# Analysis of Petrol Station Vulnerability Factors Regarding **Accidents Using Analytic Hierarchy Process and Ranking**

Ashraf Labib<sup>a</sup>, Dylan Jones<sup>b</sup>, Oleksii Ivanov<sup>c</sup>, Olena Arsirii<sup>c</sup>, Sergiy Smyk<sup>c</sup>,

<sup>a</sup> Faculty of Business and Law, University of Portsmouth, Portsmouth, POI 3DE, United Kingdom

<sup>b</sup> Lion Gate Building, University of Portsmouth, Portsmouth, PO1 3HF, United Kingdom

<sup>c</sup> Odesa Polytechnic National University, Shevchenko Avenue 1, Odesa, 65044, Ukraine

#### Abstract

The article considers the problem of determining the criteria of petrol stations vulnerability in terms of the consequences of a possible accident under 3 proposed scenarios. The criteria, which include lost lives, economic, social and environmental consequences of a possible accident, are determined using a system analysis. The analytic hierarchy process and a survey of experts using a web form (ranking) are performed to determine the weight of the criteria for the petrol stations vulnerability and to reduce their amount in a reasonable basis.

#### **Keywords**

Multi-criteria decision analysis, analytic hierarchy process, petrol stations, ranking method, accidents.

# 1. Introduction

Ensuring the technogenic safety of territories to prevent accidents at potentially hazardous facilities (PHFs) is one of the priority tasks of any country. This process becomes especially important in times of crisis in countries, for example, during martial law, when an accident at such PHFs can cause a manmade disaster with a significant number of civilian casualties, as well as material losses and environmental damage.

As part of the joint Ukrainian-British scientific project of cooperation between the Odesa Polytechnic National University and the University of Portsmouth (United Kingdom), the issue of using a multi-criteria fuzzy logic based methodology for risk mapping of petrol stations and the consequent decision optimization is investigated. Petrol stations are a potential hazard, as they have the capacity to cause loss of life, infrastructure damage, environmental damage and social disruption if they catch fire. Being able to more accurately quantify and visualize each of these aspects will help to enhance safety by informing of danger. The proposed project develops a methodology by which the multi-criteria impact of a singular or set petrol stations can be quantified and used to inform strategic decisions on the building of new petrol stations or the temporary or permanent closure of existing ones, as well as the location and building of new facilities (such as high density housing or environmentally sensitive facilities) in the vicinity of petrol station. This allows active risk control and hence limits potential economic and environmental damage and social disruption, thus enhancing the economic development and welfare.

This research article will consider the issues of developing vulnerability criteria for petrol stations in terms of possible consequences of a possible incident (accident), as well as the implementing of expert evaluation (ranking) and analytic hierarchy process (AHP) to determine the relative contribution of each factor.

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EMAIL: Ashraf.labib@port.ac.uk (A. Labib); dylan.jones@port.ac.uk (D. Jones); lesha.ivanoff@gmail.com (O. Ivanov); e.arsiriy@gmail.com (O. Arsirii); smyk@op.edu.ua (S. Smyk)

ORCID: 0000-0002-5481-5833 (A. Labib); 0000-0002-9101-746X (D. Jones); 0000-0002-8620-974X (O. Ivanov); 0000-0001-8130-9613 (O. Arsirii); 0000-0001-7020-1826 (S. Smyk)

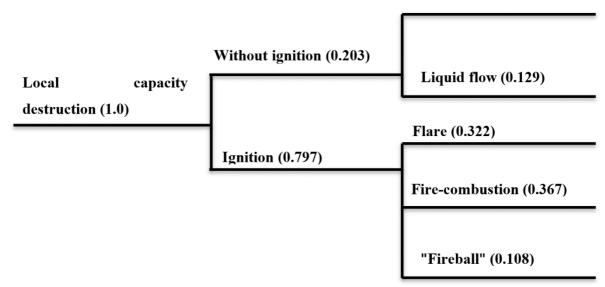
#### 2. Literature overview

Numerous works have been devoted to the issues of determining the anthropogenic safety of petrol stations and possible factors of origin and evolution of accidents at them, so in this section, more attention will be paid to the publications on which the project is based [1-5], as well as publications of researchers who use a multi-criteria decision-making method for the study of petrol stations.

