MANAGING THE RISK WHEN TRANSPORTING THE HAZARDOUS MATERIALS THROUGH AN INHABITED AREA. A FUZZY LOGIC APPROACH

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ABSTRACT

We witness the numerous traffic accidents when hazardous materials are transported. Some materials are hazardous by themselves, eg. the selfigniting ones, so they can cause damage and jeopardize people even when there is no accident. In this paper, the problem of managing the risk when transporting hazardous materials through the road network in an inhabited area was considered. Two different aspects of this risk were analysed: the individual and the social risk, and the models for their evaluation were created. The problem was being solved by applying approximative reasoning, i.e. by establishing the fuzzy logical system. The models and the approximative approach were tested on a hypothetical network with hypothetical parameters and they showed an efficient application of this system.

Key words:
hazardous materials, fuzzy logic, transport, managing the risk, approximative reasoning.

ABSTRAKT

Sme svedkami početných dopravných nehôd pri ktorých sú prepravované nebezpečné látky. Niektoré materiály sú samé o sebe nebezpečné, napr. sú samozápalné, takže môže dôjsť k poškodeniu a ohroziť ľudí. V tomto článku je považovaný za nebezpečenstvo riadenia rizík pri preprave nebezpečných látok po cestnej sieti v obývanej oblasti. Analyzovali sa dva rôzne aspekty tohto rizika: individuálne a sociálne riziká, a boli vytvorené modely pre ich hodnotenie. Tento problém bol vyriešený použitím približne úvahy, t.j. o založení fuzzy logický systém. Modely a

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približného prístup, boli testované na hypotetické sieti s hypotetickým parametrami a ukázal efektívne uplatňovanie tohto systému.

Kľúčové slová:
nebezpečné materiály, fuzzy logika, doprava, riadenie rizika, približné usudzovania

1 INTRODUCTION

Transporting and storing of hazardous materials are the processes of vital economic importance for every prosperous and technologically oriented society. All the materials which bear the risk and the properties of which can endanger the environment are classified as hazardous materials. More than 3,300 materials and their products make a list of dangerous materials which contains of inflammable, corrosive, radioactive, poisonous and explosive materials. This list keeps expanding because there are more and more materials which manifest some of the listed characteristics. (Office of Federal Register, 1990; United Nations ADR 1985/2012; TRB Special Report 197, 1983).

Dangerous materials manifest their negative influence on the environment when they appear in it without control. To control the risk which is connected with managing and transporting of dangerous materials, it is important to develop the management systems which include the procedures for supporting the strategic, tactical and operational decisions and their goal is the reduction of risks by two dimensions: The first one is reducing the possibility of accidents, and the second one reducing the consequences of the prospective accident. The first objective is achieved by applying preventive actions, which is one of the aims of this paper. These procedures aim to minimize or, potentially, eliminate the possible risk factors which are the products of human mistakes or of the lack of the infrastructure. The second objective is achieved by application and implementation of the corresponding regulations and procedures which aim to minimize the damage caused by a possible unwanted situation.

In the last few decades, numerous models for managing the risk when transporting hazardous materials were being developed ((List et al., 1991; Quelch and Cameron, 1994; Spadoni et al., 1995; Bonvicini et al., 1997; Lu et al., 2007; Dadkar et al., 2008; Gumus, 2009; Kheirkhah et al., 2009; Verma, 2009; Jia et al., 2011; Dasa et al., 2012; Xiea et al., 2012; Davidović et al., 2013).

Bonvicini at all., (1998) are engaged in managing the risk when transporting hazardous materials, with emphasis on the air protection because of hazardous materials releasing when the accident happens. Their approach is based on fuzzy logic and it considers the dangers for the transport participants themselves as well as for the local population. The results show that this model evaluates the caused damage faster and more successfully than the traditional methods as Monte Carlo.

