Modeling the Consequences of Accidents during the Process of Transferring Waste Thinner from the Paint Shop of an Automotive Industry using ALOHA Software

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Abstract

Aims: During the past decade, the application of engineering and managerial techniques for designing a variety of qualitative and quantitative risk assessment methods and modeling the consequences of accidents have had a great contribution to the promotion of safety in the industrial systems. The present study was conducted to identify and prioritize safety risks in one of the automotive industries. Risk management of the operation of transferring waste thinner from the paint shop represents a critical issue owing to special safety. **Materials and Methods:** One of the most important theories for the modeling of events is the bowtie analyzing method. Bowtie is a qualitative analyzing method which incorporates managerial system techniques and provides a highly accurate analysis in the form of fault and event trees. In the present study, the process of risk identification and management was carried out using the Bowtie analyzing method and the obtained results were applied to the structure of a bowtie graph and the consequence was modeled using ALOHA software. **Results:** In the study, the operation of transferring waste thinner from the paint shop of an automotive industry was examined. Possible safety risks that may happen during the loading and unloading operations of the waste thinners were detected using bowtie analyzing method and the modeling of fire at chemical tanker carrying thinner and also the modeling of BLEVE phenomenon was conducted. The results represent that the area, in which employees are stationed is at very high risk that in the event of a possible fire, the personnel will be quickly caught in fireballs caused by the burning of thinner. **Conclusion:** According to the results, it was found that one of the administrative units is positioned inappropriately and incorrectly in the vicinity of thinner loading station that in the case of nondisplacement of the mentioned unit and the incident of fire or explosion in the place of loading and unloading of thinner, undoubtedly there would be fire at the mentioned administrative unit.

Keywords: ALOHA, bowtie, explosion, fire, risk management

INTRODUCTION

Developed countries and in particular, the developing countries, are faced with the risk of industrial accidents in their industries that depending on the consequences of the accidents, they may cause great and irreparable physical and financial damages. Considering the economic and political competition in today's world, industrial accidents and crisis are considered as one of the damaging factors for the growth and economic development of countries.[1-3]

During the past decade, the application of engineering and managerial techniques for designing a variety of qualitative and quantitative risk assessment methods and modeling the consequences of accidents have had a great contribution to the promotion of safety in the industrial systems. Identification, assessment, and control of hazards before the occurrence of accidents has always been a major concern of system safety experts. The base of safety of any system is the analysis of hazards. Risk management systems sought to reduce the level of existing risks to the extent that is tolerable for the system.[2,4-6]

The results of qualitative and quantitative assessment of risk and modeling of the consequences of accidents can be used for

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geographical placement and identification of the industries, to determine all necessary parameters for the design of equipment and facilities, for comparative evaluation in choosing different designs and plans, to determine and apply appropriate models for crisis and disaster management, for the identification of severity of the possible consequences of accidents and damages on the equipment, and hundreds of other items.

"Analysis of Consequence Modeling Software of PHAST and ALOHA" is the title of article that has been presented by Langari in 2010. In this paper, initially, the necessity of the assessment process of consequences and steps of its implementation has been highlighted and ultimately the advantages and disadvantages of PHAST and ALOHA software have been studied and analyzed. PHAST and ALOHA have been compared in terms of hazardous substances data bank, prediction of concentration in a specific moment and place, radiation graphs of fire and blast wave, wind speed, geographical conditions, land surface roughness, distance and duration of modeling, and selection of specific consequences by the user and by examining the menus and graphs of both software.[7]

"The Role of Bowtie Method in the Improvement and Optimization of the Risk Management Process" is the title of a study that has been conducted by Sameti in 2011. It is a descriptive study that in addition to introducing the bowtie method, it also shows the advantages of bowtie method in optimizing risk management through awareness and satisfaction of workforce and also through improved inspection processes. In this study, the bowtie model clearly describes the required balance through the relationship between hardware and software systems as well as the relationship between the hazards and their consequences, and on the other hand, the necessary barriers and compensation measures designed to prevent accidents and chain of consequences and the way of controlling them in safety, health, and environment management system are also demonstrated by the bowtie model.[8]

