network (BN). It was indicated that human reliability must be included in system reliability analysis for high-risk systems as it contributes significantly to hydrocarbon release that can lead to fire and explosion at offshore facilities. Vora et al. [10] presented a review of potentially relevant environmental/ecological risk assessment (ERA) guidelines. They proposed an initial suggestion for an ERA framework to understand the environmental impacts of EOR solutions. The essential elements necessary for conducting an ERA of EOR solutions were listed. These elements were then used to build the suggested ERA framework for produced water discharges, drilling discharges, and emissions to air from EOR solutions. Aziz and Said [11] developed a framework for a quantitative Bowtie analysis based on the layer of protection analysis approach in the management of change process flow for an offshore gas platform.

Wang et al. [12] presented an analysis method based on dynamic Bayesian network to assess the dynamic risk of riserless healthy intervention systems performing the plugging and abandonment (P&A) operation. It was shown that the reservoir abandonment phase had the most significant effect on P&A operation process risk. Wang et al. [13] used a computational fluid dynamics technique to model large-scale pool fires on offshore platforms. The effects of wind load and windshields on large-scale pool fires were investigated. It was demonstrated that the growing horizontal momentum of the wind load might result in a significant distance of fatal injury. Liu et al. [14] proposed a risk identification and assessment method for offshore platform equipment and operations based on text mining of hidden danger data. An automated method for risk identification was developed that combined machine learning, deep learning, and natural language processing techniques. The identified risk factors were used to build the BN model for data-driven risk assessment. A three-dimensional random large deformation finite element analysis model was developed, which was implemented by the field variable (FV) technique to map the non-stationary random field (NSRF) into the verified Coupled Eulerian-Lagrangian (CEL) model (Hereafter referred to as FVRCEL) by Jiang and Zhao [15]. The FVRCEL model was integrated with the Monte-Carlo simulation to obtain the statistical characteristics of the pipeline structural response. The failure mechanisms of the pipeline with different fluctuation scales were also investigated. The failure probability curves and surfaces were presented. More than 50% of the realized NSRF scenarios in the random analysis yielded more severe dent damage than the deterministic result.

In order to meet the increasing demands for oil and natural gas consumption and the accompanying oil products, it is necessary to increase production by revealing the oil and natural gas potential in the deep seas and the exploration and production activities carried out on land [16]. For this reason, drilling ships carry out oil and natural gas exploration and production activities in the deep seas. For drilling ships to continue their operations in the deep sea without interruption, all kinds of material, machinery, and equipment needs must be met within the required period. For this purpose, Coastal Logistics Centers (CLS) must be established in the nearest port areas. Personnel transfers to drilling ships are mostly via helicopter. Jet A-1 required for helicopter operations comes to CLS with the tanker of the purchased companies. It is filled from the tanker into Jet A-1 tanks by the particular deep-sea drilling standard and stored in an open area in the middle of the field in the CLS. Considering that approximately 500 personnel work in the field and there are other equipment and materials around it, such as drilling pipes, drilling, mud preparation process, and silos, a fire or explosion caused by Jet A-1 may cause significant loss or damage.

The main ingredient of Jet A-1 is flammable kerosene hydrocarbon liquid, and its flash point is 38 $^{\circ}$C. If this liquid starts to burn, it gives off more heat than other fuels and is very difficult to extinguish [17, 18]. Therefore, it is essential to carry out all possible hazard and risk analyses, take precautions accordingly, and constantly control them to prevent any release, fire, or explosion during filling from tanker to tank and subsequent storage and ensure process safety.

It has been observed that risk analysis has yet to be carried out on the tanker-to-tank filling and storage operations and process equipment of helicopter Jet A-1, which is within the scope of hazardous chemicals in CLS. If failures or errors in the filling process cause any fuel spillage or leakage, Jet A-1, an easily flammable liquid, may cause a fire. Water mixing with the fuel in the tanker may cause an accident as it will damage the helicopter's engine. Similarly, during the storage of Jet A-1 in offshore Jet A-1 tanks located in the middle of the CLS field and in the open area until their shipment to the ship, any deformation that may occur in the tank or leakage from the inlet/outlet valve may cause a fire. For this reason, this study was performed to determine all hazards and risks related to the tanker-to-tank filling and storage process of Jet A-1. Thus, it will be possible to detect all these errors or failures that may cause danger, determine the necessary protection barriers, determine the necessary precautions and actions, and ensure process safety.