The problem of managing the risk, depending on the requests for hazardous materials transport, can be found in the paper of Erkut and Ingolfsson (2005). Their model is based on fuzzy logic and it shows results by finding the shortest transport route in regards to the transport requests.

Alhajraf at all., (2005) developed a system which minimized the losses created during the hazardous materials transport (fuel, accidents, external costs, etc.) in real time, using the GIS technology. The results show the successful implementation of GIS on this problem.

Oggero at all., (2006) dealt with hazardous materials combined transport, by rail and by road. In their research, they came to the conclusion that during the period 1932-2004, 63% of all accidents with hazardous materials happened on the road.

Analytical approaches as Monte Carlo can be used for an unpredictable situation analysis only when there is an exact formula which copies the way out depending on the input parameters. If the distribution probability of all the input parameters is known, and if the input parameters are independent, then their distribution on the way out can be completely determined. However, there are only few cases when this distribution can be exactly calculated. By analytical approaches, it is possible to determine the contribution of each parameter and the interaction of the input parameters on the changes happening on the way out.

The aim of this paper is to suggest a model for routing the vehicles through an inhabited area, taking into account the individual and the collective risk of transporting hazardous load. In more complex situations, it is not possible to find an explicit function for the way out which will be in function of the input parameters. Then it is not possible to apply analytical approaches and some alternative approaches must be used. In this paper, the given problem is being solved by the fuzzy logical system.

2. THE MODEL OF MANAGING THE RISK

As the basis for managing the risk, the suggested model considers two risk levels. On the first level, a mathematical formulation for the individual risk was developed. The individual risk presents the degree of risk that some of the vehicles transporting hazardous materials will have an accident. The second risk level presents the possible number of people who may be endangered because of releasing of the hazardous load from the vehicle. This way of managing and distributing the risk, but with a different formulation, can be found in the work of *Bonvicini et al*., (1997). The equitation for the individual risk estimation has this formulation:

$$I(N)=\frac{n_v \cdot n_c \cdot P_I}{365}\cdot(1-f_l) \quad (1)$$

where:

$I(N)$ – individual risk,
n_v - daily number of vehicles,
n_c - weight number of accidents per year,
P_I - probability of hazardous substance release (%),
f_l - the link length factor.

The link length factor is determined in this way:

$$f_l=\frac{L_{\max}-L}{L_{\max}-L_{\min}} \quad (2)$$

where:

L_{max} - maximum link length on the network (plus 10m more),
L_{min} - minimum link length on the network (minus 10m more),
L - the length of the wanted link.

Parameters, such as the number of vehicles and the weight number of traffic accidents from the equitation (1) are the known values, but it cannot be said for the possibility of hazardous materials releasing. If we assume that a vehicle is completely technically functional and equipped by the standards, we still cannot predict with certainty which traffic accidents may happen. This value can be considered as the random variable, i.e. the model component which brings the uncertainties. In other words, the possibility of hazardous load releasing represents a stochastic value which depends on a random accident.

On transport rationalization, i.e. the evaluation of the most convenient route of means of transport carrying hazardous materials through an inhabited area, the Euclidean vehicle moving distance has a great influence. That's why it is necessary to quantify this parameter during the evaluation. Of course, the longer the route, the greater is the possibility of an accident happening, and the price of transport is also rising. The bands, at the link length, are moved 10 m each, so the boundary values wouldn't have the values 1, i.e. 0. The longer the route is, the greater is the risk of an accident happening. To achieve such a dependency in the equitation (1), the number one was subtracted from the route length factor value. This factor could have been put under the fraction bar in equitation (1), but then its influence would have been too great.

The complete area, through which the vehicles with hazardous load will pass, should be divided into zones, according to the number of inhabitants, so the number of people in danger could be known in the case of accidents. The equitation for the estimation of social risk can be presented like this:

$$S(N) = \frac{n_p \cdot P_{id} \cdot \lambda}{\omega} \tag{3}$$

where:
$S(N)$ - social risk,
n_p - number of people located in the area of an accident,
P_{id} – percent of people who stayed in their homes or in some closed objects (%),
λ - the sensitive objects distance factor,
ω - factor of weather conditions during the accident.

