UUT14 Multiple criteria fuzzy logic based methodology for risk mapping of gas filling stations and consequent decision optimization

From the Odesa Polytechnic: project coordinator - Oleksii Ivanov, Senior Lecturer of Information System Department

From the University of Portsmouth: project coordinator – Dylan Jones, professor of operational research, School of Mathematics and Physics

Project participants:

From *the Odesa Polytechnic*:

- project coordinator - Oleksii Ivanov, Senior Lecturer of Information System (IS) Department;

Executors:

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- Sergiy Smyk, associated professor of IS Department;
- Vadym Oliinyk, MSc. student of IS Department;
- Bieliaiev Kyrylo, MSc. student of IS Department.

From *the University of Portsmouth*:

- project coordinator – Dylan Jones, prof. of operational research, School of Mathematics and Physics;

Executors:

- Ashraf Labib, professor of operations and decision analysis, School of Organisations, Systems and People;
- Richard Teeuw, professor of geoinformatics and disaster risk reduction, School of Earth and Environmental Sciences;
- Phil Crook, Teaching Fellow, School of Earth and Environmental Sciences;
- Lyness Kanada, MSc. student.

1. The purpose of the project and subjects of the investigation

- *The aim of this research* is to propose a GIS-enabled decision support system for the calculation and visualization of multi-criteria risks surrounding a single or multiple gas filling stations, and hence provide decision support with respect to location decisions pertaining to the gas filling stations or other infrastructure in their vicinity
- *The subject of the research*: emergency situations that may occur at a petrol station and related risk identification methods, risk visualization methods in geographic information systems (GIS), decision-making method based on fuzzy logic

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2. Tasks of the project

To achieve this aim, the following objectives are planned:

- Development of a fuzzy logic based system for stratification of the risks surrounding a gas station based, building on previous work of the Ukrainian team and adapting methodologies being developed by the Portsmouth team on their current EU projects. GIS based visualisation of the results
- Utilisation of the Analytical Hierarchy process (AHP) to reconcile the multi-criteria risks with respect to distance from the nearest gas filling station, human casualties, economic and infrastructure damage and environmental damage
- Development of a multi-criteria decision support tool to analyse decisions regarding opening and closure of gas-filling station with respect to the above criteria

3. Waiting for project results

Among the expected results of the project, we highlight the following:

- Presentation of a joint research paper at the Production and Operations Management Society (POMS) 2023 conference, which will take place on July 18-20, 2023 in Paris
- Publication of a joint research article in an internationally renowned journal on Operational Research: *EJOR* or *JORS*
- Publication of a joint research article in an Eastern-European Journal of Enterprise Technologies

4. Road map of the project

Calendar plan of project implementation

Name of the step according to the calendar plan	The term of implementation (start – end)	The estimated volume of the project stage
Reviewing the relevant literature and definition of the project's issues, goals and objectives	02.2023 – 03.2023	15 %
Development of criteria for assessing the vulnerability of petrol stations, questionnaire forms, collection and analysis of expert opinions	03.2023 – 05.2023	30 %
Processing the collected data, drawing up the results of the research project and preparing relevant theses and articles for scientific journals	05.2023 – 07.2023	30 %
Publication of the prepared materials in scientific journals and presentations at thematic conferences	07.2023 – 12.2023	25 %

Key Stakeholders (groups with interest)

- Petrol station owners
- The population who live and work in the vicinity of the petrol section
- The vehicle users requiring petrol in the geographical district
- Emergency services, e.g. fire service
- Local and national government departments with responsibility for business safety and the environment
- The business community
- Environmental groups