2. Methodology

2.1. Risk analysis methodology

A combination of PHL, PHA, and HAZOP qualitative analyses and quantitative ETA analysis was applied in the risk analysis (Figure 1). First, PHL and PHA analysis were used to determine hazards and risks. HAZOP determined hazards, their causes, consequences, and protection barriers according to process nodes based on the hazards determined by these two methods. Probabilities and frequencies were calculated for jet fire, vapor cloud explosion, flash fire, and toxic release, which are possible accident scenarios caused by the Jet A-1 spill initiation event.

2.2. Data

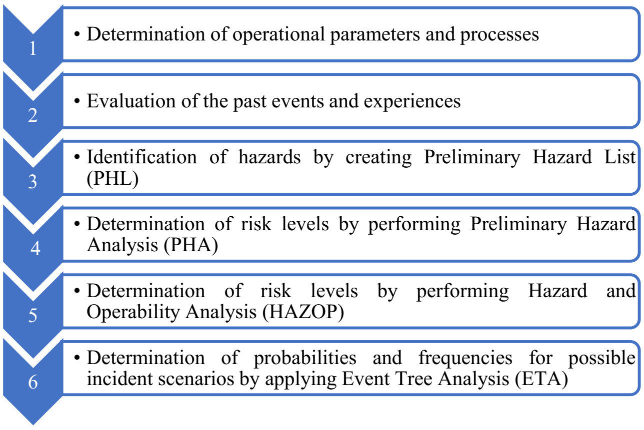
The data used within the scope of the risk assessment application are listed below:

- Jet A-1 physical and chemical properties
- Offshore Jet A-1 tank characteristics
- Jet A-1 tanker characteristics
- Zonguldak-Filyos atmospheric conditions in 2023
- Fuel tank failure frequencies
- Experiences/lessons learned in the field

2.3. Application site

The site where the risk analysis application takes place is CLS, which was built in a part of the port declared as an Industrial Zone in Zonguldak-Filyos district, which provides all kinds of material and equipment shipping and storage support to drilling ships operating in the Black Sea in Turkey. There is a reserve area in the Black Sea

Figure 1
Risk analysis methodology applied in the study



where drilling ships carry out natural gas exploration and production activities, and the approximate distance of this area to CLS is between 170 and 200 km. CLS is built on the dock right by the sea. Support ships operate under the CLS, which transfers the equipment and materials in the CLS to the drilling ships, and these ships wait around the CLS dock.

In the operational area of CLS, there are mud and cement silos, drilling pipes and equipment, containers used to send materials, workshops, hazardous waste chemicals storage tanks and areas, and Jet A-1 storage tanks. Outside the operation area are office buildings and barracks, a dining hall, and dormitories for some personnel. Jet A-1 tanks and storage area, which are the basis for CLS's layout plan and risk assessment studies, are shown in Figure 2.

In CLS, Jet A-1 is stored in 12 tanks produced to particular standards for deep-sea operations (offshore). These tanks are also portable because they are sent to ships in limited numbers that align with the demands of drilling ships. Jet A-1 is filled into the tanks by tankers arriving by land. The area where the tanker is filled is next to where the tanks are stored. The tank area where Jet A-1 tanks in the CLS are stored and filled was chosen as the application site.

The primary operations within CLS are mostly lifting, lowering, and loading onto support vessels that take materials and equipment to drilling vessels. Production of drilling mud and cement required for the drilling operation, inspection and maintenance-repair activities of the equipment, and machines required for the drilling operation are carried out. Jet A-1 filling and storage activities are other primary operations. All kinds of chemicals, materials, equipment, drilling pipes, and offshore Jet A-1 tanks required for drilling are stored. CLS is also responsible for temporarily storing and disposing of waste from ships. In addition, processes such as the emergency coordination center and equipment for emergency response support to drilling ships, fire station and fire systems, health center, and equipment are also managed.