The dissertation study [1] considered methods for determining the scenario of an accident at a PHFs (as which a petrol station was chosen) by developing models and methods for analysing and visualising risk zones in geographic information systems. The paper considers the modelling of geodata of the risk zones of petrol stations from 3 possible incidents (explosion of a vapour-air mixture of petroleum products with the formation of a shock wave, fire of petroleum products spill, "fireball"), which were used in the QGIS geographic information system to visualize risk zones on the map of Odesa city. In [2], a conceptual model of petrol station geodata was proposed for modelling zones using geographic information systems (using the example of an incident of an explosion of a vapour-air mixture of petroleum products with the formation of a shock wave).

Publication [3] is devoted to the analysis of the methodological framework for assessing the hazard of PHFs in general, including also petrol stations. It is determined that at present, due to the variety of methods for analysing the hazard of PHFs, there is no single clearly formulated and effective comprehensive methodology for assessing the risk of PHFs accidents. The same paper presents an "event tree" of an possible incident for quantitative analysis of an accident at a petrol station (Figure 1). The numbers next to the event indicate the probability of the incident occurring.





**Figure 1:** Analysis of the development of an accident at a petrol station due to the destruction of the capacity using the "event tree" [3]

The analysis of statistical data presented in work [4] shows that when flammable liquids are released, the most likely hazardous situations at a petrol station are the combustion of a cloud of petroleum products vapours with the formation of overpressure, flaring of an petroleum products spill and a "fireball" (Table 1).

Article [5] discusses the use of a multi-criteria decision-making method for the placement of medical equipment for the diagnosis of cancer in the south of the United Kingdom. The proposed methodology is planned to be used in relation to petrol stations to make decisions on their closure/re-equipment.

Consider the publications on the use of a multi-criteria method (analytic hierarchy process) for making decisions regarding petrol stations. Paper [6] considers the multicriteria problem of choosing a location for a petrol station for construction using the analytic hierarchy process. Using this method,

Table 1Statistical probabilities of various emergencies (accidents) at petrol stations [4]

Accident	Probability
Flare	0.322
"Fireball"	0.108
Spill burning	0.1862
Cloud combustion	0.1689
Cloud combustion with the development of excess pressure	0.0119
No burning	0.203

the authors determined the weights of the criteria that influence the decision-maker's choice of a petrol station construction site, taking into account the factors of traffic flows, the environment, socioeconomic factors, and physical attributes of the location. Other works that consider the issue of choosing a petrol station location using multi-criteria decision-making methods include publications [7-10].

To assess the risks and their priorities faced by petrol stations in Pakistan, the analytic hierarchy process and IPA analysis were used in [11]. It is shown that 5 main risk factors have the greatest impact on petrol stations, namely transportation/unloading of tanks, fuel dispensing, storage of fuel on site, repair, maintenance or modification, and other risk factors.

The integrated use of environmental impact assessment and analytic hierarchy process with subsequent data visualization in GIS to determine the suitability of a land plot for a petrol station is discussed in [12]. Also, the multi-criteria analytic hierarchy process is used to assess the risks of building gas compressor stations and prioritize hazardous factors in a study [13]. The general issues of identifying hazards for accidents at petrol stations and risk assessment are discussed in [14].

The application of 6 methods of multicriteria analysis and SWOT analysis to improve service at petrol stations is discussed in article [15]. Evaluation and ranking of petrol stations with the help of AHP was studied by the authors in article [16].

## 3. Problem statement

The purpose of the study to be considered in this article is to develop criteria for the petrol stations vulnerability to possible accidents in terms of possible consequences, as well as to use a multi-criteria analytic hierarchy process and expert assessments (ranking) to assess the relative contribution of each group of factors.