"Application of Bowtie Techniques in the Analysis of the Accident in SRP unit of Tehran's Tondgooyan Refinery" is the title of article that has been presented by Tekye *et al*. in 2011. In this study, one of the important process – accidents, which has led to the death of people at the National Iranian Oil Refining and Distribution Company, has been modeled using the bowtie technique (the most effective and modern method for analyzing the events). The study showed that the use of bowtie technique, which is a systematic and analytical method, is very effective in determining the causes of events and also in specifying critical tasks aimed at ensuring the integrity and effectiveness of ongoing controls and plays an important role in identifying key performance indicators of HSE and in improving them.[9]

"Propane Leak Propagation Modeling in an Industry" is the title of an article that has been conducted by Golbabaei in 2012. The case of the study was an industrial center in the East

of Tehran. Input data were entered into software on the basis of the regional weather conditions and it was found that at a distance of 1 km, propane density is 17 times higher than the existing TLV, and on the other hand, the effect of explosion is more destructive at this distance, which results in the loss of around 916 personnel and 130 drivers as well as financial losses of at least 401 billion Toman. Therefore, recommendations such as constructing and equipping crisis management and the rescue center, installing dikes, fencing and controlling the traffic, ensuring that the equipment near the tank have the "Ex" (a symbol for an explosion-protected devices) symbol to prevent and control the hazards of dissemination of propane were proposed.[10]

An article entitled as "Application of Bow-tie Method in the Risk Assessment of Pigging Operations of Gas Pipelines in the Tenth Region during the Gas Transmission Operations" was carried out by Kabiri *et al*. in 2014. The application of bowtie method in the risk assessment of pigging operations of gas pipelines in the tenth region during the gas transmission operations was examined and studied in this paper. In this study, the bowtie method was presented as a useful tool for introducing risk.[11]

"Analysis of Road Accidents Caused by the Transport of Toxic Gases in Hassan AbadLocated on the Transit Route of Tehran-Bandar Abbas" is the title of the study that has been conducted by Owari in 2014. In this article, the effects caused by the toxic gas leakage have been discussed. To simulate the affected area, Gaussian or heavy gas model was used, in which effects related to speed and direction of wind and atmospheric conditions were taken into consideration. For implementing the case study, the affected areas were detected using ALOHA software, and then, these areas were entered into Geographical Information Systems (ArcGIS v 9.3) and special features of GIS were used for the spatial analysis. Considering that the place of accident was the city of Hassan Abad, the number of people at risk of death from ammonia gas was equal to 386.[12]

Heyrani and Baghayi (2015) conducted a study which was entitled as "Risk Assessment of Oil and Gas Transmission Pipelines on the Basis of Fuzzy Bowtie Method." In this study, the bowtie method was used in combination with fuzzy logic and by employing a Likert scale method for quantifying qualitative (linguistic) data in order to reduce uncertainty in risk assessment of No. 10 pipelines of Amak gas and No. 12 pipelines of Bangestan oil, in a way that, initially, factors affecting the safety of transmission lines were determined by preparing checklist, and then, the risk of studied pipelines were assessed using the mentioned methods. According to the obtained results, instructions were provided to reduce and control the potential consequences with emphasis on eliminating possible causes of them.[13]

"Modeling the Consequences of Hexane Leakage from Storage Tanks and Planning an Emergency Response Program in a Petrochemical Complex" is an article that was written by Beheshti in 2016. In this study, beside the explanation

of factors that affect unloading and release of substances, ALOHA software has been used as one of the most appropriate software for modeling hexane emissions from the storage tank with the capacity of 579 thousand gallons in one of the units of petrochemical and on the basis of results of modeling, emergency response plans were prepared and presented at the time of leakage of hexane. According to the results of study, the diameter of the emerged pool is 200 m and up to 140 m around the reservoir, the concentration of hexane gas is 8600 ppm that threatens the life of people who live in this region. Consequence of hexane toxicity is the most serious danger that threatens personnel. Provision of response plan in emergency conditions would have an important role in limiting the harmful effects that are caused by the emission of hazardous and toxic gases.[14]

A study entitled as "Risk Assessment and Modeling of Consequences of the Blast Wave of BLEVE Phenomena of LPG Spherical Tank in a Refinery" was conducted by Komaei *et al*. in 2016. In this study, the risk of phenomena of boiling liquid expanding vapor explosion (BLEVE) was assessed using the bowtie method and consequence of blast wave of BLEVE phenomena was also examined and the resulting wave quantity and its impacts on the neighboring machineries and equipment were analyzed. In this assessment, generally five causes and two consequences were identified for BLEVE phenomenon. To reduce its consequences, 43 controlling measures were introduced to prevent the BLEVE phenomenon and the impacts of 31 control measures were identified. According to the conducted analysis, it was found that the spherical tank blast wave caused by LPG can lead to explosion of tanks that are near the LPG and it can create a chain of explosions.[15]