The process flow diagram of the filling and storage of helicopter Jet A-1 in the CLS from the tanker to the tank is given in Figure 3. Additionally, a separate process flow diagram showing the current process flow inside the Jet A-1 tanker is presented in Figure 4 [19, 20].

Since the fuel of the helicopters flying to the drilling ships decreases after a 1.5-hour flight, particular offshore helicopter Jet A-1 tanks are kept full on the ship to transfer fuel. CLS, offshore helicopter Jet A-1 tanks are filled and stored from tankers arriving by land, and in line with the demand from the drilling ship, the tank is loaded and sent on the support ship. In this study, within the scope of the risk assessment application, the works carried out specifically for the filling and storage operation of Jet A-1 tanks in CLS are listed below:

- Supplying the Jet A-1 tanker for filling when the number of full tanks drops below 3 out of 12 tanks
- When the fuel tanker arrives, all documents are checked and allowed to enter the facility.
- The tanker arrives at the tank area and is accompanied by a material specialist working at CLS.
- The fire truck in CLS arrives at the tank area
- Checking the sprinkler and foam system in the tank area
- Checking the general grounding system in the tank area
- Checking the pressure of the tank to be filled, and if the pressure is above 2.5 bar, opening the pressure relief valve to reduce the pressure inside the tank
- Opening a work permit for filling Jet A-1 from tanker to tank
- Parking the tanker relative to the tank, chocking the tires, and making the grounding connection of the tanker

Figure 2
The basic layout of CLS

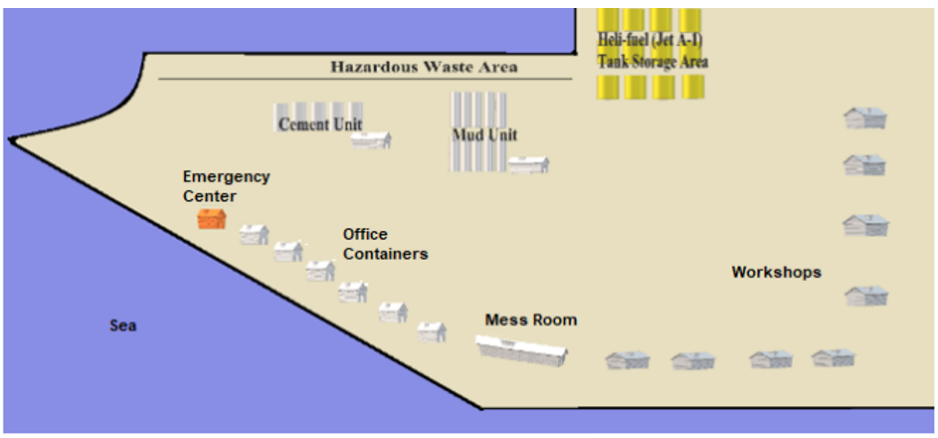


Figure 3
Filling and storage process flow chart of Jet A-1 from tanker to tank in CLS

Figure 4
Process flow diagram for the inside of the Jet A-1 tanker

- Taking a sample from the Jet A-1 to be filled from the side valve of the tanker and checking whether there is water in it with a rapid sample test kit (If the color in the test kit is pink, it means there is water in the fuel)
- If there is water, stopping fuel filling and requesting a new fuel tanker
- If there is no water, establishing the Jet A-1 filling process from tanker to tank
- Opening the top cover of the tank and making the connection for fuel filling from the tanker to the tank
- Opening the valves, starting the pump, adjusting the flow rate, resetting the volumetric device, and starting the counter with filling
- During tank filling, take and store two more samples from the discharge valve at the back of the tank
- After the tank filling is completed, the tank top cover is closed and sealed by the fuel company official,
- The tanker is assembled and leaves the area,
- Storing the filled tanks in the open tank area at CLS to be delivered to drilling ships together with other Jet A-1 tanks
- Testing the grounding in the Jet A-1 tank area once a year through the tests of the general grounding system in CLS
- Sending fuel tanks to pressure testing every four years

