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VISUALIZATION OF THE POOL FIRE ACTION ZONES WITH USING MAPINFO GIS FOR THE NUMBER OF FILLING STATIONS OF THE ODESSA (UKRAINE) RESIDENTIAL DISTRICT

Проаналізовані сценарії ініціювання та розвитку аварії для ряду автозаправних станцій в масштабі Малиновського району міста Одеса (Україна). Проведені розрахунки радіусів дії факторів ураження для події проливу чи витоку нафтопродуктів. Розроблено метод візуалізації зон дії фактора пожежі проливу із застосуванням MapInfo GIS. Ідентифіковані умови виникнення «ефекту доміно» та розвитку сценарію каскадної аварійної ситуації для груп близько розташованих автозаправних станцій.

Ключові слова: *потенційно небезпечний об'єкт, автозаправна станція, пожежа проливу, геоінформаційна система, ефект доміно.*

1. Introduction

The negative consequences of urbanization processes for the environment are diverse. In general, they lead to dynamic changes in the system «city – surrounding natural environment». Urbanization is not only in the growth of the urban population, today in Ukraine reaches 68.9 %. Changes include the uncontrolled spreading of the territory of cities, the formation of urban agglomerations in place of natural complexes. Along with the increase in population density, its unevenness in the urban space is increasing.

Urbanization processes determine the appropriate concentration of urban services, infrastructure and transport in areas of dense population. An inalienable consequence of the concentration of vehicles in the residential areas of the population is the corresponding tight placement of such potentially hazardous facilities, which are filling stations (filling stations) [1].

Obsolete regulatory acts regulating the design and construction of facilities with increased requirements for fire and explosion safety do not take into account modern requirements for the safety of the location of filling stations in the urban space. As a consequence, a number of filling stations, which, as a rule, belong to different owners, and represent different networks, concentrated in a limited space, at close distances from each other. In cases where an emergency situation occurs at the filling station, those belonging to level «B» [2] and the development of which extend beyond the territory of the filling station, initiate dangerous events at filling stations which location is included in the zone of influence of the accident factors.

So, the work is relevant for assessing and predicting the impact of the emergency on a single filling station on the initiation of dangerous events in groups of filling stations located in the action zone of non-accident factors of the accident.

2. The object of research and its technological audit

The object of research is a system of filling stations of the traditional type within the Malinovsky district, Odessa, Ukraine).

An analysis of potential hazards associated with the peculiarities of the technology of storage and distribution of fuel at filling stations and corresponding scenarios for the development of emergency situations is carried out in [3]. Events that lead to an accident at a single filling station, related both to a violation of the normal technological regime of the filling station (human factor or equipment failure), and to possible cases of depressurization of equipment and violations of the rules of fire and explosion hazard. The former relate to type I events, and the rest to type II events.

The increased fire hazard is inherent in both tanker trucks and cars that can be refueled at the same time, depending on the number of posts fueling oil and oil posts [4]. In the capacitive equipment of the filling station, significant amounts of gasoline and diesel fuel are spouted, which create sources of fire in the case of their leakage. When a fuel leak in a technological well creates the danger of formation of explosive concentrations of the fuel-air mixture (FAM), which, in the presence of an initiation source, can cause the explosion of this mixture in technological wells and create conditions for further development of the accident in underground storage facilities. With an increase in the rate of loading of petroleum products in the tank, a spark discharge can occur that causes an explosion of the vapor mixture and a fire. Thus, the initial event of an accident at a filling station is a leak or a spill of fire and explosion hazard of the product.

One of the most problematic places of functioning of the filling station, as a potential hazardous facility, is their location within residential areas, along motorways with high traffic intensity, along with other infrastructure facilities.

A significant danger is the placement of several filling stations in a limited area, in close proximity to each other.

As a simulation object, 37 filling stations located in the Malinovskiy district of the city of Odessa are selected and refer to the networks of Ukrnafta, WOG, OKKO, Lukoil, Shell, Mawex, Amic, Katral. The main types of work at the filling station are the reception, storage and distribution (refueling) of petroleum products. Calculations are carried out for 4 types of fuel (A-80, A-92, A-95 and diesel fuel). Capacitive equipment of the filling station is standard [5], including a reservoir of capacity of 40 m^3 (maximum possible for a city with a population of more than 200 thousand) and tanks with a capacity of 15 m^3 and 40 m^3. The amount of oil products that can spill onto the free surface as a result of an emergency situation with local destruction of the reservoir and subsequent outbreak of fuel leakage is taken according to [6].

3. The aim and objectives of research

The aim of research is visualization of the zones of thermal radiation action from a pool fire as a result of an accident at a filling station, as well as to identify dangerous consequences for high-risk facilities, are within the limits of influence.

To achieve this aim, the following tasks are defined:

1. To conduct an analysis of possible scenarios for development of an emergency situation at filling stations for oil leakage cases and identify the most dangerous events.
2. To determine the radius of action of the thermal radiation factor for the variatn of pool fire.
3. To evaluate the possibilities of applying the MapInfo GIS geoinformation system for visualization of the affected zones by the consequences of an emergency at a filling station in the urban space.
4. To visualize the destruction zones of the Malinovsky district with thermal radiation in the pool fire scenarios at city filling stations using MapInfo GIS.
5. To identify groups of filling stations dangerous from the point of view of the risk of cascading accidents or the manifestation of the dominoes mechanism and propose precautionary measures.