"The bowtie method: A review" is the title of article that was presented by Ruijter and Guldenmund in 2016. In this article, qualitative and quantitative bowtie methods are introduced. Quantitative bowties use a fault tree together with an event tree and barriers to calculate risk. Qualitative bowties use simpler cause–effect scenarios with barriers to communicate the risk to an audience.[20]

As whole, the previous studies highlight the importance of risk management and modeling the consequences of process accidents. It is necessary to identify and prioritize safety risks

so that major factory risks can be managed in better manner.

In this research, for the first time in car manufacturing factory, we identified the risks and hazards of industry based on the bowtie technique and ALOHA software. The strength point of this research is that the selected methods were able to assess and manage all the potential and actual risks in the Process of an Automotive Industry. The weakness point of this research is the lack of necessary collaboration between the factory staff.

MATERIALS AND METHODS

The present study was conducted to identify safety risks in car manufacturing factory and manage them using ALOHA and bowtie techniques. The research was carried out in unloading operations of waste thinner from temporary storage. This is an applied research. Data were collected using inspection, audit, risk assessment, safety checklists, documentation of past accidents, technical documentation of unloading operation, meteorological, and geographical information. Bowtie technique was used for risk management and ALOHA software was applied to modeling of fire and explosion consequences. Using these methods, it was possible to manage and control process hazards and risks.

Risk management process and bowtie method
This method of analysis uses the risk matrix to categorize the various scenarios and then carries out more detailed analysis (in the form of fault and event trees) on those with the highest and unacceptable risks.[21,22]

For building a bowtie diagram in Figure 1, we would need data about events (that the intention is to prevent it), threats (that the cause of the events), consequences (after the occurrence of event), controls to prevent the occurrence of events, and control to reduce the effect of consequences.[23-26]

For building a bowtie diagram, the following details and data are required:
- Event – an event that we want to prevent it
- Threat – threats that are the cause of the event
- Consequence – consequences after the occurrence of event
- Control – controls to prevent the occurrence of the event
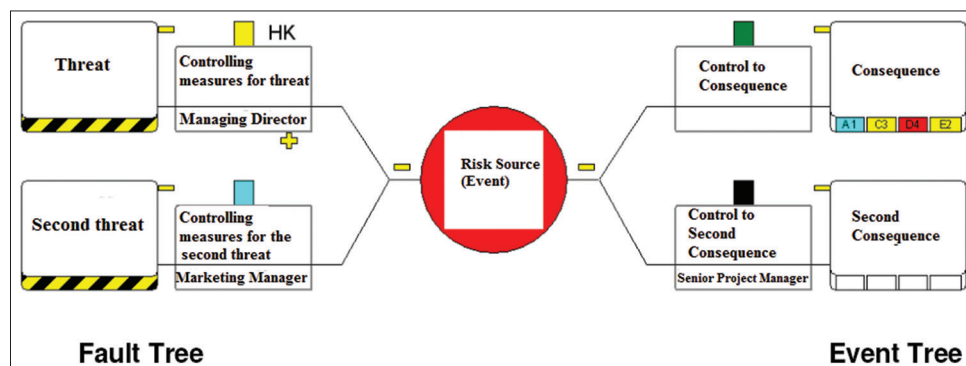- Control to Consequence – controls to reduce the effect of consequences.

Figure 1: Structure of the diagram of bowtie analyzing method

Process of building a bowtie diagram

The process involves the systematic identification of hazards and effects, assessment of the associated risks, and the specification of the control and recovery measures which must be in place and maintained in place. The bowtie process is iterative and is often carried out by a team.

The steps are as follows:

Step 1: Identifying the hazards:
- Are the people and the staff, environment, assets and properties, current activities of organization, or even company's credibility at risk?

Step 2: Assessing the risks:
- What kind of causes and consequences exist?
- Is there any probability of failure of the controlling measures?
- What kinds of risks are involved and are they at a tolerable levels or as low as reasonably practicable?

Step 3: Controls (controlling measures)
- Is it possible to eliminate the cause?
- What kinds of controls are required?
- How effective are controls?