Offshore helicopter Jet A-1 tanks must be manufactured and certified by international standards, as they must both store flammable materials and be transferred by sea. In general, tanks are produced according to CAP 437. In order to prevent the transfer process from damaging the tank, the tank is located in a special stainless steel frame/cage and is subject to particular standards within this frame. The fuel tank complies with the “ASME VIII Part 1” standard, and the external frame complies with DNV 2.7-1 and BS EN 12079 standards. It is certified. The tank has a 3-inch inlet/outlet valve at the bottom, a 0.75-inch sampling port, a 2.5-inch pressure relief valve, and a 500 mm manhole (inlet/landing hatch) at the top. The pressure inside the tank should not be over 2.5 bar. When it is, excess pressure is released with the pressure relief valve. The tank capacity is 2900 liters, the total load weight is 4700 kg, and it is stainless steel with SS316L [20].

The tankers from which helicopter Jet A-1 is supplied in CLS have a capacity of 5000 liters, and the tanker’s storage tank has four compartments. The tanker has a transfer/filling hose, centrifugal pump that can operate at a maximum speed of 300 LPM, solenoid and manual valve, pressure and temperature transmitter, flowmeter (usually set to 250 LPM during operation), empty pipe detector, digital control. The panel, emergency stop button, and grounding equipment for fuel filling are also available in the tank [19].

2.4. Assumptions and limits

The assumptions made within the scope of this study are stated below:

Table 1
PHL example for the system element of “Tanker-to-tank filling operation of Jet A-1”

No	System component	Hazard	Effects of hazard	Recommendations
System element: Tanker-to-tank filling operation of Jet A-1				
H-18	Checking the fuel level in the tank	Overflow from the tank due to overfilling	Fuel spill Fire	1. Installing a level indicator on the tank. 2. Installing an audible alarm sensor when the tank is filled to total capacity. 3. Building a closed pool/dyke area on the tank floor to collect leakage. 4. Installing an audible alarm sensor to warn when there is any accumulation in the closed pool/dyke area. 5. Sources that may cause static electricity generation should be removed from the tank area, and all equipment should be anti-static. 6. There should be no heat source in the tank area. 7. Each tank should be grounded from the general grounding system.

Table 2
High-level failures and critical system functions identified by PHL

No	High-level failures	Critical system functions
1	Fire, Explosion, Death, Injury	The process of loading the offshore Jet A-1 tank from the port to the platform supply vessel (PSV)
2	Fire, Explosion, Toxic release	The process of storing tanks in an open area under atmospheric weather conditions
3	Helicopter accident/fall	The process of fuel sampling and analysis
4	Fuel Spill, Fire	The process of filling operation from tanker to tank

Table 3
Risk assessment matrix, probability, and severity categories

Risk assessment matrix				
Probability	Severity			
	4. Negligible (Less than marginal severity effects)	3. Marginal (Minor injuries or occupational illness/Minor process loss/Minor environmental impact)	2. Critical (Serious injuries or occupational illness/ Process loss/ Environmental impact)	1. Catastrophic (Death/ Serious process loss/ Serious environmental impact)
A Almost certain (Often occurs)	MEDIUM RISK	SERIOUS RISK	HIGH RISK	
B Likely (Could quickly happen)				
C Possible (Could happen or known it to happen)	LOW RISK		SERIOUS RISK	
D Unlikely (It has not happened yet, but could)			MEDIUM RISK	SERIOUS RISK
E Rare (Conceivable but only in extreme circumstances)				

- The average flow rate provided by the pump of the Jet A-1 tanker is 250 LPM.
- The tank area where Jet A-1 tanks are stored is open. Zonguldak-Filyos maximum air temperatures are assumed to be 40.5 °C in July in summer and −8 °C in winter in February and March [21].
- The initiating event frequency value for spilling Jet A-1 due to tank overflow was taken as 6.2×10^{-2} year^{-1} [4].
- Tank transportation has also been considered in case of disruption of the external structural integrity of the tank.
- Impacts on humans and the environment have been considered.