Source gov.uk

Source Reuters

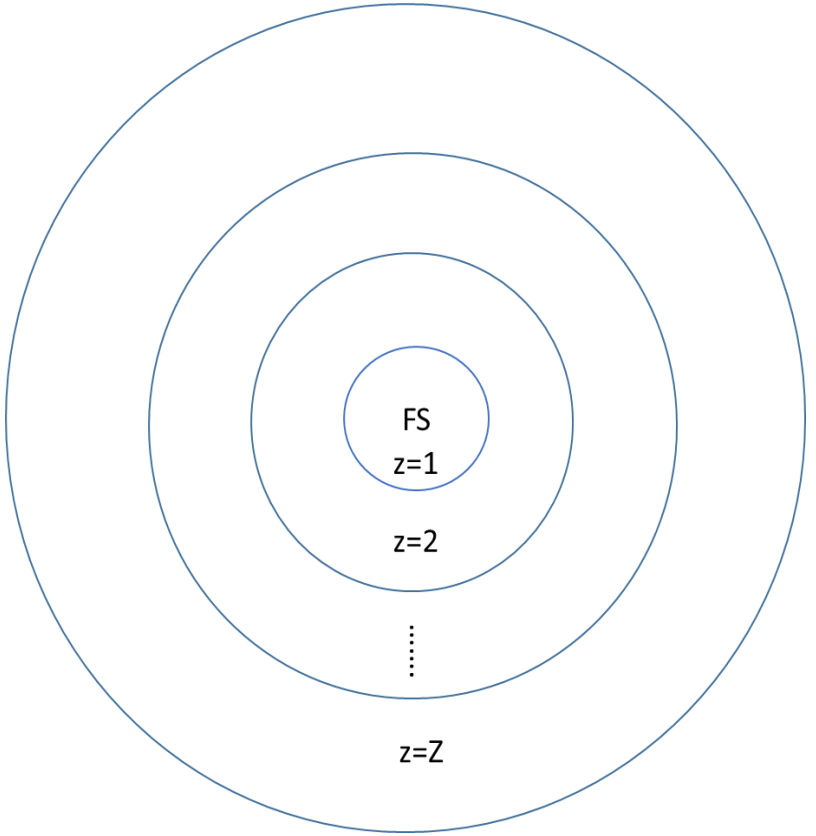
Key Principles

- 1) Loss of life should not be directly compared to the other criteria, rather kept below acceptable thresholds
- 2) Loss of life is of equal importance throughout the locales
- 3) Decisions to close or open gas filling stations should be made within acceptable risk to life limits, and should consider economic, social, and environmental sustainability consequences of an incident as well as inconvenience to the population stakeholders of any closures

5. Obtained project results

Consequence Scores: Indices

- Let f=1,…,F be the set of existing or proposed filling stations in a district
- Let z=1,…,Z be a set of geographical zones radiating from a gas filling station (see the schema)
- E.g. z=1: 100 metres, z=2: 200 metres, z=3: 400 metres



Consequence Scores: Data and Weights

- Let L_{fz} be the estimated loss of life in zone z of filling station f if an incident occurs
- Let E_{fz} be the estimated economic impact in zone z of filling station f if an incident occurs
- Let S_{fz} be the estimated social impact in zone z of filling station f if an incident occurs
- Let A_{fz} be the estimated environmental impact in zone z of filling station f if an incident occurs
- Let w_{ez} be the weight assigned for economic consequence in zone z
- Let w_{sz} be the weight assigned for social consequence in zone z
- Let w_{az} be the weight assigned for environmental consequence in zone z

Consequence Scores

- The overall consequence score for petrol station f is therefore defined as the lexicographic vector:

$$V_f = \left[VL_f, VS_f\right]\left[\sum_{z=1}^{Z} L_{fz}, \sum_{z=1}^{Z}\left(w_{ez}E_{fz} + w_{sz}S_{fz} + w_{az}A_{fz}\right)\right]$$

Factors that take into account lost lives:

- 1.1) the number of employees at the petrol station – in the event of an emergency, they are at high-risk group;
- 1.2) the number of fuel dispensers - determines the maximum number of vehicles that can be fuelled at one time;
- 1.3) the average number of vehicles per hour (throughput) - based on the previous indicator and this one allows to determine the presence of possible queues;
- 1.4) the presence of crosswalks, pedestrian highways with significant traffic near the petrol station – increases the likelihood of people who may suffer from an accident;
- 1.5) 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;
- 1.6) the presence of a single, two or multi-lane road near the petrol station - this may increase the traffic flow through the petrol station;
- 1.7) 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;
- 1.8) the presence of a public or private transport stops near the petrol station - increases the likelihood of people who may suffer from an accident;
- 1.9) 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.