4. Research of existing solutions of the problem

The problems of increasing accidents at fueling stations of various types of fuel (gasoline, diesel fuel, gas, liquefied gas, hydrogen, etc.) against the backdrop of uncontrolled growth in population density and urban development have been investigated for almost all parts of the world.

Thus, in work [7] the risks of fires in densely populated areas of Kendari, Indonesia are estimated. The developed method for visualizing the probabilities of fires in urban buildings based on GIS Grid geo-information systems is developed. The model demonstrates the increased risks of fires due to the impact of accidents on the arterial highway and the presence of combustible materials in building elements. The GIS Grid system makes it possible to identify areas with high fire risks densely populated in the urban space. The developed model also takes into account the level of hazards in the presence of simultaneous fires.

Minimizing the risk of fires at filling stations located in densely populated residential areas is especially important for China, where at the end of 2006 there were 93,879 gasoline filling stations [8]. The main strategy chosen by the country is the introduction of gas and liquefied gas instead of gasoline as fuel. So, for 5 years the number of city gas filling stations increased 4.5 times (from 130 to 712), and the average annual growth rate of refueling stations related to gas was 34.3 %, and gas – 32.2 %. But the work also notes the risks of operation of process equipment with increased pressure, which may result in an explosion or gas leak.

In Japan in recent years, vehicles on fuel cells and hydrogen are being distributed. Therefore, hydrogen generation stations have become an important infrastructure of cities. Hybrid hydro-petrol stations are inherently safer and more compact. [9] estimates the risks of a hybrid station using the HAZID (HAZard IDentification) method, which examined 314 emergency scenarios using gasoline and organic chemical hydride systems. The most critical scenarios included a significant spiral of flammable substances, an automobile collision and a fire.

The study of the Spanish authors [10] is devoted to the methodology of risk analysis in the technological processes of oil transshipment and spill. HAZOP (Hazard and Operability analysis) method is proposed for the analysis of performance characteristics and relevant harmful factors. The quantitative assessment of the risk of accidents at the terminals of the overload and fuel storage facilities is based on the fault tree analysis (FTA). FTA shows that the most likely event is a fuel spill, and the human factor is very important in all scenarios of possible accidents. The importance of the human factor and the qualifications of personnel is also noted in [11] using the example of managing the operational risks of gasoline filling stations in Kenya.

In order to achieve the fire safety of Korean filling stations operating on liquefied gas, scripts for flare fires, pool fires, and explosions by the BLEVE mechanism (Boiling liquid expanding vapour explosion) have been investigated [12]. The calculations carried out for the last scenario shows that if the emergency situation occurs with a leakage of 10 tons of butane, then the fireball with a diameter of 129 m, a height of 97 meters and a thermal flux of thermal radiation intensity of 421 kW/m^2 at a distance of up to 21 m will result in the explosion and fire.

For each type of emergency, the levels of necessary protection are determined based on the constructed risk matrix for determining the risk category. The matrix consists of the frequency and consequences of each of the scenarios for which independent levels of protection are determined by LOPA analysis. Let's note that the analysis of security protection levels (LOPA – Layer of protection analysis) is a semi-quantitative method for assessing the risks of undesirable events or scenarios. The method has recently been extended to analyze the adequacy of protective measures to minimize risks.

In recent years, interest has arisen in the manifestations of the effects of «dominoes», which significantly increases the scale of the accident, the severity of the consequences, especially in transport. In works [13, 14], the effects of «dominoes» were found for 330 cases of major accidents in the example of Spain. It is shown that fire and explosion have an equal contribution to the initiation of the first «domino» event. Although the radii of the

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action of fire factors are less than explosions, fires occur with greater frequency. But the situation changes for the BLEVE mechanism. It is fixed that the first event, which occurs in approximately 70 % of the cases of BLEVE accidents is an explosion, this is true for all stages of the domino effect in different sequences. The proportion of the explosion before the fire is 1.7 to 1. Analysis of the statistical data carried out by the authors [13] reveals the overwhelming majority of accidents in the cases of the use of liquefied gas and liquid hydrocarbons. In work [15], the necessity of applying special measures for responding to fires developing by the «domino» mechanism is substantiated. Modeling such on-line situation on the basis of Petri-net is important for developing an effective strategy for overcoming an emergency situation.

Thus, the problems of the emergence and development of an emergency situation in the transportation, storage and distribution of fuel of various types (or other flammable and combustible substances) are studied by scientists from different countries. In Ukraine, such studies are limited to qualitative assessments of the consequences of accidents at filling stations and the development of individual means to ensure their fire and explosion hazard. Thus, the author of [16] notes the danger to the population and surrounding objects of the consequences of an emergency fire at a filling station taking into account the probability of an explosion suggests effective methods for stopping flare burning. [17] establishes the relationship between the fire area and the amount of emissions of toxic combustion products using their specific values. To reduce emissions, the effectiveness of the extinguishing method under the foam layer is proved, and a system of under-layer fire extinguishing is proposed. The problems of location of filling stations as potentially dangerous objects in urban areas with high population concentrations have not been studied, and therefore are very important for research.

