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A New Conceptual Model for Quantitative Fire Risk Assessment of Oil Storage Tanks in the Tehran Refinery, Iran

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Abstract
The purpose of this research was to introduce and describe a model for Fire Quantitative Risk Assessment of in petroleum Storage Tanks. A novel model was designed to determine the risk of a fire occurrence using of Loss Causation and Swiss cheese models. Then, based on FTA, model and its integration with our initial proposed model, the final model was obtained for fire hazard determination in hydrocarbon tanks. The risk level of the hazard was identified using the energy trace and barrier analysis (ETBA). The **q**uantitative fire risk assessment in the tank were carried out in accordance to the International Association of Oil & Gas Producers (IOGP) guideline. Base on the results, 22 risks were identified which 4 of them were unacceptable risks and corrective action was proposed for them. This method is commonly used in conjunction with the safety analysis of the system. This technique was the final part of this research.

Keywords: Risk assessment, Oil storage tanks, FTA, ETBA, Loss causation model

Introduction

Oil storage tanks are one of the most important industrial installations that are always exposed to the toxic emission, fire and explosion risks (Tauseef et al. (2018) and Suhaim and Mustapha (2016)). Quantitative risk assessment is an inseparable part of the design of process units (Pramanathan et al. 2018). The main objective of risk management is to determine the system's uncertainty and the cost of it (Abul-Haggag and Barakat 2013). Due to the importance of fire and explosion hazard, and in order to control these risks, the risks should be carefully analyzed, critical points identified and ways of fighting and control are identified (Šakėnaitė, 2010; Wajdi Akashah et al. 2013). The development and expansion of complex and important technologies in various industries, especially process industries, has led the safety philosophy to change from a post-incident approach to a pre-occurrence approach (Jafari et al. 2012; Russoa et al. 2018). The occurrence of fire and explosion in the small and large industries annually causes many financial and environmental damage to various communities (Wang et al. 2018; Jensen. 2007). In the chemical industry, especially in the petroleum and petrochemical industries, the fire and explosion hazard are always important due to the flammability and reactivity of the materials, the high temperature and operating pressure, the volatility and evaporation of liquids, and

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subsequently the formation of cloudy explosive vapors (Ibrahim and Syed, 2018; Shapiro and Koissi, 2015).

The elements related to important components of the incident hierarchy associated with the work of individuals were introduced in a model by James Reason (Reason, 1990). The subsequent application of this method in the Bird and Germain research in 1996 led to the development of the Loss Causation model. This technique creates a hierarchical system of events and pre-conditions of an accident in an industrial environment. Analysis begins with death or injury to an individual or process and continues with a chain of events and conditions that lead to this injury (Bird and Germain,1996).

The Swiss cheese model is a similar accident modeling technique that was initially used in the aviation industry to prevent human disease and is, in any case, used in many industries (Reason.1990). The Loss Causation model is based on the principle that successive safety protections create a hole in the next cut when they fail. If all the cuts fail, then they create the caverns that create the path to the incident. In many studies, it has been emphasized that an incident is never under the responsibility of a particular person or agent. It is a set of conditions that creates an incident. (Amyotte and Oehmen. 2002)

Each safety barrier is subdivided into sub-branches in order to illustrate the more detailed factors, FTA is a hierarchical and logical model for adverse conditions, which is based on all the main events and mediators that led to that situation (Cheliyan and Bhattacharyya, 2018; Fu et al. 2016)). The results of the ETBA are effective in estimating risk values and evaluating specific options to eliminate or control the risks (Ahmadi et al 2019). The method is commonly used in system safety analysis. The Energy Trace and Barrier Analysis (ETBA) method is an essential tool to examine the safety of systems, based on the management Oversight and Risk Tree (MORT) (Mohammadfam et al. 2012).

This study aimed to evaluate quantitative risk and present a new conceptual model in the incident of fire in oil storage tanks in a refinery unit. Using the results of modeling and quantitative risk assessment, it is possible to correctly identify and prioritize the causes of damage and damage to humans and equipment, and based on which preventive control measures are designed and implemented.