Factors that take into account economic consequences:

- 2.1) the type of construction of the petrol station and the equipment used - affects the amount of material damage to the enterprise itself;
- 2.2) the number of tanks, their volume and type - the amount of oil products directly affects the size of a possible emergency;
- 2.3) 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 emergency;
- 2.4) the presence of public utilities near the petrol station: main water and gas pipelines, heating networks, communication networks and power lines;
- 2.5) the presence of high-risk enterprises near the petrol station - the possibility of their damage as a result of the «domino» effect increases;
- 2.6) presence of other petrol stations nearby;
- 2.7) the presence of residential buildings near the petrol station;
- 2.8) unfulfilled orders from regulatory authorities - a willful failure to fulfil safety obligations entails greater material and other types of liability;
- 2.9) operating time of the petrol station - wear and tear of equipment over time may increase the risk of an emergency;
- 2.10) 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.

Factors that take into account social consequences:

- 3.1) 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;
- 3.2) 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;
- 3.3) 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;
- 3.4) 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;
- 3.5) 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;
- 3.6) presence of cultural monuments near the petrol station – it increases the vulnerability of a petrol station;
- 3.7) location in or proximity to a war zone - a multivariate factor that proportionally affects the risks of an accident and undesirable consequences;
- 3.8) 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;
- 3.9) 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;
- 3.10) 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.

Factors that take into account environmental impacts:

- 4.1) type of fuel used, standard - directly affects the number of harmful substances, heavy metals that can be released during the combustion of oil products;
- 4.2) 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;
- 4.3) 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.;
- 4.4) 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;
- 4.5) soil type and structure - affects the depth of penetration of the pollutants into the soil;
- 4.6) 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;
- 4.7) 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;
- 4.8) the presence of significant forest areas near the petrol station - presence causes a greater likelihood of forest fires and environmental damage;
- 4.9) 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;
- 4.10) 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;
- 4.11) 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.

Using Analytic hierarchy process (AHP) to evaluate factors

The following hierarchy of criteria for assessing the petrol stations vulnerability with the use of AHP can be drawn up:

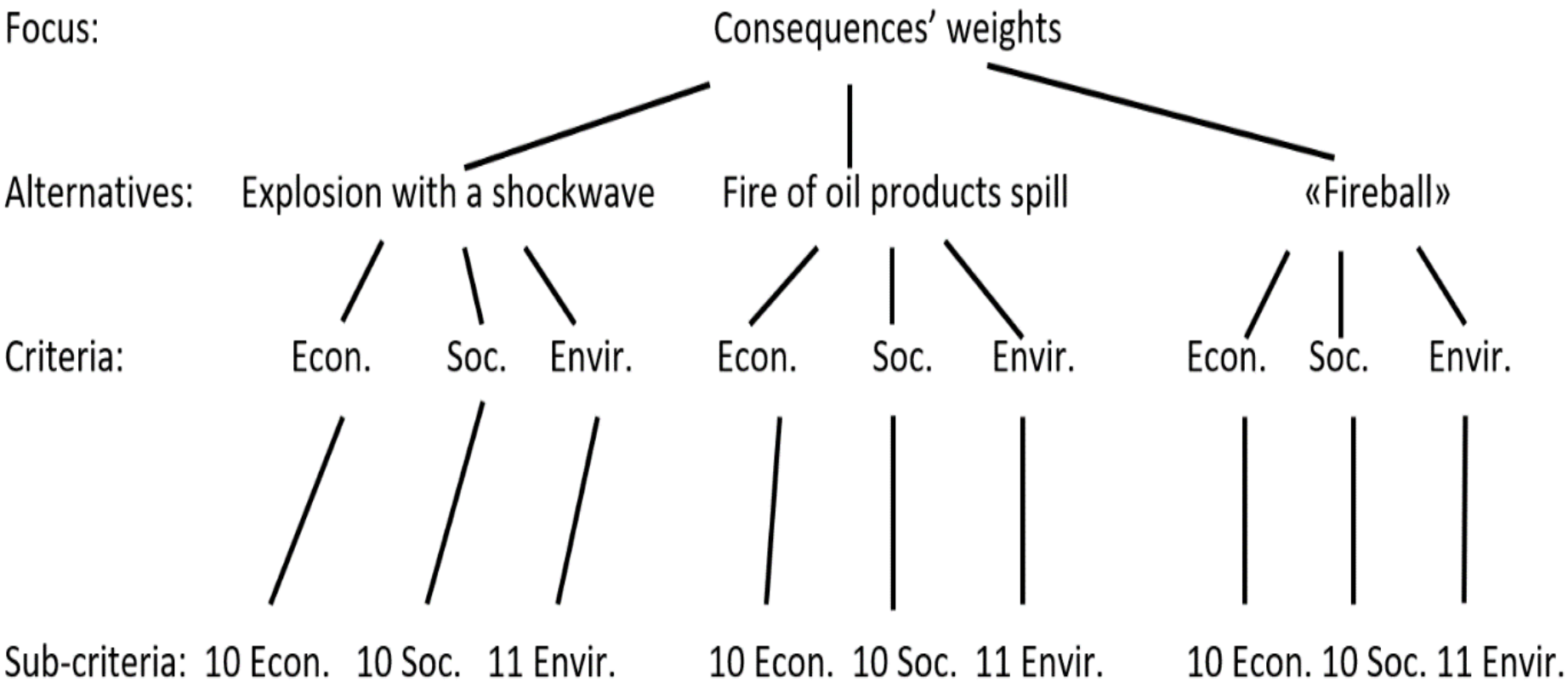


Table 1 – The result of performing a pairwise comparison for the incident of an explosion of a vapour-air mixture of petroleum products (economic consequences)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Geom. mean	x_j – priority vector	%
E1	1	1/5	1/5	1/5	1/5	1/5	1/5	2	3	3	0.5083	0.0355	3.55
E2	5	1	2	3	3	3	2	8	8	8	3.5008	0.2442	**24.42**
E3	5	1/2	1	2	2	2	1	7	7	7	2.419	0.1687	**16.87**
E4	5	1/3	1/2	1	1	1	1/2	6	6	6	1.5683	0.1094	**10.94**
E5	5	1/3	1/2	1	1	1	1/2	6	6	6	1.5683	0.1094	**10.94**
E6	5	1/3	1/2	1	1	1	1/2	6	6	6	1.5683	0.1094	**10.94**
E7	5	1/2	1	2	2	2	1	6	6	6	2.3097	0.1611	**16.11**
E8	1/2	1/8	1/7	1/6	1/6	1/6	1/6	1	2	2	0.3500	0.0244	2.44
E9	1/3	1/8	1/7	1/6	1/6	1/6	1/6	1/2	1	1	0.273	0.0190	1.90
E10	1/3	1/8	1/7	1/6	1/6	1/6	1/6	1/2	1	1	0.273	0.0190	1.90
										Σ	14.3385	1	100
$x_j \cdot \Sigma_{i=1}^{n} a_{ij}$	1.14	0.87	1	1.17	1.2	1.2	1	1	0.9	0.88	λ_{max}	10.3577	
											C.I.	0.03975	
											C.R.	2.66%	

Complete tables can be obtained from the link:
https://drive.google.com/drive/folders/130AklO1dX8V7yfDOCu1_put1phkM0mOM

Table 2 – Results of factor priority calculation for 3 incidents using AHP

Economic factors	Priority, %	Social factors	Priority, %	Environmental factors	Priority, %
Explosion of vapour-air mixture of petroleum products with the formation of a shock 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 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
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**