To achieve this goal, the following tasks are proposed:

- Development of criteria for the petrol stations vulnerability, including lost lives, as well as economic, social and environmental consequences of a possible accident;
- Use of the analytic hierarchy process to establish the weights of the criteria developed in the previous step;
- Use of expert opinions (ranking method) to assess the rank of the criteria for the petrol stations vulnerability developed in the first task.

The study will apply the following methods: a system analysis method to develop criteria for the petrol stations vulnerability, including lost lives, as well as possible economic, social and environmental consequences in the event of a possible incident at a petrol station under 3 scenarios. To assess the weights of the criteria, it is suggested to use the analytic hierarchy process and the method of expert assessments (ranking) with the subsequent comparison of the results obtained using the 2 methods.

The key principles on which the project is based include the following:

1. Loss of life should not be directly compared to the other criteria (economic, social and environmental), rather kept below acceptable thresholds;

2. Loss of life is of equal importance throughout the locales regardless of their socio-economic development or political significance;

3. Decisions to close or open petrol stations should be made within acceptable risk to life limits, and should consider economic, social, and environmental consequences of an incident as well as inconvenience to the population stakeholders of any petrol stations closures.

# 4. Determination of petrol station vulnerability factors using system analysis

Based on the previous considerations, the following structure of vulnerability factors of the petrol stations can be proposed.

1. Factors that take into account lost lives:

LL.1. The number of employees at the petrol station – in the event of an accident, they are at high-risk group;

LL.2. The number of fuel dispensers – determines the maximum number of vehicles that can be fuelled at one time;

LL.3. The average number of vehicles per hour (throughput) – based on the previous indicator and this one allows to determine the presence of possible queues;

LL.4. The presence of crosswalks, pedestrian highways with significant traffic near the petrol station – increases the likelihood of people who may suffer from an accident;

LL.5. The presence of traffic lights and road restriction signs nearby of the petrol station – the application of speed limits or temporary stopping of vehicles increases the number of potential victims;

LL.6. The presence of a single, two or multi-lane road near the petrol station – this may increase the traffic flow through the petrol station;

LL.7. The importance of the road near which the petrol station is located – traffic intensity on local roads is lower than on national or international transport corridors;

LL.8. The presence of a public or private transport stops near the petrol station – increases the likelihood of people who may suffer from an accident;

LL.9. The number of employees of enterprises near the petrol station that provide additional services to drivers – the location of such additional service enterprises increases the attractiveness of the petrol station area and, therefore, the likelihood of people being in a potentially dangerous area.

2. Factors that take into account economic consequences:

E.1. The type of construction of the petrol station and the equipment used - affects the amount of material damage to the enterprise itself;

E.2. The number of tanks, their volume and type – the amount of oil products directly affects the size of a possible accident;

E.3. The presence of enterprises providing additional services to drivers alongside the petrol station: service stations, car washes, shops, catering establishments – high probability of damage of material assets due to a possible accident;

E.4. The presence of public utilities near the petrol station: main water and gas pipelines, heating networks, communication networks and power lines;

E.5. The presence of high-risk enterprises near the petrol station – the possibility of their damage as a result of the «domino» effect increases;

E.6. Presence of other petrol stations nearby;

E.7. The presence of residential buildings near the petrol station;

E.8. Unfulfilled orders from regulatory authorities -a willful failure to fulfil safety obligations entails greater material and other types of liability;

E.9. Operating time of the petrol station – wear and tear of equipment over time may increase the risk of an emergency;

E.10. Belonging of the petrol station to a trademark (chain) – chains have additional costs for the brand and better equipment, on the other hand, private small petrol stations will have less economic losses from an emergency.