The factor of sensitive objects distance is determined like this:

$$\lambda = \frac{L`_{\max} - L`}{L`_{\max} - L`_{\min}} \tag{4}$$

where:
$L`_{max}$ - maximum distance from critical objects (plus 10m more),
$L`_{min}$ - minimum distance from critical objects (minus 10m more),
$L`$ - distance from the critical objects of the desired link.

As with the model for individual risk, the variable n_p can be assumed from the population density and the ω factor can be quantified (Table 1). The value of the ω factor is taken approximately, so the value of this variable cannot be precisely determined, too. The P_{id} variable is of random character because human behaviour is a random dimension. In other words, it is hard to predict which percent of people will stay at home because of the stochastic ruling the decisions of each individual. The λ factor also has a stochastic character because the accident can happen in the node itself (at the intersection) or at any other part of the link. When calculating this value, the place of the accident on the link is taken randomly.

Table 1. Values of the ω factor depending on the weather conditions

Weather conditions	ω
Light rain	0,98
Heavy rain	0,95
Light snow	0,94
Heavy snow	0,97
Light wind	0,96
Strong wind	0,98

By a special model of weighting, the accident severity is taken into account, that is to say, each TA (Ttraffic accident) has been weighted by assigning the severity index (the weights of significance), depending on the accident severity. The weight indexes have been determined on the basis of accident costs in the inhabited areas, as given in the Road Safety Manual (*PIARC, 2004*), and they are:

- TA with slight injuries (estimated costs c. 21,939 $/TA) multiplied by the weight index 1,
- TA with serious injuries (estimated costs c. 220,270 $/TA) multiplied by the weight index 10,
- TA with casualties (estimated costs c. 1,866,382 $/TA) multiplied by the weight index 85.

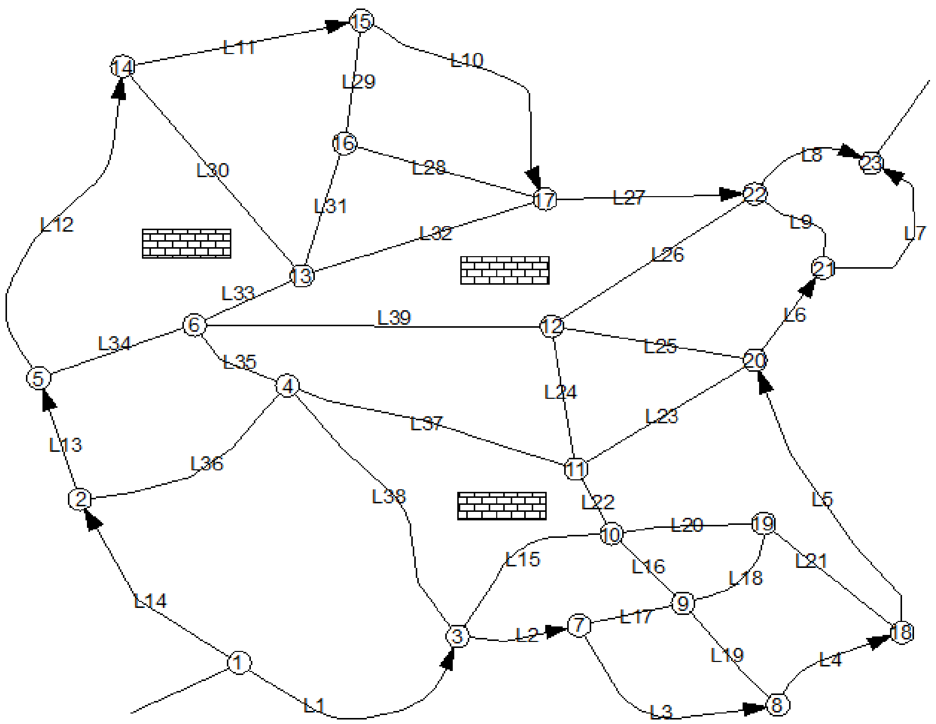
It is clear from the stated above that the individual and social risk cannot be observed exactly because they have the fuzzy component which is derived from their probabilistic character. When projecting the fuzzy logical system, the individual and the social risk represent two input dimensions into the fuzzy logical system, while the complete risk will represent the way out of the fuzzy logical system. The suggested model consists of the next steps:

1. Dividing the design network into zones and establishing the number of people who could be influenced by a possible accident.
2. Defining the known parameters which consist of no coincidence and which are predicted by the equitation for individual and social risks (number of vehicles etc.).
3. Choosing randomly all the random values planned by models for individual and social risks (number of people out in the open etc.).
4. For every link of the proper network, calculating, according to the planned models, the individual and the social risk. On that basis, defining the fuzzy sets as the input values into the fuzzy logical system.
5. Formation of the fuzzy set: the complete risk, which represents the way out of the fuzzy system. Applying that value to each of the links of the proper network through which the vehicles carrying dangerous load are passing.
6. Defining “the shortest route”, which represents the route suggestion for vehicles carrying hazardous load, using some of the available models (Dijkstra etc.), by such assigned values.

Further in this paper, the suggested model will be tested on a hypothetical example. We should mention that fuzzy sets are formed depending on the area of application, specific conditions and particularities for each location.

3 MODEL TESTING ON A HYPOTHETICAL NET

In figure 1, a test network is presented, with hypothetical input parameters which will be shown in table 2. It is necessary to estimate the smallest possible risk when transporting hazardous load from the initial node 1 to the final node 23. Three sensitive objects are planned on the network (a hospital, a school etc.) and they were considered as proper when calculating the λ factor.



- *sensitive objects*

Figure 1. A test network

It was also planned that links on the edge of the network should be one way so the contraflow vehicle movement should be disabled.

Table 2. Values of the individual and the social risk with calculation parameters

Link	L(m)	f_l	L\`(m)	n_c	n_v	$P_I(\%)$	n_p	P_{id} (%)	λ	ω	I(N)	S(N)
1	386	0,32	353	54	20	0,88	25000	0,79	0,21	0,98	1,77	4276
2	170	0,86	171	23	20	0,54	45000	0,13	0,65	0,95	0,09	4068
3	336	0,44	250	29	20	0,44	45000	0,20	0,46	0,94	0,39	4502
4	205	0,77	413	30	20	0,56	45000	0,54	0,07	0,97	0,21	1750
5	440	0,18	341	49	20	0,43	45000	0,35	0,24	0,96	0,95	4007
6	162	0,88	334	14	20	0,89	55000	0,82	0,26	0,92	0,08	12732
7	285	0,57	432	19	20	0,82	55000	0,59	0,02	0,98	0,36	789
8	154	0,90	318	12	20	0,14	55000	0,95	0,30	0,95	0,01	16435
9	144	0,93	316	26	20	0,82	55000	0,73	0,30	0,94	0,09	12964
10	387	0,32	190	51	20	0,64	40000	0,75	0,60	0,97	1,22	18643
11	334	0,45	246	32	20	0,65	40000	0,64	0,47	0,96	0,63	12611
12	503	0,03	101	28	20	0,65	40000	0,47	0,82	0,92	0,97	16605
13	182	0,83	306	21	20	0,37	25000	0,69	0,33	0,98	0,07	5703
14	331	0,46	416	46	20	0,71	25000	0,62	0,06	0,95	0,98	1021
15	278	0,59	50	46	20	0,13	45000	0,97	0,94	0,94	0,13	43689
16	140	0,94	152	28	20	0,60	45000	0,34	0,70	0,97	0,06	11048
17	143	0,93	166	25	20	0,48	45000	0,72	0,66	0,96	0,05	22314
18	173	0,85	254	28	20	0,81	45000	0,53	0,45	0,92	0,18	11732
19	196	0,80	287	25	20	0,54	45000	0,38	0,37	0,98	0,15	6465