5. Methods of research

Methods of visualization and geoinformation modeling, a method of statistical data processing, methods of analysis, synthesis and generalization, methods of risk analysis are involved.

The «event tree» method is used to determine the probabilities of accident scenarios development depending on various factors (availability and reliability of the accident lockout systems, human factor – personnel actions, weather conditions at the time of the accident, etc.).

Technological audit of a single filling station as an object of modeling an emergency situation is presented in [3]. There are 2 typical scenarios for the development of an accident at a filling station. The probability of the first scenario of a complete destruction of a container with the complete release of a fire and explosion hazard due to a natural, technogenic or social disaster is about 10^{-8}. Therefore, the second scenario of local destruction of equipment with a leak of flammable (LFS) and combustible substances is considered in the work.

6. Research results

6.1. Analysis of the consequences of an emergency situation at the filling station in the scenario of leakage of oil products. The scenario is analyzed, when the initial event of an accident at the filling station is a leakage of fire and explosive product. Based on the statistical data [18], it is determined that the development of an accident can lead to one of the following events:

– Event A_1 – instantaneous ignition of a leaked product followed by fire.
– Event A_2 – there is a spill of fuel on the surface, ignition doesn't occur (the interlocking system is triggered).
– Event A_3 – the interlocking systems don't work, there is a pool fire.
– Event A_4 – evaporated fuel forms a steam cloud, its ignition occurs without excessive pressure.
– Event A_5 – a flash fire occurs with the formation of excess pressure.
– Event A_6 – «a fireball» is formed.

The probabilities of each intermediate event (Table 1), determined on the condition that the probability of the initiating event (local destruction of the equipment of the filling station) is 1.

Among these scenarios, which are presented in Table 1, the most likely for realization is the torch, the combustion of the cloud, and the pool burning.

Table 1

Statistical probabilities of different scenarios for the development of accidents with the release of a combustible substance*

Accident scenario	Probability
«Fireball» (A_6)	0.108
Fire – flash: Pool burning (A_3) Cloud burning (A_4) Cloud burning with the development of excess pressure (A_5)	0.367 0.1862 0.1689 0.0119
Torch (A_1)	0.322
Liquid jet (A_2)	0.129
Liquid spillage	0.074

Note: * is compiled on the basis of data [6].

In Fig. 1, in accordance with the data of Table 1, «event tree» of the emergency situation at the filling station with a leak of flammable (FS) and combustible (CS) fuel components is presented.

It is the pool burning that contains additional hazards factors and can be accompanied by secondary events of outbreak and burning. The initiation of undesirable events can occur both within the filling station itself and in the zones of influence. So, in the confines of a fire can get to the tanks that are at a certain distance and even belonging to another near the filling station. These tanks with a probability of 70 % explode as a result of the «BLEVE» effect (Boiling liquid expanding vapour explosion). An explosion of this type occurs when a superheated liquid leaks (heated above the boiling point at atmospheric pressure) according to the following scheme:

1) coverage of the reservoir flame, increase of pressure inside and heating of the metal with loss of its strength;

2) rupture of the shell of the tank, release of the substance and effervescence of the ejected substance;

3) explosion of boiled up liquid vapors with ignition and «the fireball» formation.

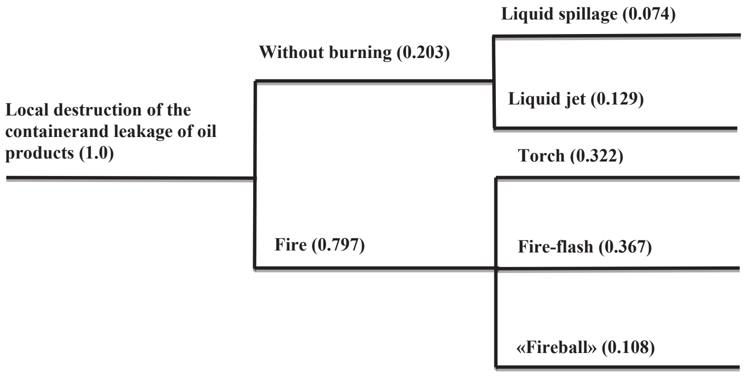

Fig. 1. «Event tree» of local destruction of a container with petroleum products at a gasoline station

As noted in [12], the BLEVE scenario can only take place in road tankers, since underground reservoirs can't be heated enough to initiate it. But it is quite possible that a fire spreads to a nearby filling station when there is a discharge of fuel from a tank truck into an underground tank or a supply to vehicles. This situation is undesirable (dangerous) event, and may be the first in the sequence of «dominoes» with the involvement of another filling station.

Pool fire can also occur along with diffuse burning of FS vapors and combustible substances in the air above the surface of the liquid. Diffusive combustion is combustion under conditions when the combustible substance and oxidizer are separated by a combustion zone [19].