Table 4
PHA example for "Tanker-to-tank filling operation of Jet A-1"

No	Hazard	Causes	Effects	Mode	PRI	Preventive measures	SRI	Opinions
System 2: Tanker-to-tank filling operation of Jet A-1 Subsystem/function: Checking the fuel level in the tank								
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
A-08	Overfilling of the tank	1. Overfilling of the tank due to lack of level indicator and difficulty in checking the fuel level in the tank 2. Incorrect calculation of flow rate volume 3. Not stopping the tanker pump	Fuel spill Fire Death Injury	Level Control	1B	1. Installing a level indicator on the tank. 2. Installing an audible alarm sensor when the tank is filled to total capacity. 3. Building a closed pool/dyke area on the tank floor to collect leakage. 4. Installing an audible alarm sensor to warn when there is any accumulation in the closed pool/dyke area. 5. Sources that may cause static electricity generation should be removed from the tank area, and all equipment should be anti-static. 6. There should be no heat source in the tank area. 7. Each tank should be grounded from the general grounding system.	3C	Taking preventive measures is sufficient to reduce both the severity and the probability of the incident.

3. Results and Discussion

3.1. Preliminary hazard list (PHL)

PHL was first carried out while performing a risk assessment regarding the filling and storage of helicopter Jet A-1 tanks in CLS. Two separate system elements were identified for PHL:

- Jet A-1 Tank
- Tanker-to-tank filling operation of Jet A-1

PHL was detected in the system element "Tanker-to-tank filling operation of Jet A-1." An analysis example for the hazard of "tank overflow due to overfilling," which is also determined as the initiating event of the ETA, is given in Table 1.

The high-level failure and critical system functions detected in PHL are presented in Table 2.

As a result of PHL, 18 hazards were identified, and four were determined as high-level mishaps and critical system functions.

3.2. Preliminary hazard analysis (PHA)

Based on the high-level failures and critical system functions identified after PHL, PHA was carried out for the following two systems and their subsystems.

Table 5
Node, parameters, guide words, and deviations for HAZOP study

Parameter	Guide words	Deviation
Node: Tanker-to-tank filling operation of Jet A-1		
Static electricity	More	High static electricity
Level	More	High level
	Less	Low level
Pressure	More	High pressure
Flow	More	High flow rate
	Less	Low flow rate
	None	No flow
Temperature	More	High temperature
	Less	Low temperature

System 1: Jet A-1 Tank

- Tank external structure
- Tank top manhole

System 2: Tanker-to-tank filling operation of Jet A-1

- Taking a sample of Jet A-1 in the tanker and performing water testing
- Checking the tank level

Table 6
HAZOP study for the node of the tanker-to-tank filling operation of Jet A-1

No	Element	Function	Parameter	Guide word	Consequences	Possible causes	Hazard	Risk	Actions required	Opinions
1	Grounding system	Release of static electricity into the ground	Static electricity	More	Accumulation of static electricity	Insufficient/bad grounding	Fire/explosion if static electricity accumulation contacts with the fuel	2C	*Grounding of each tank in addition to the general grounding system of the tank area. *Carrying out periodical control and testing of the general grounding system once a year. *Sources that may cause static electricity generation should be removed from the tank area, and all equipment in the area should be anti-static.	It builds a special indoor Jet A-1 filling and tank area that eliminates static electricity.
2	Jet A-1 tank	Storage of Jet A-1	Level	More	Jet A-1 in the tank is more than the tank level.	Lack of level indicator and difficulty in checking the fuel level in the tank Incorrect calculation of flow rate volume Incorrect adjustment of fuel tanker valve and pump They are not stopping the tanker pump.	Fuel spill due to overflow of the tank Fire if there is an ignition source around	1B	*Installing a level indicator on the tank. *Install an audible alarm sensor when the tank is filled to its total capacity. *Building a closed pool/dyke area on the tank floor to collect leakage. *Installing an audible alarm sensor to warn when there is any accumulation in the closed pool/dyke area. *Sources that may cause static electricity generation should be removed from the tank area, and all equipment in the area should be anti-static. *There should be no heat source in the tank area. *Apart from the general grounding system, each tank should be grounded.	Instead of purchasing ready-made standard Jet A-1 tanks, they should be designed and supplied in particular order.
3	Jet A-1 tank	Storage of Jet A-1	Level	Less	The amount of Jet A-1 in the tank is lower than the requested	Incorrect/unfixed connection of the filling fuel hose connection from a tanker-to-tank manhole, and the fuel hose comes out of the tank manhole during filling, spilling fuel around.	Fuel spill due to fuel hose movement around Fire if there is an ignition source around	1B	*Fixing the filling fuel hose to the tank manhole by using fasteners. *Sources that may cause static electricity generation should be removed from the tank area, and all equipment in the area should be anti-static. *There should be no heat source in the tank area.	A fuel line process should be designed instead of using a fuel hose to fill the tank.
4	Jet A-1 tank	Storage of Jet A-1	Pressure	More	The inner tank pressure is more than 2.5 bar.	Exposing the Jet A-1 tank to high temperatures in the summer because of outdoor storage	Tank rupture Fire Explosion	1D	Reducing the period of tank pressure tests and gauge checks from 4 years to 1 year. *Establishing a periodic control routine. *Using the pressure relief valve, which consists of corrosion-resistant material.	Instead of purchasing ready-made standard Jet A-1 tanks, they should be designed and supplied in particular order.