20	210	0,76	157	9	20	0,16	45000	0,23	0,68	0,95	0,02	7501
21	247	0,67	410	36	20	0,13	45000	0,96	0,08	0,94	0,09	3529
22	121	0,98	72	13	20	0,32	45000	0,55	0,89	0,97	0,00	22490
23	292	0,56	98	31	20	0,58	55000	0,92	0,82	0,96	0,44	43360
24	207	0,77	111	37	20	0,73	55000	0,42	0,79	0,92	0,34	20089
25	284	0,58	99	42	20	0,31	55000	0,74	0,82	0,98	0,30	33959
26	338	0,44	68	51	20	0,57	55000	0,13	0,90	0,95	0,89	6970
27	290	0,56	135	20	20	0,56	40000	0,68	0,74	0,94	0,27	21182
28	288	0,57	148	26	20	0,66	40000	0,83	0,71	0,97	0,41	24264
29	177	0,84	244	14	20	0,16	40000	0,34	0,47	0,96	0,02	6678
30	388	0,31	35	19	20	0,82	40000	0,69	0,98	0,92	0,59	29101
31	199	0,79	118	33	20	0,66	40000	0,99	0,78	0,98	0,25	31403
32	353	0,40	43	42	20	0,26	40000	0,28	0,96	0,95	0,36	11255
33	164	0,88	67	10	20	0,45	40000	0,38	0,90	0,94	0,03	14615
34	227	0,72	115	20	20	0,86	40000	0,26	0,78	0,97	0,27	8311
35	145	0,92	153	19	20	0,88	25000	0,52	0,69	0,96	0,07	9403
36	341	0,43	345	36	20	0,80	25000	0,74	0,23	0,92	0,90	4664
37	416	0,24	70	62	20	0,69	25000	0,58	0,89	0,98	1,77	13259
38	440	0,18	72	69	20	0,77	25000	0,40	0,89	0,95	2,37	9373
39	493	0,05	60	42	20	0,90	55000	0,37	0,92	0,94	1,97	19949

The idea of fuzzy logic application in this paper is, that from the input data (individual and social risk), the total risk for each link on the network should be suggested. According to that, fuzzy sets were formed, as shown in figure 3.