Material and Methods

Case study

The Tehran Oil Refinery Company is located 15 kilometers south of Tehran and consists of two refineries, South and North. The refinery accounts for about 15 percent of Iran's refinery capacity and supplies most of the fuel consuming needs, especially gasoline for the city and province of Tehran. The case study of this research was TK-2002 oil storage tank (atmospheric float roof tank) as one of the Tehran Oil refinery tanks.

Loss causation and Swiss cheese Combination model

Domino Loss Causation Model

The Domino Loss Causation Model is a tool that can be used to investigate events to help identify the root causes of accidents in the workplace (figure 1). This method is a structure for identify and categorize multiple events that lead to an incident (Bird and Germain. 1996).
The symbol of the surreas in cheese are the last level of activity carried out by the human factor and the safety of them has not been addressed.

By combining the two methods of Loss causation and Swiss cheese, our proposed model was designed to the fire risk determination (figure 2).

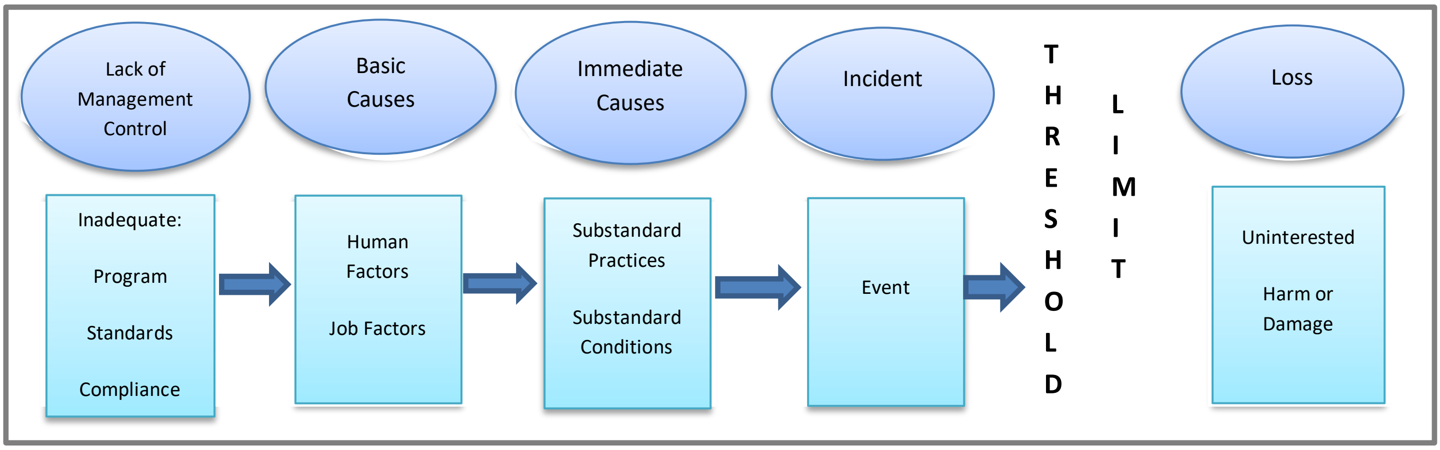

Figure 1. Domino Loss Causation Model

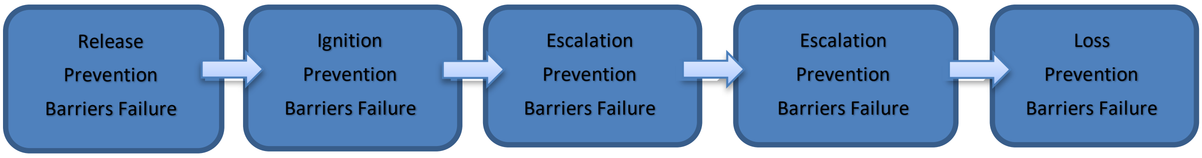

Figure 2. Proposed model for of fire event factors determination

Fault tree analysis (FTA)

The final model of the fire hazard identification was obtained in hydrocarbon tanks using the FTA model.