Thus, the scenario of leakage of fuel substances with the consequences of a pool fire occurs in a branched out scheme and with the initiation of unfavorable situations on closely located potentially hazardous facilities, which are filling stations.

6.2. Determination of the action zones of thermal radiation during a pool fire. The main damaging factors of the pool fire are thermal radiation and hot combustion products, open flame and burning petroleum products, toxic combustion products. The main value that is calculated in the case of pool fires is the intensity of thermal radiation q, kW/m^2. Table 2 shows typical values of the maximum permissible intensity of thermal radiation for different degrees of human damage and materials.

Table 2

Typical maximum permissible values of the thermal radiation intensity for different degrees of damage*

Damage degree	Typical maximum permissible values of the thermal radiation intensity, kW/m^2
Degree of injury Without negative consequences for a long time	1.4
Safe for man in canvas clothes	4.2
Unbearable pain in 20–30 seconds First degree burn in 15–20 seconds Second degree burn in 30–40 seconds Cotton fiber fire after 15 minutes	7.0
Unbearable pain in 3–5 seconds First degree burn in 6–8 seconds Second degree burn in 12–16 seconds	10.5
Burning of wood with a rough surface (humidity 12 %) with an irradiation duration of 15 min	12.9
Burning of wood, painted with oil paint on the planed surface, ignition of plywood	17.0

Note: * is compiled on the basis of data [20].

The results of calculating the intensity of heat radiation from the pool fire are carried out for 4 types of fuel (gasoline A-80, A-95, A-95, diesel fuel) for the tank (40 m^3) and cistern (15 m^3) according to the standard method [6], are given in Table 3.

Table 3

The results of calculating the damage zones from thermal radiation of a pool fire with the destruction of tanks (40 m^3) and cisterns (15 m^3) containing oil products

Calculated parameter	Gasoline A-80		Gasoline A-92		Gasoline A-95		diesel fuel	
	Tank	Cistern	Tank	Cistern	Tank	Cistern	Tank	Cistern
Pool fire								
Specific mass burnup rate of fuel M_V, kg/m^2·s	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04
Effective pool diameter d, m	87.40	53.52	87.40	53.52	87.40	53.52	87.4	53.52
Flame height H, m	75.55	53.73	75.55	53.73	75.55	42.47	58.9	41.95
The angular irradiation coefficient F_q	0.005	0.004	0.004	0.004	0.005	0.018	0.005	0.004
The average surface density of the heat flux of flame radiation E_f, kW/m^2	25	25	25	25	25	25	18	18
The transmittance coefficient of thermal radiation through the atmosphere ψ	0.7394	0.6565	0.7384	0.655	0.873	0.651	0.75	0.678
Radii of the zones r, m, for which the intensity of thermal radiation q is:								
17 kW/m^2	215.6	144	215.6	144.5	215.6	143	–	–
10.5 kW/m^2	272	187	278.3	188	272	184	–	–
7 kW/m^2	327	221	328.6	222	328	220	294	200
1.4 kW/m^2	645	458	647	460	655	457	598	420

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The effective diameter of the spillage and the height of the flame are determined by calculations. The angular coefficient of radiation, the transmittance coefficient of thermal radiation through the atmosphere is calculated. And also the radii of the zones in which the intensity of the thermal radiation is, respectively, 17; 10.5; 7 and 1.4 kW/m^2.

According to [20], a fire in wood and plywood is possible in an area in which the intensity is 17 kW/m^2. Regardless of the type of gasoline, the radius of the zone is 215.6 m for the tank and 144 m for the cistern. For diesel fuel, as calculations have shown, the intensity of thermal radiation of 17 kW/m^2 is not achieved.

The radius of the zone, which is dangerous for a person for the high probability of getting burns of the 1st and 2nd degrees (the intensity of thermal radiation is 10.5 kW/m^2), reach:

– more than 300 m for all types of fuel for the tank;
– more than 200 m for the cistern.

Radii safe for human areas (the intensity of thermal radiation is less than 1.4 kW/m^2) are:

– 645 m – for gasoline A-80;
– 647 m – for gasoline A-92;
– 655 m – for gasoline A-95;
– 200 m – for diesel fuel.

The safest of all types of fuel, which is mainly used at Ukrainian filling stations, is diesel fuel, gasoline is less safe. The safety of gasoline increases with the increase in fuel quality, in particular, with the growth of the octane number.

6.3. The application of the geo-information system for the visualization of the action zones of the pool fire factor. Advantages of using geo-information systems to visualize the zone of such dangerous consequences of an emergency at a filling station as a shock wave are shown in [3]. There is also a diagram of the architecture of the complex geo-information system for assessing the consequences of an accident in the specific conditions of the location of the filling station.

As a GIS for modeling the action zones of the pool fire factor, the MapInfo Geo-information System is used in the current study, which is quite common, relatively cheap, easy to master. With the help of MapInfo Professional, it is possible to fully use all the possibilities of geo-information mapping, namely, display data on the map in the form of points, colored ranges, diagrams, areas, etc. It is also possible to perform operations with geographic objects such as zoning, combining objects and buffering [21].