(*Continued*)

Table 6
(*Continued*)

No	Element	Function	Parameter	Guide word	Consequences	Possible causes	Hazard	Risk	Actions required	Opinions
5	Jet A-1 filling hose line.	Fuel filling from tanker-to-tank	Pressure	More	Disconnection of filling fuel hose line	Insufficient performance of tanker pressure vacuum (PV) valve	The fuel hose is coming out of the tank manhole. Fuel spilling around Fire if there is an ignition source around	2D	*Carrying out maintenance, repair, and certifications periodically. *Fixing the filling fuel hose to the tank manhole by using fasteners. * Sources that may cause static electricity generation should be removed from the tank area, and all equipment in the area should be anti-static. *There should be no heat source in the tank area.	A fuel line process should be designed instead of using a fuel hose to fill the tank.
6	Jet A-1 filling hose line.	Fuel filling from tanker-to-tank	Flow	More	Pressurized flow when filling from the top of the tank	Increasing pump capacity	Helicopter engine failure/ helicopter crash due to the formation of air bubbles and subsequent condensation of moisture and water mixing with the fuel Death Injury	1D	*Providing flow control. *Automatic flow stop in case of deviation from the specified flow rate. *Instantly detect water presence with a rapid sample test kit before fuel is loaded into the helicopter. *Different fuel samples from the tank are taken and sent to the authorized laboratory for analysis before being loaded onto the helicopter.	Instead of purchasing ready-made standard Jet A-1 tanks, they should be designed and supplied in particular order.
7	Tanker pump	Fuel filling from tanker-to-tank	Flow	Less	Having difficulty pumping fuel into the filling fuel hose	Decreasing fuel level in the tanker	Cavitation occurs in the pump and creates operability problems. Failure to refuel or take a long time to refuel	4D	*Different fuel samples from the tank are taken and sent to the authorized laboratory for analysis before being loaded onto the helicopter. *Installing a system to stop the pump when no fuel reaches the pump inlet. * Installing a fuel level indicator in the tanker. *Install a system to shut down the pump automatically when the fuel level in the tanker is lower than the specified level value.	
8	Tanker solenoid valve	Fuel filling from tanker-to-tank	Flow	Less	Extended tank filling time	The flow direction is different within the solenoid valve and in the filling fuel hose line.	Failure to refuel or taking a long time to refuel	4D	*The flow direction of the filling fuel hose line must be the same as that indicated by the arrow on the valve.	
9	Tanker solenoid valve	Fuel filling from tanker-to-tank	Flow	None	Failure to supply fuel to the tank	Failure to open the valve due to coil burning in solenoid valve	Failure to refuel	4D	*Replacing the coil in the solenoid valve.	
10	Tanker solenoid valve	Fuel filling from tanker-to-tank	Flow	None	Failure to supply fuel to the tank	Clogging of the pilot control hole on the diaphragm of the solenoid valve	Failure to refuel	4D	*Install a filter on the valve inlet. *Conducting periodical valve cleaning and maintenance	

The risk assessment matrix and probability and severity categories used when performing PHA are given in Table 3.