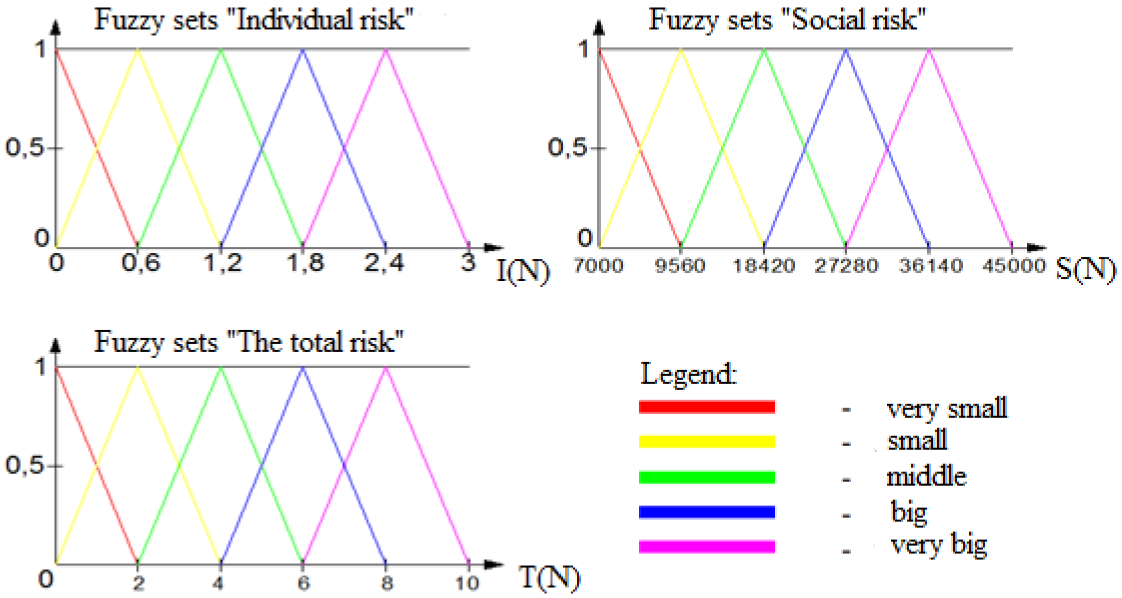


Figure 3. Fuzzy sets

Fuzzy variables “individual risk” and “social risk” represent a way into the fuzzy logical system and they are the basis for deciding about the output variable, “the total risk”. Models based on fuzzy logic consist of the fuzzification, the “if-then” rules base formation and, as the last step, of the choice of one value for the output variable, that is, the defuzzification.

Fuzzy logical system was developed in the “MATLAB” programming language (Version: 7.10), that is, by using: ”Fuzzy logic toolboxes – FIS EDITOR GUI”. In the following table 3, a base of applied fuzzy rules was presented.

Table 3. The fuzzy rules base

The rule ordinal number	If	The first entrance	Logical operator	The second entrance	Then	Way out
1	If	very small I(N)	i	very small S(N)	then	very small T(N)
2	If	small I(N)	i	very small S(N)	then	very small UR(N)
3	If	medium I(N)	i	very small S(N)	then	small UR(N)
…	If	…	i	…	then	…
24	If	big I(N)	i	very bigS(N)	then	very big UR(N)
25	If	very big I(N)	i	very big S(N)	then	very big UR(N)

In table 4, the output results from the fuzzy logical system are shown, i.e., the values of the total risk distributed on the branches of a hypothetical network. The characteristic of fuzzy logic as a universal approximator can be clearly seen here. In other words, when we burden the network by the values obtained at the exit of the fuzzy logical system (Figure 4.), that represents the basis for the last step when determining the route of the vehicle with hazardous load.

Table 4. Way out of the fuzzy logical system. UR(N) values by links

Link	I(N)	S(N)	UR (N)	Link	I(N)	S(N)	UR (N)	Link	I(N)	S(N)	UR (N)
1	1,77	4276	3,41	L14	0,98	1021	1,86	L27	0,27	21182	1,96
2	0,09	4068	1,42	L15	0,13	43689	5,15	L28	0,41	24264	2,71
3	0,39	4502	2,04	L16	0,06	11048	1,19	L29	0,02	6678	1,10
4	0,21	1750	1,32	L17	0,05	22314	1,33	L30	0,59	29101	3,80
5	0,95	4007	1,84	L18	0,18	11732	1,70	L31	0,25	31403	3,33
6	0,08	12732	1,29	L19	0,15	6465	1,80	L32	0,36	11255	2,15
7	0,36	789	0,99	L20	0,02	7501	1,06	L33	0,03	14615	1,07
8	0,01	16435	1,00	L21	0,09	3529	1,40	L34	0,27	8311	1,96
9	0,09	12964	1,34	L22	0,01	22490	0,88	L35	0,07	9403	1,28
10	1,22	18643	3,99	L23	0,44	43360	5,89	L36	0,90	4664	1,96
11	0,63	12611	2,46	L24	0,34	20089	2,11	L37	1,77	13259	3,47
12	0,97	16605	3,40	L25	0,30	33959	3,56	L38	2,37	9373	4,35
13	0,07	5703	1,43	L26	0,89	6970	2,26	L39	1,97	19949	4,20