Step 4: Improvement and recovery (corrective and improving measures)
- Can the potential consequences or threats be mitigated?
- What kind of preventive or corrective actions are required?
- Are these measures suitable and sufficient?

The results obtained from the bowtie diagram, in addition to identifying the causes of accidents and making personnel ready for dealing with the possible consequences, provide the possibility to create a detailed and documented plan to prevent the occurrence of new accidents and the like for the management and all other responsible units.

Modeling of consequences of process – accidents and ALOHA software

ALOHA software is a modeling program that is used professionally for training and planning in an emergency situation caused by the dissemination and release of chemicals in industries and factories. Significant hazards, including the hazards of toxicity, flammability, heat resulted from thermal radiation, and overpressure of explosive blast force (that can result in the release of chemicals) are modeled by ALOHA software. This modeling can include the release of toxic gases, fire, or explosion.

Database of this software contains the physical properties of approximately 1000 common and widely used chemicals, and this database is editable and the data related to any chemical substance can be added to it. This software has very high accuracy and speed in performing the calculations and processing that are required for modeling.

ALOHA software has been designed for responding and reacting in the shortest time possible and also for obtaining the most accurate and complete results, and it minimizes user errors. This software is able to check input data, and in the case of error, it notifies the user.

Using the ALOHA software, fire and explosion scenarios can be modeled like the toxic gases emission scenarios. ALOHA models the release of chemicals using four types of sources that are as follows: direct, puddle, tank, and gas pipeline.[16-19]

RESULTS: THE STUDY OF PROCESS OF TRANSFERRING WASTE THINNER FROM A PAINT SHOP OF AN AUTOMOTIVE INDUSTRY (CASE STUDY)

Circulation unit in the paint shop of automotive industries

In general, car manufacturing factories are consisted of various production halls and sections that each is responsible for a part of the production process. One of the most important processes is the process of painting the body of the vehicle. Paint shops of automotive industries are among the highly complex and sensitive parts that a set of chemical processes occur in them. One of the most important parts of paint shops are the circulation units. Preparation of paint for sending it to spraying cabins and robotic paint feed system is on circulation unit. In fact, paint circulation process refers to the series of activities in which paint is prepared for being sprayed and it is charged into the lines through the pipelines and once again, it is returned to the initial tank. Washing process of the paint transmission lines, spraying cabins, and robots are totally performed by chemical thinner. All the consumed thinner are returned into a cylindrical tank (with a capacity of several 1000 L) by a return line. The returned thinners are not usable, and because of this, they are called waste thinner. The waste thinner is temporarily accumulated in the mentioned tank to be unloaded from the paint shop at the earliest opportunity. Before the completion of capacity of the waste thinner containing tanks, the accumulated thinners are loaded by tankers carrying dangerous chemicals and they are immediately taken out from the company and are sent to chemical industry companies for reprocessing, refining, and recycling.

Risk management of loading operations of waste thinner on the basis of bowtie method

Unloading operations of waste thinner from temporary storage tank located in the circulation hall and loading it by tankers carrying dangerous chemicals are performed periodically and before the completion of the capacity of the tank. The mentioned activity is very important from two perspectives of production and safety. If the unloading operation is not performed timely, the production line of paint shop will be stopped and violation of safety principles and rules of loading and unloading operations would cause accidents and irreparable consequences. Chemical thinner is highly flammable and volatile due to its chemical properties and incidence of any uncontrolled event can result in the release, fire, or explosion of this chemical substance that this can cause

damage to people, equipment, or the environment. The bowtie diagram designed for the loading and unloading operations of waste thinner is presented in Figure 2.

Application of ALOHA software in modeling the consequences of ignition of waste thinner carrying tanker

Thinner leakage, ignition, or explosion of the tank and the tankers that contain thinners are among the possible scenarios for loading and unloading operations of waste

thinner from the circulation unit of a paint shop is an automotive industry. In the following part, we are going to study the scenario of BLEVE phenomena in the tank of thinner carrying tanker in the station of loading and unloading thinner.