MapInfo combines the advantages of information processing based on databases (including powerful SQL queries), and the visibility of maps, charts and graphs. MapInfo combines powerful tools for analyzing and presenting data. The features of the MapInfo software product are as follows:

1. Direct access to files created in dBASE or FoxBASE, ASCII, shapefile, Lotus 1-2-3, Microsoft Excel and Microsoft Access; import of graphic files of various formats; the ability to create database files from MapInfo.

2. View data in any number of windows of three types: Map windows, Lists and graphs. The technology of synchronous data representation allows to open several windows simultaneously containing the same data, and changing the data in one of the windows is accompanied by an automatic change in the representation of this data in all other windows.

3. «Live» access to remote databases, Oracle or SQL Server; and the type of multi-layered stitched maps allows to process several maps at the same time. Thematic maps allow to analyze data with high visibility, including 3D-maps, thematic raster maps and prism maps; the ability to put raster images under vector maps.

MapInfo makes it possible for queries of varying complexity: from simple selections from individual files to complex SQL queries on several files; saves windows and allows to run files or URLs directly from them. In GIS, there is a universal set of drawing and editing tools, as well as sets of ready-made maps and functions for creating their own maps.

It is the MapInfo method that is used to visualize radiation zones in cases of pool fire at the existing 33 filling stations in the Malinovsky district of Odessa (Ukraine).

6.4. Visualization of damage zones by thermal radiation in scenarios of a pool fire at city filling stations within the territory of the Malinovsky district. The location are marked on the map of Malinovsky district, Odessa (Ukraine), which was coded in MapInfo with a comparison of coordinates of filling stations with a description of streets on the map StreetInfo. Coordinates of 20 filling stations are represented in Fig. 2, since 12 filling stations are located on the periphery of the Malinovsky district, Odessa, far from dense areas and infrastructure facilities. StreetInfo is a special type of MapInfo data that is used to store addresses.

For each of the stations, the radii of four zones are calculated, for which the intensity of thermal radiation q is, respectively, 17 10.5, 7 and 1.4 kW/m^2 (Table 3). The results of calculations for each of the stations located on the territory of Malinovsky district are similar to the result of standard capacitive equipment and standard limits of fuel storage volumes at filling stations for cities with a population of more than 200,000 inhabitants. Ground reservoirs are prohibited in this case [5].

The calculated radii of damage by thermal radiation are visualized using MapInfo on the map of Malinovsky district based on the location of each filling station shown in Fig. 2.

The results of visualization of the action zones of the pool fire factors for different intensities of thermal radiation are shown in Fig. 3. In this case, the direction of the spill liquid is considered to be equally probable. The map shows that the filling stations cover the territory of the district with a sufficiently dense network and create the risks of damage to the consequences of an emergency fire on most of it.

The boundaries of the action zones of the pool fire factor, established for all filling stations, clearly demonstrate which objects fall into the zone of high, medium and minimal damage by thermal radiation. In Fig. 3 it can be seen that in the case of an accident with a pool fire, under the intensity of thermal radiation from 17 to 10.5 kW/m^2 (the danger of a flash of materials and significant burns of a person [20]) different «caring objects» are found for each particular filling station. The zones of various filling stations include multi-storey houses, garage cooperatives, schools, hospitals, post offices, recreation areas, places of congestion (supermarkets, shopping center «Metro», «Sixth Element») and many other socially important objects and objects of housing and communal services cities.

A detailed definition of recipients that are related to «care objects» and their classification are presented in [3], and the distances from them to the boundaries of the territory of the filling station are given in Table 4.