3. Factors that take into account social consequences:

S.1. Population density in the area near the petrol station -a higher density leads to a higher number of possible accident victims and, therefore, a greater social impact;

S.2. The nature of the area in which the petrol station is located: residential, industrial, agricultural, recreational, etc. – depending on the nature, the social impact of a possible accident may vary;

S.3. The presence of socially important infrastructure near the petrol station: stadiums, schools, hospitals, etc. - if the possible accident vulnerability of the petrol station is high enough, it may cause social discontent due to the presence of a petrol station nearby;

S.4. Average income level of residents of the area where the petrol station is located – a multivariate factor that affects both the economic consequences and social discontent due to the presence of a petrol station nearby;

S.5. The growth potential of the area where the petrol station is located - given the growth of population density and traffic flows, the proximity to a petrol station may be undesirable;

S.6. Presence of cultural monuments near the petrol station – it increases the vulnerability of a petrol station;

S.7. Location in or proximity to a war zone - a multivariate factor that proportionally affects the risks of an accident and undesirable consequences;

S.8. Qualification of personnel – the impact of the human factor on the risks of accident consequences – timely qualified actions can reduce the scale of consequences and vice versa;

S.9. Petrol stations as a crime factor – the presence of "shadow" petrol stations that may not comply with all safety standards, as well as the increased crime situation near them, may have a social effect in the event of an accident at them;

S.10. Consequences for the labour market - an accident at a petrol station may lead to temporary/permanent loss of jobs for a significant number of people.

4. Factors that take into account environmental impacts [17]:

Ev.1. Type of fuel used, standard – directly affects the number of harmful substances, heavy metals that can be released during the combustion of oil products;

Ev.2. Weather conditions (temperature, wind speed, degree of vertical stability of the air (inversion, convection, isotherm)) – affect the nature and dispersion of pollutants as a result of combustion in the atmosphere;

Ev.3. Time of year – has an impact on both weather conditions and the state of all components of the ecosystem, some petrol stations may be more stable in winter than in summer, etc.;

Ev.4. The presence of open water bodies of economic importance near the petrol station - in the event of an emergency, there is a high possibility of water pollution and greater environmental damage;

Ev.5. Soil type and structure – affects the depth of penetration of the pollutants into the soil;

Ev.6. Depth of groundwater, presence of wells and boreholes nearby - if the depth is low and there are means of groundwater extraction, the risk of groundwater pollution and greater environmental damage increases;

Ev.7. The presence of nature reserve areas near the petrol station – presence causes a greater risk of environmental damage and social impact at the same time;

Ev.8. The presence of significant forest areas near the petrol station – presence causes a greater likelihood of forest fires and environmental damage;

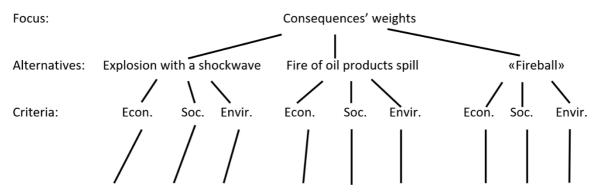
Ev.9. The presence of agricultural land (arable land, pastures, etc.) nearby the petrol station – there is a possibility of withdrawal of land from agricultural use due to possible pollution;

Ev.10. The nature of the relief near the petrol station – the presence of relief irregularities reduces the scale of pollution, while the flat relief does not prevent pollution of the area;

Ev.11. The presence of recreational areas (both large and small) near the petrol station – an accident at a petrol station may have a negative environmental effect in case of pollution of these areas, and a social effect due to the loss of these areas.

# 5. Using AHP to evaluate factors

The following hierarchy of criteria for assessing the petrol stations vulnerability with the use of AHP can be drawn up (Figure 2).



Sub-criteria: 10 Econ. 10 Soc. 11 Envir. 10 Econ. 10 Soc. 11 Envir. 10 Econ. 10 Soc. 11 Envir. **Figure 2:** Hierarchy of criteria for assessing the vulnerability of petrol stations in case of implementation of 3 possible incidents

Implementation of the AHP to achieve its goal can be done in 3 ways:

1. Full analysis of all factors – for each of the 3 possible incidents, we compile a complete matrix of factors for their pairwise comparisons. The number of pairwise comparisons for an expert performing the AHP:  $K = ((31 \times 31) - 31) / 2 = 465$  – such number of values will need to be filled in for 1 incident due to the matrix is reciprocal and the diagonal elements are equal to unity. Such an analysis seems to be cumbersome, impractical. In order to compare all the factors, the expert needs to keep in mind all the identified 31 factors.