ETBA technique

After implementation of the hazard identification model, ETBA method was used to evaluate the fire risk in the tank. ETBA is a system analysis process that helps to identify hazards by focusing on the presence of energy in the system and the available barriers to its control. Energy Trace and Barrier Analysis used as a tool for systematic analysis of accidents causes. This method has resulted from MORT technique. In the ETBA method, risk assessment is a significant part (Mohammadfam et al. 2012).To evaluate the risk and risk quantification of the Risk Assessment Inventory in the refinery, TR-IMSP-0401, derived from the OGP guide is used. Qualitative risks identified were quantitated and risk ratings for each of the underlying causes were performed and risk categorization was identified.

Results and Discussion

Quantitative risk assessment of hazards, such as the release of flammable and explosive chemicals in the environment, is one of the essential steps to increase the level of safety in existing units or in process design (Moshashaei and Alizadeh, 2016). The identification of hazards and the degree of vulnerability of industrial processes can be implemented through various methods (Wei et al., 2018). The ETBA risk assessment lasted a total of 10 sessions, with 30 worksheets completed in these sessions. The amount of time spent on this study included library studies, technical studies, field studies, observations, interviews with operational personnel, and a total of 1300 hours. Totally, 22 risks were identified by the ETBA technique that four were unacceptable risks as presented in figure 3. The ETBA is based on the logic that the damage caused by the accident is caused by unwanted exchanges that occur during the passage of energy from the shield into the targets for exposure. Tracing the energy and efficiency of barriers is a qualitative analysis method used to develop more details of hazards (Mohammadfam et al., 2012). Therefore, using ETBA, the risks in the process unit studied can be discovered be employing the principle of tracking energy flows in systems or operations (Pramanathan et al., 2018).

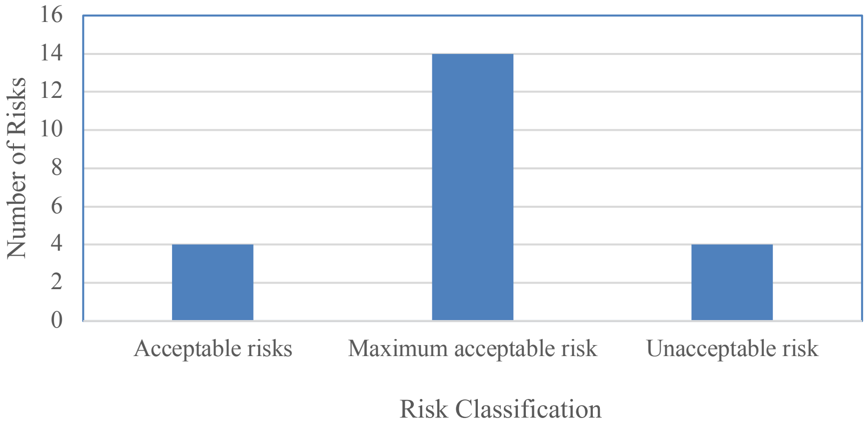

Figure 3. The identified risks in the ETBA method

For unacceptable risks corrective actions have been proposed to reduce the level of risk. (Table 2). Table 1 showed the range of risk levels.

Table 1. Level of risk in this study

1 =< R <= 5	Acceptable risk	(blue)
6 =< R <= 12	(ALARP) Acceptable risk	(yellow)
15 =< R <= 25	Unacceptable risk	(red)

With regard to the energy risk of 2-5 (thermal energy) in the floating roof tank (TK-2002), the fire in these tanks can be one of the main hazards of storage units. Given that crude oil tanks supply feed to refineries, any disruption in the activity of these tanks could endanger the production continuity and cause irreparable damage (Dadashzadeh et al., 2018). Therefore, due to the high importance of these tanks, special measures should be taken to increase their safety factors. Therefore, looking for ways to reduce the unacceptable risk is very important (Török et al., 2019).