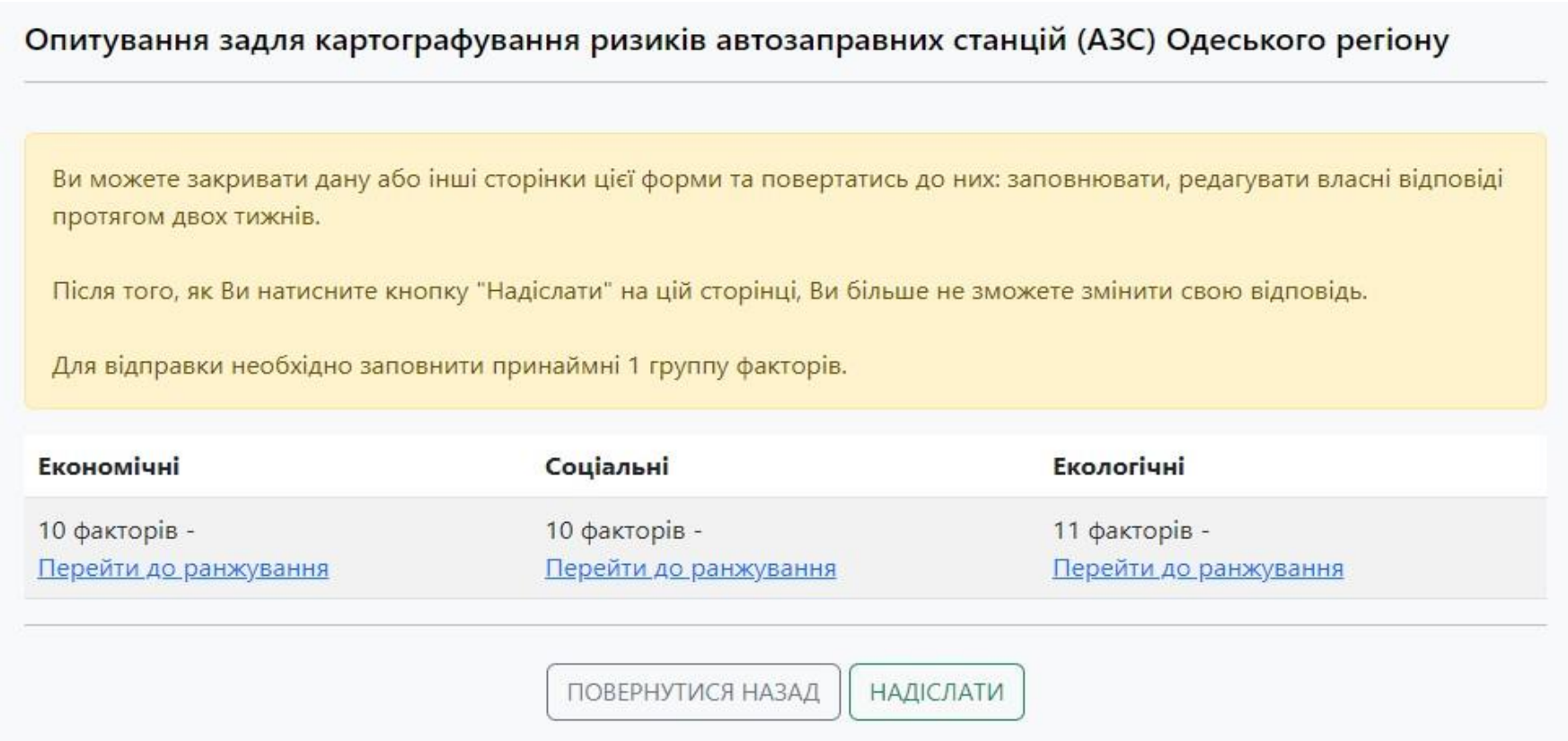
Table 2 Cont.

Economic factors	Priority, %	Social factors	Priority, %	Environmental factors	Priority, %
"Fireball"					
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 2 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.

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: https://petrol-stations-form-survey.onrender.com/). 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%.