The exact details of data recorded in the ALOHA software for processing and determining hazard distance are presented in Table 1.
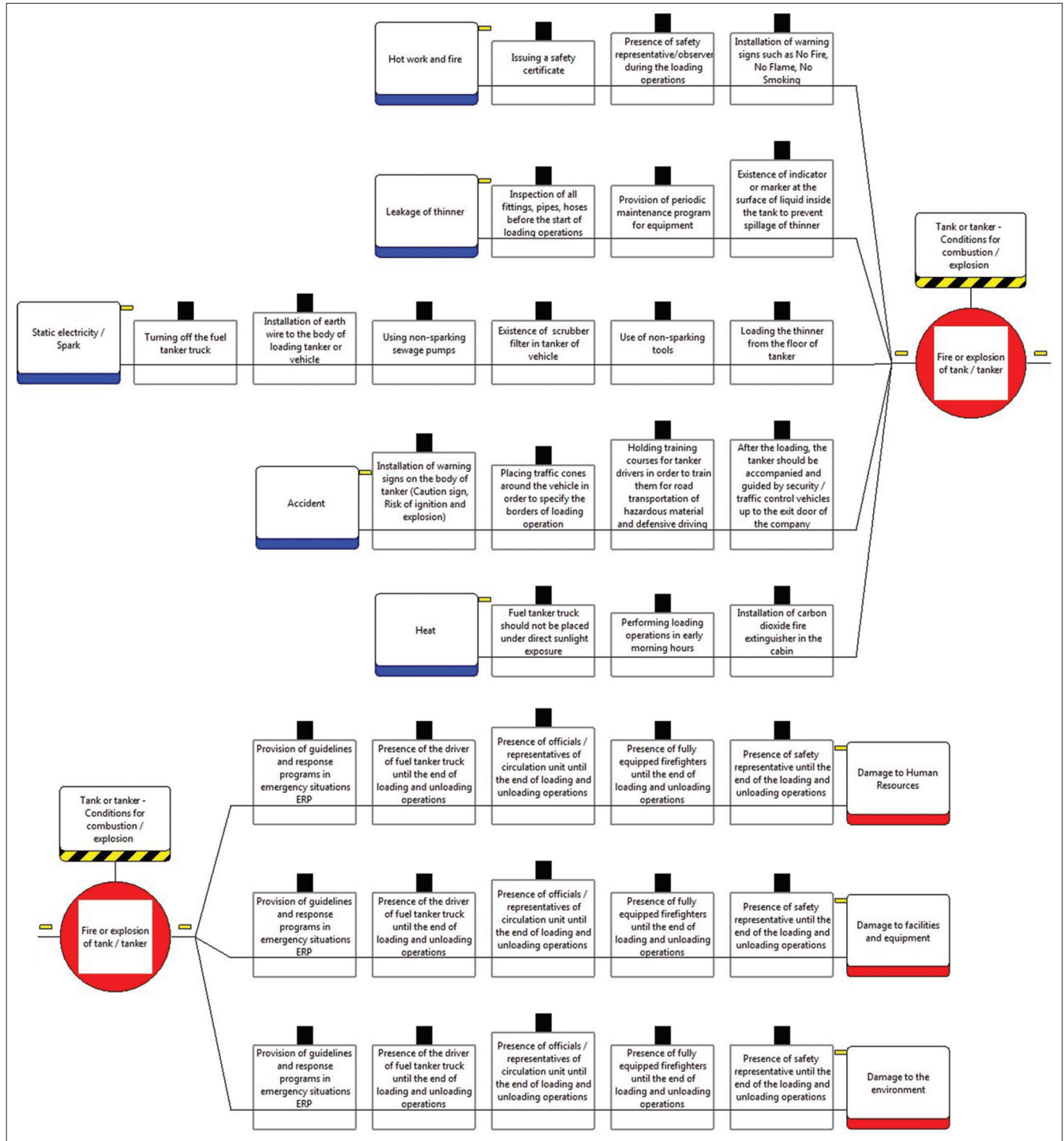

Figure 2: Bowtie diagram of the loading and unloading operations of waste thinner from the paint shop of an automotive industry

Table 1: Details of the recorded data for modeling the scenario of boiling liquid expanding vapor explosion phenomena in ALOHA software