Following the implementation of the proposed risk identification model and the ETBA assessment in the case study, it is essential to perform the following tasks in the refinery tanks unit:

- Review of precision instrumentation equipment (especially alarms)
- Review of F & G systems
- Design and installation of a lightning strike
- Automating some of the equipment that is manually placed on the service
- Update operational maps
- Exact execution of the locking and labeling system
- Revision and modification of equipment layout
- Reinforcing the tanks
- Fireproof the bases of tanks and supports

- Modify access levels
- Implementation of the workshop discipline system
- More attention to the principles of defective defense
- Review and perform corrections of noncompliance cases during Overhaul

Table 2. ETBA Work Sheets

No	Equipment Name	Type of energy	Energy Describe	Potential Objectives	Barriers	Severity	Probability	Control action	Risk level	Control action
1	Tk-2002	1-2	Move the fluid inside the container / Static electricity generation / Static electricity drain / Ignition	Equipment - product - People - Continuity of production -environment	- Earthing system - Fluid pump speed instructions - Education	4	2		8	
2	Tk-2002	7-4	Increase the volume of fluid in the container / Increase fluid level / Fluid overflow from tank / Drowning floating roof / Ignition	- Equipment - product - People - Continuity of production -environment	-Auto bilider vent - LI-2002	4	4	Installation of LAH & LAHH	16	Installation of LAH & LAHH
3	Tk-2002	7-3	Opening flanges or not using proper flush / Material leakage / Ignition	- Equipment - product - People - Continuity of production -environment	Visit and continuous monitoring	4	2	Installation of Gas Alarm system	8	Installation of Gas Alarm system
4	Tk-2002	2-5	External Fire	- Equipment - product - People - Continuity of production -environment	- Cooling system	5	3	Fire alarm system / Cooling system/ Automatic fire extinguishing system Fire @ Gas	15	Fire alarm system / Cooling system/Automatic fire extinguishing system Fire @ Gas
5	Tk-2002	2-11	heavy Rain and snow / Drowning floating roof	- Equipment - product - People - Continuity of production -Environment	Drainage system embedded tank roof	4	1	-	4	-
6	Tk-2002	4-7	fluid Move in the tank /Static electricity generation / equipment wall corrosion	- Equipment - product - People - Continuity of production -Environment	Earthing system/ cathodic protection	3	3	Timely overhaul (thickness measurement(	9	Timely overhaul (thickness measurement(
7	Tk-2002	1-7	The stored pressure of the peripheral equipment/ Material leakage / Ignition	- Equipment - product - People - Continuity of production -Environment	Timely overhaul The fence round the tanks	3	3	-	9	-

No	Equipment Name	Type of energy	Energy Describe	Potential Objectives	Barriers	Severity	Probability	Control action	Risk level	Control action
8	Tk-2002	1-10	Earthquake / Ignition and explosions	- Equipment - product - People - Continuity of production - Environment		5	2	-	10	-
9	Tk-2002	5-1	Hot work and Spark production	- Equipment - product - People - Continuity of production - Environment	Instructions for hot work doing PTW system	4	2	Supervising the work	8	Supervising the work
10	Tk-2002	1-9	Lightning collision	- Equipment - product - People - Continuity of production - Environment	Bonding and earth connection system	5	1	-	5	-
11	Tk-2002	4-8	Flammable materials	- Equipment - product - People - Continuity of production - Environment	-	4	4	Revision of F & G system	15	Revision of F & G system
12	Tk-2002	12-1	Failure to comply with operating instructions during operation / fluid level Increase / Fluid overflow from tank / Residual discharge valve	- Equipment - product - People - Continuity of production - Environment	-	3	4	People Monitoring / training	12	People Monitoring / training
13	Tk-2002	8-2	Lack of corrosion control and material leakage	- Equipment - product - People - Continuity of production - Environment	Periodic inspection program	2	2		4	
14	Tk-2002	1-4	Thrown things /Bullet / Dealing with equipment and fittings/ Ignition	- Equipment - product - People - Continuity of production - Environment	Insulation of pipes	4	2	Principles of defective defense	8	Principles of defective defense
15	Tk-2002	4-7	Move the fluid in the tank / Fluid turbulence / Drowning floating roof / Over Filling	- Equipment - product - People - Continuity of production - Environment	Guide pole	4	2	LAH Installation	8	LAH Installation
16	Tk-2002	3-11	Too much cold air / Deposition of crude oil in the tan / Lack of pumping	- Equipment - product - People - Continuity of production - Environment	- Steam coil - Steam side - Ti-2002 - MX-2002	3	2	TAL Installation	6	TAL Installation