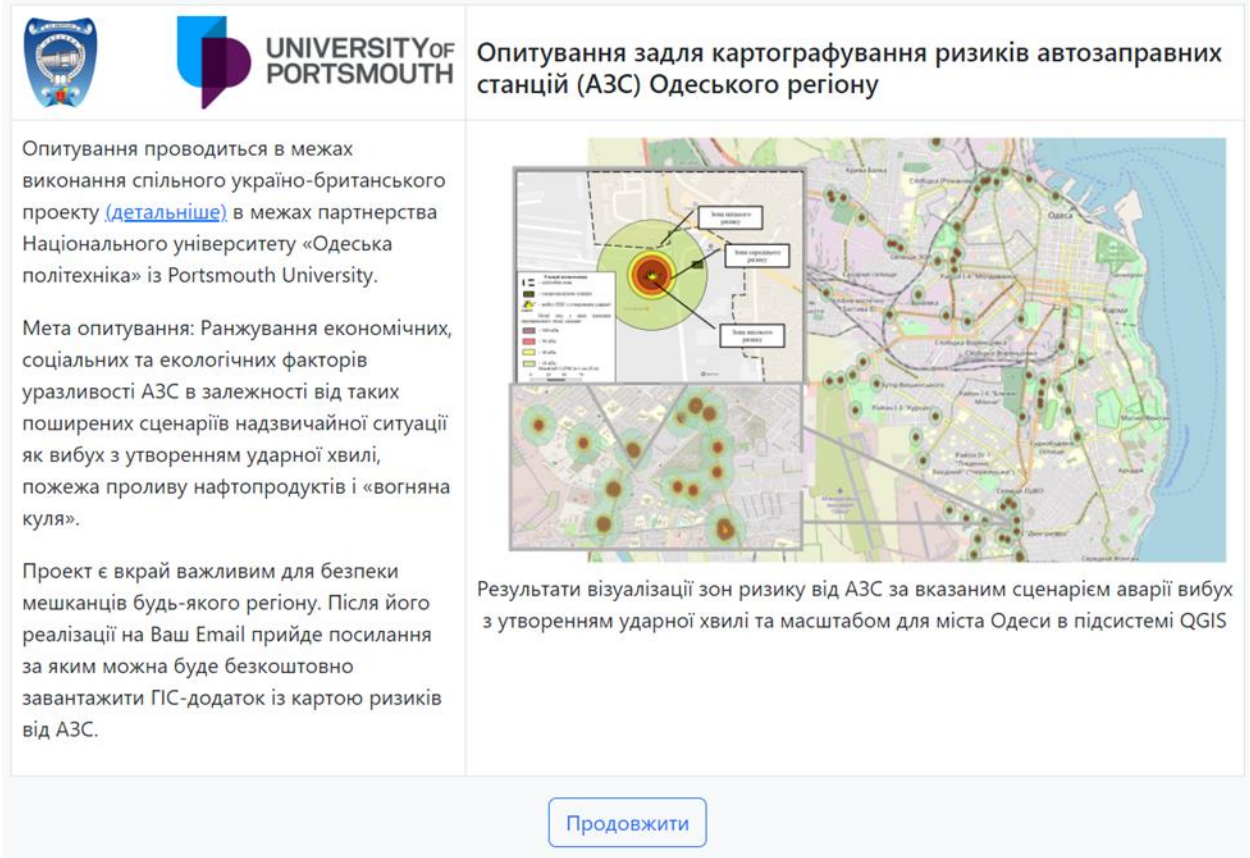


Table 3 – Results of expert assessments of petrol stations vulnerability factors after filling out the web form (ranking method)

Economic factors	Priority, %	Social factors	Priority, %	Environmental factors	Priority, %
Explosion of vapour-air mixture of petroleum products with the formation of a shock 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 spill					
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**

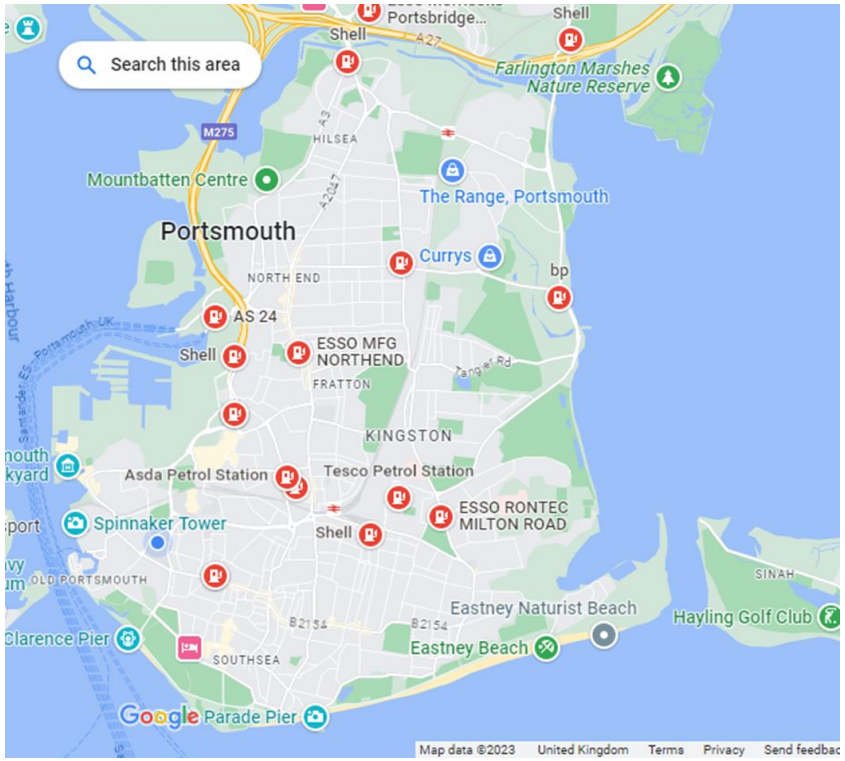
Table 3 Cont.