An analysis example of the PHA for the hazard of "tank overflow due to overfilling" detected within the "Tanker-to-Tank Filling Operation of Jet A-1" system is presented in Table 4.

A total of 8 hazards were analyzed in the PHA, which was carried out within the framework of high-level mishaps and critical system functions. In the "High-Risk" category, only the "Tank Overflow" hazard numbered A-08 was detected. It has been observed that if preventive measures are implemented, the severity and probability of this risk decrease and fall into the "Medium Risk" category. For other hazards, 4 "Medium Risk" and 3 "Serious Risk" distributions were determined.

3.3. Hazard and operability analysis (HAZOP)

HAZOP was conducted to provide a more detailed analysis of the severe and high-risk categories identified due to PHA analysis and to determine design solutions and protection barriers. In the HAZOP study, the risk matrix presented in Table 3 was considered again. The nodes, parameters, and guide words determined during the HAZOP study are summarized in Table 5 below.

The HAZOP study presented in Table 6 was performed based on these determined parameters and guide words.

As a result of this HAZOP study, ten hazards were identified, and design solutions and protection barriers were proposed for these hazards. Among the identified hazards, two hazards numbered 2 and 3 were found to be "High Risk" in terms of "level more/less" deviation. Of the remaining risks, four were distributed as "Low Risk," one as "Medium Risk," and three as "Serious Risk." The high risk detected with HAZOP was parallel to PHA.

Table 7
CCPS module input data for ETA

Parameter	Data
Level of analysis	2
Chemical	Jet A-1
Phase	Liquid
Min. ignition energy	0.2 mJ
Auto-ignition temperature	220 °C
Boiling point	140 °C
Flash point	38 °C
Process temperature	40 °C
Process pressure	Two bars
Hole diameter	500 mm
Release time	1 min

3.4. ETA

ETA was conducted to determine the probability and frequency of fire, explosion, and releases that may be caused by the hazard of overflowing the Jet A-1 tank. ETA was performed based on the initial event of a flammable material spill. Center for Chemical Process Safety (CCPS) Module was used to calculate probability values.