2. We can divide the matrix from the 1st. way on 10x10 matrices, but in this case, the expert needs to fill in 6 matrices – the problem remains the same: 465 comparisons like in 1st. way.

3. At the first stage, experts fill in only 3 matrices 10x10, comparing the factors with each other in each subgroup (economic, social, environmental), then 3 matrices for each scenario, number of comparisons:  $K = ((10 \times 10) - 10) / 2 + ((10 \times 10) - 10) / 2 + ((11 \times 11) - 11) / 2 = 45 + 45 + 55 = 145$  per 1 incident (3.2 times less than comparing all 31 factors with each other).

Based on this assessment, we determine the most significant 3-4-5 factors in each of the subgroups and then at the second stage for each of the incidents we submit a matrix ranging in size from 10x10 to 15x15 (depending on the first step, how many the most important factors will be selected in each of the subgroups). And then we compare the resulting matrix, where for each of the scenarios there will be economic, social, and environmental factors. And we will eventually get the specific weights of the consequences for assessing the petrol stations vulnerability for each of the incidents.

The methodology of performing the AHP for our study is based on the classical works of T. Saaty [18]. At the first stage, for each of the 3 possible incidents, experts will be offered 3 matrices for pairwise comparison of factors among themselves according to the following scale (Table 2).

Based on the matrix of pairwise comparisons (then matrix A), local priorities are formed by determining the main eigenvectors of the matrix A and normalizing the result. Calculation of the principal eigenvector  $x = \{x_1, x_2, ..., x_n\}$  of a square positive matrix A is carried out on the basis of certain  $Ax = \lambda_{max}x$ , where  $\lambda_{max} - \text{largest eigenvalue of matrix } A$ .

We consider the priority vector as the geometric mean of the rows of the matrix of pairwise comparisons with subsequent normalization:

$$X_{j} = \frac{\sqrt[n]{\left(\prod_{j=1}^{n} a_{jj}\right)}}{\sum_{i=1}^{n} \left(\sqrt[n]{\left(\prod_{j=1}^{n} a_{jj}\right)}\right)}$$
(1)

Next, the consistency index (C.I.) is calculated, which makes it possible to check how consistent the expert was by filling in the matrix of pairwise comparisons:

$$C.I. = \frac{\sum_{j=1}^{n} \left( x_{j} \times \sum_{i=1}^{n} a_{ij} \right) - n}{n-1} = \frac{\lambda_{\max} - n}{n-1}, \qquad (2)$$

Intensity	of		
importance on	an	Definition	Explanation
absolute scale			
1		Equal importance	Two activities contribute equally to the objective
3		Moderate importance of one over another	Experience and judgment strongly favour one activity over another
5		Essential or strong importance	Experience and judgment strongly favour one activity over another
7		Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9		Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8		Intermediate values between the two adjacent judgements	When compromise is needed

Table 2The fundamental scale [18]

where estimate:

$$\lambda_{\max} = \sum_{j=1}^{n} \left( X_j \times \sum_{i=1}^{n} a_{ij} \right).$$
(3)

The calculated consistency index is compared with the value obtained by randomly selecting quantitative values from the scale 9, 8, 7, ..., 1/8, 1/9.

Consistency ratio (C.R.) is the quotient of the consistency index divided by the corresponding random consistency value taken from the Table 3:

$$C.R. = C.I. / Rand(R.I., n).$$
<sup>(4)</sup>

#### Table 3

Consistency index value for random matrices [18]

n			3		-	-		-	-	-	
Random consistency index (R.I.)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

If the obtained value is *less than 10%*, then the level of consistency is considered satisfactory.

To fulfil the AHP for each of the incident scenarios, the expert will be asked to fill out 3 questionnaires comparing the factors of economic, social and environmental consequences in the event of an incident at a petrol station (3 questionnaires per 1 incident).