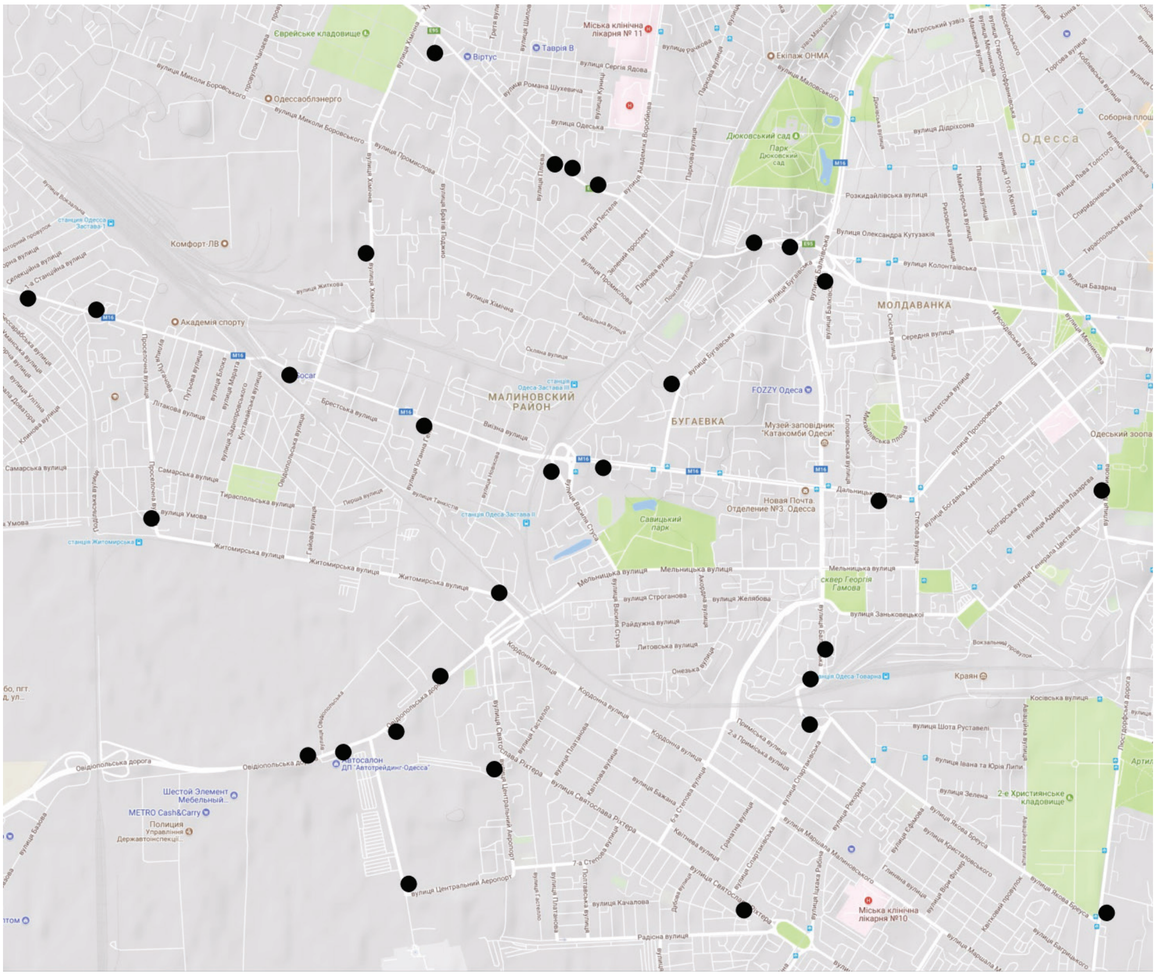

Fig. 2. Location of filling stations on the map of Malinovsky district, Odessa, Ukraine (scale 1:36780)

Fig. 3. Zones of damage by thermal radiation from a pool fire at the filling stations located within the territory of the Malinovsky district: yellow color – the radius of the action zones for the A-95 gasoline; Black color – the radius of the action zones for the A-92 gasoline; blue color – the radius of the action zones for the diesel fuel (scale 1:36780)

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Table 4

Fire-prevention distances from objects of the city to facilities of the filling station*

The name of the object to which the distance from the facilities of the filling station	The minimum distance from the structures of the filling station, m				
	Types A and B with underground tanks			Type C with ground tanks	
	small	medium	large	small	large
1. Residential and public buildings	25	40	50	50	80
2. Places of mass gathering of people (to a stop of public transport, border of territory of the market)	30	50	50	50	80
3. Separate trading tents, booths	20	20	25	25	25
4. Garages and parking lots	18	18	18	20	30
5. Sewage treatment, not related to filling stations	15	15	15	25	30
6. Production (with the exception of those specified in 8), administrative and household buildings, warehouses and facilities of industrial enterprises of I, II and III degrees of fire resistance	12	12	15	15	20
7. The same IIIa, IIIb, IV, IVa, 4-th degree of fire resistance	18	18	20	20	25
8. Production buildings with the presence of radioactive or harmful substances	100	100	100	100	100
9. Warehouses of forest materials, peat, fibrous combustible substances	20	20	20	25	25
10. Forests, parks, city squares:					
– coniferous and mixed species	25	25	25	30	40
– leaf species	10	10	10	15	15

Note: * is compiled on the basis of data [20].

In a city with a population of more than 200,000 inhabitants, according to the norm [5], filling stations of type A and B are permitted with medium underground reservoirs.

Thus, the use of MapInfo GIS makes it possible to establish that the size of the action zones of the accident factors with a pool fire for almost all filling stations in the Malinovsky district exceeds the fire-prevention distances from the city facilities to the facilities of the filling station. This creates the first level of danger for the population and important objects of urban infrastructure. The second level is associated with the development of a cascade of accidents at nearby filling stations and the synergetic complication of their consequences.

6.5. Identification of the dangers of a cascade mechanism for development of an emergency situation. One of the most important aspects of assessing the potential danger of implementing emergency scenarios at filling stations in a branched scenario is the identification of the cascade development conditions of the accident as a result of the heat radiation from the pool fire.

Domino effects, leading to cascading events, are known causes of severe accident scenarios. For such unfavorable development of the accident, a fire at a separate filling station causes consequences that initiate a dangerous event at another nearby filling station. In general, the «Domino effect» is characterized by a shift in the spectrum of possible accident scenarios toward the most unfavorable factors and phenomena. So, thermal radiation can lead to overheating of ground equipment of the filling station or tank during the unloading of fuel, cause a spark, a flash of transport that is refueling, and other dangerous events.