No	Equipment Name	Type of energy	Energy Describe	Potential Objectives	Barriers	Severity	Probability	Control action	Risk level	Control action
17	Tk-2002	1-4	Thrown things /Bullet / Dealing with equipment and fittings/ Ignition	- Equipment product - People - Continuity of production -environment	Pipe insulation	4	2	Principles of defective defense	8	Principles of defective defense
18	Tk-2002	6-2	Failure in the shelling system of the tanks during fire and fire spreading to adjacent tanks	- Equipment - product - People - Continuity of production	Firefighting Instructions for tanks Periodic inspections by fire stations	5	2		10	
19	Tk-2002	1-12	Do not evacuate people from the burning tanks	- People	ERP Instruction	3	3	Training	9	Training
20	Tk-2002	13-1	Use the cellphone in the tanks Bondawall area / Ignition	- Equipment - product - People - Continuity of production	Use of explosion-proof wireless	2	5	Determine the prone areas of the line (zoning) in accordance with IEC & NEC500 standards	10	Determine the prone areas of the line (zoning) in accordance with IEC & NEC500 standards
21	Tk-2002	13-1	Entry of gasoline-powered car to the tanks Bondawall area / Ignition	- Equipment - product - People - Continuity of production	Use of diesel vehicles	2	2	Determine the prone areas of the line (zoning) in accordance with IEC & NEC500 standards	4	Determine the prone areas of the line (zoning) in accordance with IEC & NEC500 standards
22	Tk-2002	2-5	The presence of water in the burning tank and the creation of Boil Over	- Equipment - product - People - Continuity of production	Drainage of water at the bottom of crude oil tanks Do not pour water into the burning tank	5	3	Cooling the burning tank to prevent the occurrence of Boil Over	15	Cooling the burning tank to prevent the occurrence of Boil Over

Conclusion

Quantitative risk assessment Dangers such as releases of flammable chemicals and explosions in the environment are one of the essential steps to increase the safety level in existing units or in process design.

The proposed integrated model in this study presented with the aim of drawing an incident scenario in the study unit. It showed that by combining the two techniques of Swiss cheese and Loss Causation, it is possible to create an integrated method for modeling process incidents. The identification of hazards and the degree of vulnerability of industrial processes can be implemented through various methods. Using Loss Causation Hierarchical Technique in combination with the Swiss cheese model, a new model was designed to identify the causes of the occurrence of fire. Each safety barrier was split into sub-branches in order to illustrate the more detailed factors, which in this section FTA method was helpful. Fault tree analysis is a hierarchical and logical model for adverse conditions, which is expressed in terms of all possible scenarios of the main events and mediators that led to that situation. The results of the

ETBA provided a quantitative risk assessment and identification and evaluation of specific options for the elimination or control of dangers. This method is commonly used in conjunction with the safety analysis of the system. This technique was the final part of this research.

References

Abul-Haggag, O.Y., Barakat, W. (2013). Application of Fuzzy Logic for Risk Assessment using Risk Matrix. International Journal of Emerging Technology and Advanced Engineering, 3(1).

Ahmadi, O., Mortazavi, S. B., Pasdarshahri, H., and Mohabadi, H. A. (2019). Consequence analysis of large-scale pool fire in oil storage terminal based on computational fluid dynamic (CFD). Process Safety and Environmental Protection, 123, 379-389.

Amyotte, P.R., and Oehmen, A.M. (2002). Application of a Loss Causation Model to the Westray Mine Explosion. Process Safety and Environmental Protection, 80(1), 55-59.

Bird, F. E., and Germain, G. L. (1996). Practical loss control leadership. Georgia: Det Norske Veritas (USA).

Cheliyan, A.S., Bhattacharyya, S.K. (2018). Fuzzy fault tree analysis of oil and gas leakage in subsea production systems. Journal of Ocean Engineering and Science, 1-11.