Based on the data processing of the obtained matrices, it becomes possible to identify the most important factors of consequences. Then you can proceed to the compilation of the final matrix, where there will be the most significant economic, social and environment vulnerability factors, which we can already compare with each other and obtain vulnerability weights (economic, social and environmental) for each of the incidents.

Table 4 shows the results of processing a pairwise comparison of the economic consequences factors for the incident of an explosion of a vapour-air mixture of petroleum products with a shockwave formation.

The consistency ratio is 2.66%, which is less than the value of 10%, and therefore the result can be considered satisfactory. As you can see, from the point of view of the economic consequences of the explosion of the vapor-air mixture of petroleum products, the most significant factors are E2-E7 (highlighted in bold).

## Table 4

The result of performing a pairwise comparison for the incident of an explosion of a vapour-air mixture of petroleum products (economic consequences)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Geom. Mean	x <sub>j</sub> — priority vector	%
E1	1	1/5	1/5	1/5	1/5	1/5	1/5	2	3	3	0.5083	0.036	3.6
E2	5	1	2	3	3	3	2	8	8	8	3.5008	0.244	24.4
E3	5	1/2	1	2	2	2	1	7	7	7	2.419	0.169	16.9
E4	5	1/3	1/2	1	1	1	1/2	6	6	6	1.5683	0.109	10.9
E5	5	1/3	1/2	1	1	1	1/2	6	6	6	1.5683	0.109	10.9
E6	5	1/3	1/2	1	1	1	1/2	6	6	6	1.5683	0.109	10.9
E7	5	1/2	1	2	2	2	1	6	6	6	2.3097	0.161	16.1
E8	1/2	1/8	1/7	1/6	1/6	1/6	1/6	1	2	2	0.3500	0.024	2.4
E9	1/3	1/8	1/7	1/6	1/6	1/6	1/6	1/2	1	1	0.273	0.019	1.9
E10	1/3	1/8	1/7	1/6	1/6	1/6	1/6	1/2	1	1	0.273	0.019	1.9
										Σ	14.3385	1	100
$x_j \cdot$													
$\Sigma_{i=1}^{n}$	1.14	0.87	1	1.17	1.2	1.2	1	1	0.9	0.88	$\lambda_{max}$	10.3577	
a <sub>ij</sub>													
											C.I.	0.03975	
											C.R.	2.66%	

In the following Table 5, we present the results for other factors, which were obtained by the AHP for all 3 incidents. Complete tables can be obtained from the link [19].

#### Table 5

Results of factor priority calculation for 3 incidents using AHP

Economic factors	Priority, %	Social factors	Priority, %	Environmental factors	Priority, %
Explosion o	of vapour-air mix	ture of petroleum p	products with th	e formation of a sh	ock wave
E1	3.55	S1	20.00	Ev1	22.99
E2	24.42	S2	14.75	Ev2	1.42
E3	16.87	S3	22.97	Ev3	1.42
E4	10.94	S4	3.31	Ev4	4.51
E5	10.94	S5	2.60	Ev5	1.92
E6	10.94	S6	9.21	Ev6	1.92
E7	16.11	S7	9.21	Ev7	6.71
E8	2.44	S8	1.33	Ev8	6.71
E9	1.90	S9	1.63	Ev9	6.71
E10	1.90	S10	15.00	Ev10	25.34
_	-	-	_	Ev11	20.34
		Fire of petroleum	n products spill		
E1	2.20	S1	11.37	Ev1	3.29
E2	24.01	S2	23.01	Ev2	6.82
E3	19.50	S3	30.52	Ev3	6.82
E4	9.85	S4	5.20	Ev4	10.58
E5	9.67	S5	1.63	Ev5	2.22
E6	9.67	S6	7.22	Ev6	2.22