Economic factors	Priority, %	Social factors	Priority, %	Environmental factors	Priority, %
"Fireball"					
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 3, we identified the most important factors for each incident those that have a rank of 6 and above. Table 3 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.

Portsmouth Case Study

- Island City of c140,000 inhabitants
  - Most densely populated in Europe
- Low-Lying, Home of UK Navy
- Military, Engineering and Space Industries
- Ferry port, transport hub
- Some tourist and historical sites
- University city
- Some districts with relatively high social deprivation index
- 11 Petrol Stations
- 400m initial single zone



Source: Google Maps

Results : Pairwise comparison

	Economic	Environmental	Social
Economic	-	1.5	3
Environmental	0.667	-	1.667
Social	0.333	0.6	-

Eigenvalue method (http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/AHPweb.html)

Sustainability Dimension	Initial Weight
Economic	0.505
Environmental	0.317
Social	0.179

Inconsistency Index: 0.0018

Results: Consequence Rankings

Rank	Station Code	Lives Lost	Economic	Environmental	Social	Sustainability
1	4	1.000	1.000	0.679	1.000	0.899
2	2	0.854	0.754	0.464	0.986	0.704
3	5	0.828	0.799	0.679	0.884	0.777
4	10	0.828	0.737	0.679	0.894	0.747
5	7	0.823	0.959	0.679	0.710	0.827
6	11	0.818	0.703	0.679	0.932	0.737
7	3	0.797	0.853	1.000	0.855	0.901
8	9	0.776	0.765	0.679	0.643	0.716
9	6	0.766	0.980	0.893	0.884	0.936
10	1	0.655	0.730	0.571	0.874	0.706
11	8	0.532	0.509	1.000	0.700	0.699

6. Summary of the results

- As a result of the study, based on the system analysis, a set of 40 factors was formulated that characterize the vulnerability of petrol stations from the point of view of the consequences of a probable incident, 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, 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 and decision making, which of the 31 vulnerability factors of petrol stations should be to be taken into account (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 Ev11 can be identified. 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
- Due to the impossibility of visualization of petrol station vulnerability data on maps of Ukraine due to the state of war, a case study was conducted by British colleagues for the city of Portsmouth, where the existing 11 petrol stations in the city were ranked according to the consequences of a probable emergency incident, including all groups of factors in general

Publication of research materials at conferences and in scientific journals

- Ivanov O.V., Arsirii O.O., Bieliaiev K.O. Analysis of emergency situations at petrol stations and their environmental consequences in geoinformation systems. ***Prospects for the development of geoinformation technologies in the conditions of climate change*** *: collection of materials of the international science and pract. conf. (Odesa, 20th April 2023).* Odesa : Oldi+, 2023. P. 23-29.
- Bieliaiev K.O., Ivanov O.V., Arsirii O.O. Method of assessing stability of gas stations based on intelligent analysis of data on potentially dangerous objects in gis. ***«Modern Information Technology - 2023»*** *: materials of 13th intern. scien. conf. of students and young researchers (Odesa, 18-19th May 2023)* / MES of Ukraine; Odesa Polytechnic National University; Institute of Computer Systems. Odesa : Science and technology, 2023. P. 68-70.
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