Dadashzadeh, M., Kashkarov, S., Makarov, D and Molkov, V. (2018). Risk assessment methodology for onboard hydrogen storage. International Journal of Hydrogen Energy, 43, 6462 – 6475.

Fu, S., Yan, X., Zhang, D., Li, C. and Zio, E. (2016). Framework for the quantitative assessment of the risk of leakage from LNG-fueled vessels by an event tree-CFD. Journal of Loss Prevention in the Process Industries, 43, 42 -52.

Ibrahim, H. A., and Syed, H. S. (2018). Hazard Analysis of Crude Oil Storage Tank Farm. International Journal of Chem Tech Research (pp. 300-308).

Jafari, M. J., Zarei, M., and Movahhedi, M. (2012). The Credit of Fire and Explosion Index for Risk Assessment of Iso-Max Unit in an Oil Refinery. International Journal of Occupational Hygiene, 4, 10-16.

Jensen, N. (2007). Modifying the Dow Fire & Explosion Index for Use in Assessing Hazard and Risk of Experimental Setups in Research Laboratories. 12th International Symposium on Loss Prevention and Safety Promotion in the Process Industries" - Edinburgh, Scotland, United Kingdom.

Mohammadfam, I, .Mahmoudi, S., and Kianfar, A. (2012). Comparative safety assessment of chlorination unit in Tehran treatment plants with HAZOP & ETBA techniques. Procedia Engineering 45, 27–30.

Moshashaei, P. and Alizadeh, S. (2016). Fire Risk Assessment: A Systematic Review of the Methodology and Functional Areas. Iranian Journal of Health, Safety & Environment, 4(1), 654-669.

Pramanathan, S. S., Tauseef, S. M., Kumar, D., and Mohanty, P. N. K. (2018). Quantitative Assessment of Risk Caused by Domino Accidents in Chemical Process Industries. In Advances in Fire and Process Safety (pp. 45-55). Springer, Singapore.

Reason, J. (1990). Human error. Cambridge: Cambridge University Press.

Russoa, P., De Marcoa, A., Mazzarob, M. and Capobianco, L. (2018). Quantitative Risk Assessment on a Hydrogen Refuelling Station. Chemical Engineering Transactions, 67, 739-744.

Šakėnaitė, J. (2010). A Comparison of Methods Used for Fire Safety Evaluation. Mokslas – Lietuvos Ateitis, 2(6).

Shapiro, A. F & Koissi, M. C. (2015). Risk Assessment Applications of Fuzzy Logic. Casualty Actuarial Society, Canadian Institute of Actuaries, Society of Actuaries.

Suhaimi, N. S. and Mustapha, S. (2016). A Review of Fire Risk Assessment Tools in Compartment. ARPN Journal of Engineering and Applied Sciences, 11(11), 7284-7287.

Tauseef, S. M., Abbasi, T., Pompapathi, V., and Abbasi, S. A. (2018). Case studies of 28 major accidents of fires/explosions in storage tank farms in the backdrop of available codes/standards/models for safely configuring such tank farms. Process Safety and Environmental Protection, 120, 331-338.

Török, Z., Petrescu-Mag, R. M., Mereuță, A., Maloș, C. V., Arghiuș, V. I., and Ozunu, A. (2019). Analysis of territorial compatibility for Seveso-type sites using different risk assessment methods and GIS technique. Land Use Policy.

Wajdi Akashah, F., Anak Kayan, B. and Haniza Ishak, N. (2013). Quantitative Risk Assessment for Performance-Based Building Fire Regulation. The 3rd International Building Control Conference, Kuala Lumpur, November 21, 2013.

Wang, T., Li, Y., Xie, T., Liu, Y., and Zhu, X. (2018). Analysis on Dangerous Source of Large Safety Accident in Storage Tank Area. In IOP Conference Series: Earth and Environmental Science (108 (4), p. 042044). IOP Publishing.

Wei, T., Qian, X. and Yuan, M. (2018). Quantitative risk assessment of direct lightning strike on external floating roof tank. Journal of Loss Prevention in the Process Industries, 56, 191-203.