Economic factors	Priority, %	Social factors	Priority, %	Environmental factors	Priority, %
E7	16.12	S7	10.45	Ev7	10.58
E8	4.50	S8	5.24	Ev8	22.66
E9	2.24	S9	2.21	Ev9	16.31
E10	2.24	S10	3.15	Ev10	2.19
_	_	_	_	Ev11	16.31
		"Fireb	all"		
E1	1.39	S1	21.99	Ev1	8.01
E2	27.49	S2	12.44	Ev2	13.09
E3	20.24	S3	29.16	Ev3	13.09
E4	9.53	S4	4.98	Ev4	5.14
E5	9.53	S5	1.40	Ev5	1.94
E6	9.53	S6	8.11	Ev6	1.94
E7	14.81	S7	12.44	Ev7	8.01
E8	3.19	S8	2.53	Ev8	25.75
E9	2.48	S9	2.22	Ev9	8.01
E10	1.81	S10	4.74	Ev10	1.94
_	_	-	_	Ev11	13.09

#### Table 5 Cont.

Table 5 shows that for all 3 incidents, economic factors E2-E7, social S1-S3 and environmental Env11 can be identified as the most significant and common. Some of the differences in incidents in social and environmental factors are due to the different nature of these incidents.

## 6. Using the method of expert evaluations (ranking)

Due to the time-consuming and large financial component of conducting a survey of a large number of experts for the implementation of the AHP to determine the weight of petrol station vulnerability factors, we proposed to create a web form for the survey of experts (the version in Ukrainian is available at the link [20]). The Python programming language with the Django framework and the PostgreSQL DBMS were chosen for a fast and high-quality web form development process. The main pages of the web form were described using HTML JavaScript tools.

After familiarizing the expert with the content of the project and giving agreement to the processing of his data, he first fills in statistical data about himself (gender, age, education, etc.), then he proceeds to the ranking, where he is offered to rank the criteria of economic, social and environmental factors to choose from, rating their importance from 1 (least important) to 10 (most important).

So far, 16 experts have been interviewed using a web form. The analysis of statistical data on the experts who participated in the survey is as follows:

- Gender: male 87.5%, female 12.5%.
- Age: 18-35 25%, 35-60 56.2%, 60+ 18.8%.
- Income: low 12.5%, medium 87.5%, high 0%.
- Marital status: single -31.2%, married -68.8%.
- Presence of children: no children 68.8%, have children 31.2%.

• Education: full secondary -6.25%, technical and vocational -6.25%, first cycle of higher education -12.5%, second cycle of higher education -75%.

• Doctorate: no - 31.2%, yes - 68.8%.

• Experience of a car using: none – 45.5%, less than 1 year – 0%, 1-2 years – 9.1%, 2-5 years – 0%, 5-10 years – 18.2%, 10+ years – 27.2%.

• Does your professional activity involve risk, risk assessment or management: no – 50%, yes – 50%.

- Is there a petrol station near your place of residence: no 50%, yes 50%.
- Is there a petrol station near your place of work: no 62.5%, yes 37.5%.

According to the results of the survey and the averaging of the rank estimates obtained after the experts filled out the web form, the following results were obtained for the ranking of the vulnerability factors of petrol stations (Table 6).

#### Table 6

Results of expert assessments of petrol stations vulnerability factors after filling out the web form (ranking method)