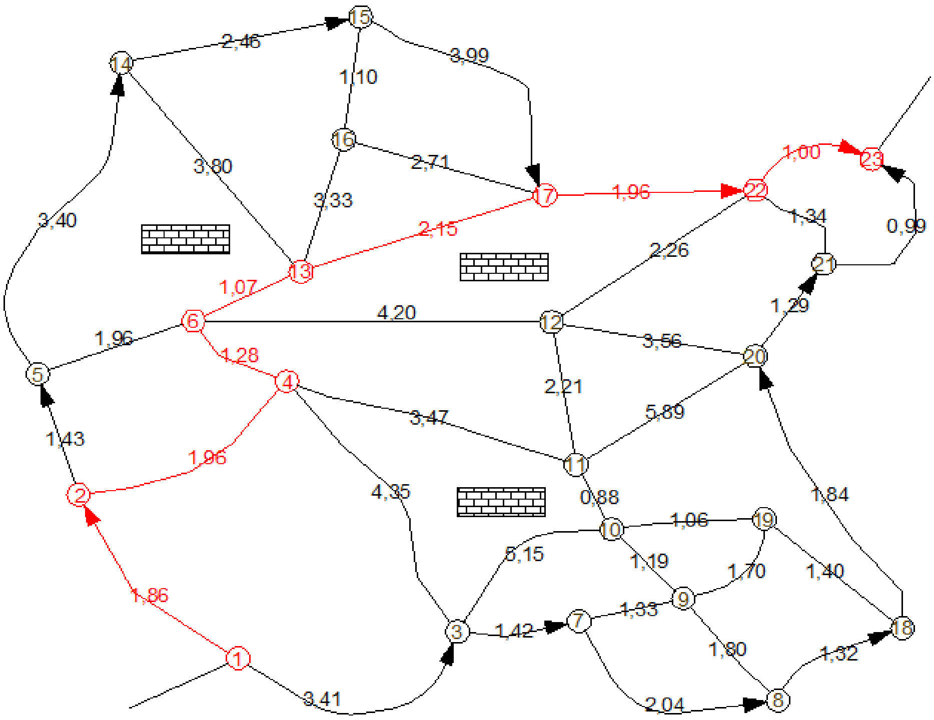


Figure 4.3. Display of a hypothetical network burdened by the ways out of the fuzzy logical system

In the end, the wanted route can be found by some of the models for finding the shortest way through the network. In this case, the Dijkstra model was applied, and with more complex networks it is also possible to apply dynamic programming.

As the final result of this whole research, the route *1 – 2 – 4 – 6 – 13 – 17 – 22 – 23* is suggested.

4 CONCLUSION AND THE DIRECTIONS OF FUTURE RESEARCH

In this paper, the problem of minimizing the risk when transporting hazardous load through an inhabited area was considered. The developed model considered two aspects of such a risk, the individual and the social one, which presented a risk that the accident would happen and the effects of such an accident on the population.

In this case, a relatively small network was considered, but we could set a problem on a broader scale. For example, a vehicle should transport hazardous load from one part of town to the other where the possible locations for storing could be, and the optimization of its route should be performed in such conditions.

Through a numerical example, it was shown how the uncertainties in the risk analysis could be managed by fuzzy logic, and how the fuzzy logic was, as a universal approximator, suitable for such calculations. Starting from such a model, a software should be developed to serve as support when choosing the route for transporting hazardous load through an inhabited area.

The model developed could further be improved by developing factors which would quantify the influence of different kinds of hazardous load, because it's not the same whether we transport explosive or uranium. In future research, it will be possible to perform a more complex risk evaluation of releasing hazardous load on the population, according to the possible air and land pollution, and depending on the kind of hazardous load which is being transported.

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Článok recenzovali dvaja nezávislí recenzenti.