Data entry procedures	The recorded data
Determining the geographic location (city) of scenario	City name: Tehran
	Height above mean sea level: 1047 m
	Time difference with GMT:+ 3: 30
Determining the time (h) and the date of release of scenario	Date of occurrence of event: July 30, 2016
	Time of the event: 14:20 at local time
Determining the structure and type of studied building in the scenario	This parameter is not used for fire and explosion scenario
Choosing the type of studied chemicals in the scenario	Thinner
Entering the information about the weather conditions of region at the time of the release of chemical	Wind speed is 11 m per s
	Wind direction is from the South (S)
	Height of measuring wind speed is 3 m from ground level
	Surface roughness of the city
	Clear sky and no clouds
	Air temperature is 42°C
	Stability class: C
	Absence of temperature inversion
	Relative humidity is 20%
Description of the way of leakage and release of the chemical substance from resources or their maintenance container	Type of the tank of tanker for transport of chemicals: Cylindrical
	Tank capacity: 6500 l
	Tank dimensions: 3.83 m in length and 1.47 m in diameter
	The current temperature of the tank: Ambient temperature
	Filled tank volume: Ninety percent of the total volume
	Kind of the studied scenario: BLEVE phenomenon

BLEVE: Boiling liquid expanding vapor explosion, GMT: Greenwich mean time, ALOHA: Areal locations of hazardous atmospheres

After entering all the above information into the software and performing the necessary processing, the radius of danger zone was determined on the basis of released material and the nature of the potential hazards. Figure 3 shows the threatened areas on the basis of the intensity of thermal radiation. On the basis of the input data, the software has estimated that fireballs resulted from the BLEVE phenomena have an approximate diameter of 102 m and burn for about 8 s.

DISCUSSION AND CONCLUSION

By looking at the results obtained from risk management of loading operations of waste thinner and modeling of BLEVE phenomenon of thinner tank of chemical tanker, threat zones were fully identified and disaster-prone areas were discovered. All areas that in the accident of BLEVE phenomenon and possible ignition of tank would be caught in flames and the resulted heat were identified. With this information in hand and the results obtained from the scenario of BLEVE phenomenon, we can now make a conclusion
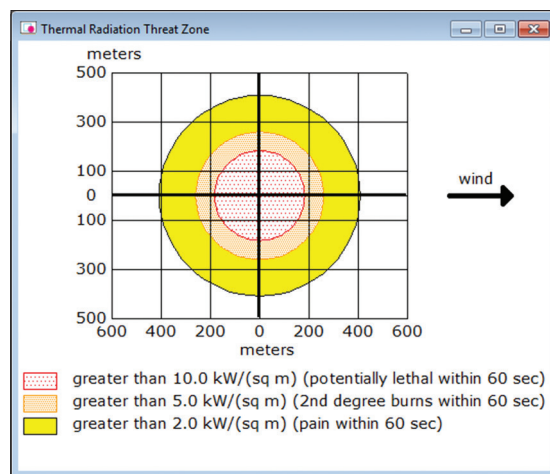

Figure 3: Threatened areas on the basis of the intensity of thermal radiation

about the assessment of the possible consequences of combustion in the tankers.

An administrative office has been embedded in the paint shop and at a very short distance from the place of loading and unloading of thinner. The distance of this office with four employees stationed at the place of loading and unloading of thinner is exactly 10 m, while according to the estimation of the software and the input data, fireballs resulted from the BLEVE phenomena have an approximate diameter of 102 m and burn for about 8 s, and also, red threat zone (the worst hazard level) spreads in all directions for about 182 m. The results and figures represent that the area, in which employees are stationed is at very high risk that in the event of a possible fire, the personnel will be quickly caught in fireballs caused by the burning of thinner. According to the results, it was found that one of the administrative units is positioned inappropriately and incorrectly in the vicinity of thinner loading station that in the case of nondisplacement of the mentioned unit and the incident of fire or explosion in the place of loading and unloading of thinner, undoubtedly there would be fire at the mentioned administrative unit.

Now that we have analyzed our findings and have obtained clear results about the consequences of fire at the thinner carrying tanker in the place of loading and unloading in circulation unit of a paint shop in the automotive industry, it is time to present effective solutions and recommendations. Since the cost of performing basic reforms and improvements about this issue (relocating offices) would be much less than direct and indirect costs of occurrence of accident for personnel deployed in the vicinity of the loading and unloading position (source of danger); and this relocation is technically applicable, it is recommended to relocate the administrative office and its personnel as quickly as possible and before occurrence of any possible accident. Also in future projects before placing any hardware and software equipment, construction of industrial and administrative buildings disaster-prone areas and potential sources of danger in the surrounding environment should be identified and the necessary inquiries in the field of safety

should be obtained from the safety experts and consultants during the design phase, before the implementation and before the imposition of exorbitant costs.

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Conflicts of interest

There are no conflicts of interest.

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