Economic factors	Rank	Social factors	Rank	Environmental factors	Rank
	<sup>f</sup> vanour-air m	ixture of netroleum n	roducts with	the formation of a sho	ck wave
E1	6.83	S1	8.18	Ev1	6.0
E2	7.75	S2	6.36	Ev2	4.42
E3	6.75	S3	7.82	Ev3	3.5
E4	6.75	S4	3.55	Ev4	4.58
E5	7.67	S5	3.36	Ev5	3.5
E6	5.75	S6	4.73	Ev6	3.5
E7	7.5	S7	6.73	Ev7	4.83
E8	5.33	S8	6.55	Ev8	5.92
E9	5.5	S9	5.73	Ev9	4.92
E10	3.83	S10	5.64	Ev10	6.25
-	_	-	_	Ev11	6.33
		Fire of petroleum	products spil		
E1	6.67	S1	7.18	Ev1	6.67
E2	7.08	S2	7.0	Ev2	6.67
E3	6.17	S3	7.55	Ev3	4.83
E4	6.08	S4	3.36	Ev4	5.17
E5	7.25	S5	3.09	Ev5	4.67
E6	5.58	S6	4.18	Ev6	5.17
E7	6.75	S7	7.0	Ev7	5.67
E8	5.75	S8	7.18	Ev8	7.58
E9	5.58	S9	5.91	Ev9	6.58
E10	3.75	S10	4.82	Ev10	6.67
_	_	-	_	Ev11	6.33
		"Firebo	all"		
E1	7.0	S1	7.82	Ev1	6.25
E2	8.17	S2	6.64	Ev2	6.08
E3	6.33	S3	7.91	Ev3	4.42
E4	6.83	S4	3.45	Ev4	4.17
E5	7.5	S5	3.0	Ev5	3.75
E6	6.33	S6	4.45	Ev6	3.67
E7	7.42	S7	6.73	Ev7	5.08
E8	5.67	S8	6.73	Ev8	7.08
E9	5.67	S9	5.64	Ev9	5.67
E10	3.83	S10	5.09	Ev10	5.17
-	_	-	-	Ev11	6.33

When analysing Table 6, we identified the most important factors for each incident those that have a rank of 6 and above. Table 6 shows that economic E1-E5 and E7, social S1-S3, S7-S8 and

environmental Ev1 and Ev11 are common among the most important factors of petrol station vulnerability for all 3 incidents.

## 7. Conclusions

As a result of the study, based on the system, a set of 40 factors was formulated that characterize the vulnerability of petrol stations as PHFs from the point of view of the consequences of a probable incident (on the basis of previous studies, the analysis was carried out for the explosion with the formation of a shock wave, a fire of petroleum products spill and a "fireball"), which were divided into 4 groups: lost lives, as well as economic, social and environmental consequences of the incident.

In order to reduce the number of factors that will be taken into account for the analysis and quantitative assessment of petrol stations, it is proposed to use the analytic hierarchy process, as well as the method of expert evaluations (ranking) with the subsequent comparison of their results (weight of factors and rank) and decision making, which of the 31 vulnerability factors of gas stations should be to be taken into account when assessing the vulnerability of a particular gas station to a probable incident (factors involving lost lives are not compared with others).

As a result of the implementation of the AHP to achieve this goal, it was established that for all 3 incidents, the most significant and common economic factors E2-E7, social S1-S3 and environmental E11 can be identified. There are also some differences, which are presented in Table 5 (the most important factors for the following comparison are highlighted in bold). Data analysis using the method of expert assessments (ranking) gave similar results, establishing that the most significant and common factors for 3 incidents are E1-E5, E7, S1-S3, S7-S8 and Ev1 and Ev11. As can be seen, the results of the AHP and the ranking method give similar results, which provides the basis for the selection of key factors of petrol station vulnerability from 3 groups for each of the incidents and the subsequent assessment of the weight of the selected criteria for the vulnerability of the petrol station already with the application of the AHP.

Among the advantages of using the selected methods (AHP and ranking) for evaluating the weights of petrol stations vulnerability criteria, it should be noted a simplified evaluation mechanism using an intuitive scale for an expert, which makes it possible to solve a multi-criteria problem without experimental confirmation of evaluations. But among the shortcomings of the methods used, we can mention the human factor, the possible inconsistency of experts in forming assessments, and the lack/insufficiency of experience in the problem under consideration.

The obtained results make it possible to additionally select and evaluate the weights of the selected criteria regarding their contribution to the petrol stations vulnerability from the point of view of the possible consequences of an unwanted incident. And this, in turn, allows us to move on to the solution of a multi-criteria problem based on a fuzzy logic for the selection of petrol stations that should be closed/reequipped in the region, from the point of view of both the possible consequences of an unwanted incident and the resulting inconveniences for the population when petrol stations are closed. The results of the project can be valuable for a wide range of interested parties, among who should be noted the population, civil protection and emergency services, entrepreneurs and petrol station owners, state controlling authorities, as well as public organizations, etc.

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