Such hazards identify as a result of visualization of the affected areas for a number of nearby filling stations. As can be seen in Fig. 3, there are several groups of filling stations for which the geo-locations of the affected zones are combined on the map. In practice, this means that the impact factor of thermal radiation at a dangerous level of intensity from 17 to 10.5 kW/m^2 covers the location of the fire and explosion hazard equipment of another filling station, and initiates a non-event that becomes the first in a further series of fires, explosions, leaks of toxic substances and other.

Fig. 4 shows the enlarged element of the zone of destruction by thermal radiation for a group of four filling stations along the Ovidiopol Road. The route belongs to the objects of the critical infrastructure of the city, characterized by a high traffic intensity, among which a significant share of trucks. It is shown in Fig. 4 that for each of the 4 filling stations, in the zones of the highest radiation level up to 17 kW/m^2, the surface of another, closely located filling station, is attracted. This creates risks for the development of a cascade of emergency situations and catastrophic consequences for the population and urban infrastructure.

Especially dangerous for the escalation of the accident is the event of overheating of the fuel tank during its unloading into the underground reservoir as a result of external heat radiation. In this case, the initiation of the BLEVE mechanism is quite likely. During unloading from a tank truck into an underground tank or supplying vehicles, liquid fuel and a vapor cloud can be released from a damaged or loosely connected pipeline and form a leakage basin. In the presence of an external source of ignition, a pool fire, a fire in the stream, an explosion or other events, 1 according to the scheme of Fig. 1. Therefore, there is an escalation of the accident, which, in turn, can initiate other hazards of the event at the next filling station.

Also, let's note that among the listed filling stations, neither the presence of hybrid stations using gas or liquefied gas for refueling of motor vehicles has been officially recorded. As already shown in [9, 12, 14], the BLEVE mechanism predominantly develops for these fuels, and with 70 % probability will initiate the explosion.

Fig. 4. The action zones of thermal radiation for a group of four nearby filling stations in the area of the Ovidiopol Road (scale 1:36780)

With the development of the market of cars on gas in Ukraine, the provision of such vehicles to the Ukrainian police, the range of gas filling stations in the city is expanding. Such filling stations are often located in the territory of service stations, car washes and profile stores. The lack of official information on the availability of hybrid gas-petrol filling stations and the geo-positions of filling stations on the city map only increases the risks of using the BLEVE mechanism in the chain of emergency events.

Direct location of the filling stations along the route can lead to the inclusion of vehicles in the emergency scenario. So, a cascade accident can include events with collision of cars, their explosion and fire, as well as the explosion and fire of large vehicles, especially in cases of transport of flammable and combustible substances.

Thus, the mutual arrangement of a number of filling stations creates a cell in the residential area of a heightened danger to the population, property, infrastructure facilities. To manage the risks of cascading accidents, it is necessary to determine, on the basis of the event tree, the sequences with the most severe consequences of emergency situations for the safety of the population and the surrounding urban environment. It is advisable to create a coordinated procedure for the temporary distribution of the importation of petroleum products by tank trucks and their unloading into the underground reservoir of the «risk group» of filling stations.

As additional technical means of protection from thermal radiation, it is possible to offer special fences and protective strips with high heat absorbing capacity, which is separated by closely located filling stations. Such elements supplement the system of fire-prevention and anti-explosive protective measures in that they create conditions for inertia and quenching of the heat of radiation.

From the point of view of emergency management, an emergency at one of the «group» petrol stations should be considered as very dangerous; personnel and the public should be immediately evacuated beyond certain hazardous areas.

In general, it is necessary to develop a comprehensive risk management strategy for cascading accidents in the system of organization of environmental safety of the city.

7. SWOT analysis of research results

Strengths. The visualization of the action zones of the pool fire factor for a number of filling stations in specific conditions of urban space will be the following useful properties. The obtained map of the residential area of the city with the zones of risk of damage to the population and objects of the surrounding urban environment, the consequences of an emergency situation at such potentially hazardous facilities as are filling stations. The results of the visualization of the action zones of the pool fire factor for each particular filling station visually demonstrate the geo-location of objects that fall into the zone of high, medium and minimal damage by thermal radiation. A positive factor of the application of the geoinformation system StreetInfo is additional opportunities to visualize the mutual location of the filling stations as sources of negative impacts and potential accidents, and the corresponding recipients in specific urban conditions. This allows for each emergency situation to detail measures to minimize the risks for the «objects of care». The visualization results are presented simultaneously for 20 fixed filling stations of the residential area allowing to identify the groups of filling stations for which a cascade mechanism of emergency situation development is possible. Visualized and presented on the map of the city, the action zone of the pool fire factor for closely located filling stations makes it possible to identify the conditions for the occurrence of initiating events both for the filling

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stations themselves of the «risk group» and for critical infrastructure facilities.

Weaknesses. For the identified groups of filling stations, where there are conditions for a cascade accident mechanism, there is a need to expand research in the following areas:

– carrying out alternative calculations of the action zones of the damaging factors during the escalation of the accident;
– development of «event tree» of a branched type;
– modeling of the situation taking into account the time factor, for which the heat flux of dangerous intensity will reach the other petrol station after the other equipment.