Figure 5
ETA for the initial event of Jet A-1 spill due to overfilling tank

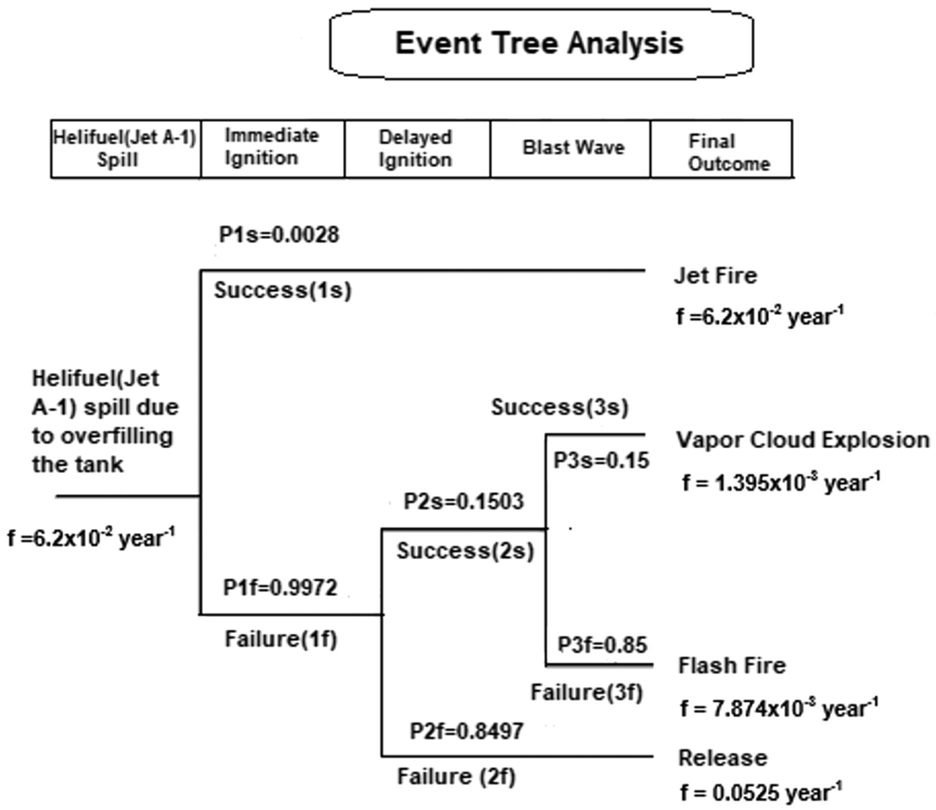


Table 8
Probabilities and frequencies determined by ETA

Incident scenario	Probability	Frequency(year^{-1})
Jet fire	0.0028	1.736×10^{-4}
Vapor cloud explosion	0.0225	1.395×10^{-3}
Flash fire	0.0127	7.874×10^{-3}
Release	0.8470	0.0525

The data entered regarding the environmental conditions required for probability calculation in the Module and the data taken from the SDS of Jet A-1 are given in Table 7.

The probabilities in the CCPS Module are defined as follows [22]:

- Probability of Immediate Ignition – POII,
- Probability of Delayed Ignition – PODI,
- Probability of Explosion Given Delayed Ignition – POEGDI

For the initial event, the spill frequency value $f = 6.2 \times 10^{-2}$ year^{-1} was taken as a basis due to the overflow of the fuel tank determined in the risk analysis study by Fuentes-Bargues et al. [4] on fuel storage in terminals. The ETA performed on this initial event frequency, and CCPS Module probability values are given in Figure 5.

The probability and frequency values calculated for each accident scenario according to the frequency value of the initial event and POII, PODI, and POEGDI probability values are given in Table 8.

It was determined that all accident scenario frequencies obtained were higher than the legislation threshold value (10^{-4}/year) [23]. It was determined that the release accident frequency was the highest, and the jet fire accident frequency was the lowest.

4. Conclusion

Jet A-1 is a flammable liquid and has a flash point of 38 °C. In the filling and storage process of helicopter Jet A-1 tanks at Zonguldak-Filyos CLS, four different risk analysis methods (PHL, PHA, HAZOP, and ETA) were used within the scope of risk assessment, taking into account these dangerous properties of the fuel. First of all, 18 hazards were identified by PHL. Among these hazards, fire, explosion, toxic release, spillage, and helicopter accident/crash were determined to be high-level mishaps and critical system functions. PHA was performed according to these high-level failures and critical system functions. Eight hazards were identified, and among these hazards, overflow due to overfilling of the tank in level control mode was determined to be high risk. Ten hazards were identified in the HAZOP study applied after PHA, and design solutions and protection barriers were proposed for these hazards. Among the detected hazards, the "level more/less" deviation was in the high-risk category. It has been determined that if the level deviates too much, Jet A-1 overflows from the tank, and there is an ignition source in the environment, fire, explosion, death, and injuries may occur. In order to verify the findings determined by the HAZOP study, ETA was performed for the initial event of Jet A-1 spilling due to tank overflow. Probabilities and frequencies were calculated for jet fire, vapor cloud explosion, flash fire, and release accident scenarios. It has been determined that all calculated accident frequency values are higher than the regulatory threshold value and contain unacceptable risks. With the risk assessment, it has been shown that it is necessary to reduce the risk value of the hazard of Jet A-1 overflowing from the tank and the presence of an ignition source in the environment. It has been stated that the risk values can be decreased with some preventive measures. Design solutions such as adding a level indicator to the fuel tank, audible alarm sensor, and closed collection pool may be suggested. Other solutions can be offered, such as not keeping static electricity and heat sources in the tank area and providing separate grounding for each tank. In addition, to eliminate the danger at its source, Jet A-1 tanks can be designed and supplied in a particular order instead of being purchased by ready-made standard fuel tanks. The filling process from the tanker to the tank can be designed with transfer pipes instead of the fuel hose line.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

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