The difficulty lies in the fact that objective assessments of the state of technological equipment, protection systems, firefighting means, as well as subjective assessments of the human factor (personnel professionalism, stress resistance, etc.) are necessary to identify the most undesirable chain in a cascade of events. The influence of many dissimilar factors on the nature of the emergency scenario complicates the analysis of cause-effect relationships and modeling.

Opportunities. These weaknesses are the motivation for detailed studies of the mechanism of cascade reactions and detection of sequences with the most severe consequences.

Promising is the dissemination of research data to all areas of the studied city. Zoning of urban space by the zones of risk of damage to the consequences of emergency situations on such numerous hazardous facilities as the network of filling stations are an important component of integrated management of the environmental safety of the population. The hazardous zones presented on the GIS platform should be used as a basis for making decisions on land use planning and expanding the urban agglomeration.

Threats. The use of risk analysis methods and the construction of «event tree» in cases of cascade emergency response reactions require the analysis of a large amount of statistical data. But filling stations conduct commercial activities, are objects of private property, and belong to enterprises of different countries and forms of ownership. Therefore, open access to even technical information is difficult.

8. Conclusions

1. The scenario is analyzed, when the initial event of an accident at a filling station is a leakage of fire and explosion hazard of the product. The «event tree» method has established that the most likely to be realized is the torch, the combustion of the cloud, and the pool fire. The pool fire contains additional hazards factors and may be accompanied by secondary events of outbreak, burning and explosion. The initiation of undesired events can occur both within the filling station itself and in the impact zones, with the deployment of the BLEVE scenario or diffuse combustion.

2. For the main negative pool fire factors (thermal radiation and hot combustion products, open flame and burning petroleum products, toxic combustion products), the radii of the action zones are determined. Calculations of the intensity of heat radiation from the pool fire for 4 types of fuel (gasoline A-80, A-95, A-95, diesel fuel) for the tank (40 m^3) and cistern (15 m^3), respectively, shows the following. In the zone in which the intensity is 17 kW/m^2, regardless of the gasoline type, the radius of the zone is 215.6 m for the tank and 144 m for the cistern. The radii of the zone, with an intensity of thermal radiation of 10.5 kW/m^2, reach more than 300 m for all types of fuel for the tank, and more than 200 m for the cistern. Dangerous for a person are a distance of 650 m.

The safest of all fuels is diesel, and the safety of gasoline rises with the growth of the octane number.

3. As a GIS for modeling the action zones of the pool fire factor, the geo-information system MapInfo is proposed, which allows to fully use all the possibilities of geo-information mapping. With the use of MapInfo GIS, the action zones of the pool fire factors are visualized for various intensities of thermal radiation.

4. It is shown that filling stations create the risks of destruction by the consequences of an emergency fire in most of the district. The objects that fall into the zone of high, medium and minimal damage by thermal radiation are identified. These include multi-storey houses, garage cooperatives, schools, hospitals, post offices, recreation areas, places of congestion (supermarkets, shopping centers «Metro», «Sixth Element») and many other socially important facilities and housing and public utilities facilities of the city.

Using MapInfo GIS makes it possible to establish that the size of the action zones of the accident factors with a pool fire for almost all filling stations of the Malinovsky district exceed the fire-prevention distances from them to the objects of the city.

5. Dangers of cascade development of the accident as a result of thermal radiation from the pool fire are identified. Factors contributing to the «domino effect» are qualitatively assessed, among which the most likely is overheating of ground equipment of filling stations or tanks during the unloading of fuel, and the explosion of transport that is refueling.

The events that trigger the BLEVE mechanism are identified. In the presence of an external source of ignition, a pool fire, a fire in the jet, an explosion or other events that lead to an escalation of the accident may develop, which in turn may trigger other hazards at the next filling station.

Hazard factors are identified as a result of visualization of the affected areas for a number of nearby filling stations using MapInfo GIS. Direct location of petrol stations along the route can lead to the inclusion of vehicles in the emergency scenario.

Thus, the mutual arrangement of a number of filling stations creates a cell in the residential area of a heightened danger to the population, property, infrastructure facilities. The measures to minimize the risks of cascading accidents are proposed, including the temporary distribution of petroleum products by tank trucks, special fences and protective strips with high heat absorption capability, evacuation of personnel and residents beyond certain hazardous areas.

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ВИЗУАЛИЗАЦИЯ ЗОН ДЕЙСТВИЯ ПОЖАРА ПРОЛИВА С ИСПОЛЬЗОВАНИЕМ MAPINFO GIS ДЛЯ РЯДА АВТОЗАПРАВОЧНЫХ СТАНЦИЙ ЖИЛОГО РАЙОНА ОДЕССЫ (УКРАИНА)

Проанализированы сценарии инициирования и развития аварии для ряда автозаправочных станций в масштабе Малиновского района города Одесса (Украина). Проведены расчеты радиусов действия поражающих факторов для события пролива или утечки нефтепродуктов. Разработан метод визуализации зон действия фактора пожара пролива с применением MapInfo GIS. Идентифицированы условия возникновения «эффекта домино» и развития сценария каскадной аварийной ситуации для групп близко расположенных автозаправочных станций.

Ключевые слова: потенциально опасный объект, автозаправочная станция, пожар пролива, геоинформационная система, эффект домино.

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