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OCCUPATIONAL SAFETY RISK ASSESSMENT ANALYSIS MODELING AND SOFTWARE FOR MINES CREATED BASED ON FUZZY LOGIC

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Abstract- Risk assessment analyzes in occupational health and safety in mines around the world have become very important in terms of moral, legal and indirect costs. Hazards in the workplace environment of the mines or that may come from outside should be defined. The factors that cause these hazards to turn into risks and the risks arising from the hazards should be analyzed and graded. The risks in the mines arise from the works done, the operations carried out and various methods, the materials used, all kinds of machinery and equipment, the employees in or around the workplace, the organizations created in the workplace, the environmental conditions and the interaction of various elements with each other. In mines with many specific and uncertain hazards, it is very difficult to make a risk assessment and model a system to simulate these hazards. In this study, a computer software was developed by creating a fuzzy logic-based risk assessment analysis model, taking into account many hazards in occupational health and safety in mines.

Keywords: Risk Analysis, Risk Modeling, OHS Mines, Fuzzy Logic.

1. INTRODUCTION

The dangers brought by industrialization have increased occupational accidents in developing countries. Rapid migration from rural areas to cities, the inability to adapt employees with low levels of education to the jobs, working in adverse conditions and inadequate job inspections have led to an increase in occupational accidents. Prevention of increasing work accidents and occupational diseases is possible by making a good risk assessment analysis with a high level of accuracy close to reality at the first stage. It is a report that includes identifying the hazards related to occupational health and safety in an institution, deciding who can be harmed and how, analyzing risks, deciding on the measures to be taken, implementing these precautions, constantly monitoring the hazards, risks and precautions, changing them if necessary, and whether more precautions are needed.

The whole process is called Risk Assessment Analysis [1, 2]. Risk assessment aims to predict in advance how, where and in what way health problems may occur before anyone is injured or sick, and to take precautions in line with these predictions from the very beginning.

The risks in the workplaces arise from the works done, the processes carried out and various methods, the materials used, all kinds of machinery and equipment, the employees in or around the workplace, the organizations created at the workplace, the environmental conditions and the interaction of various elements with each other as raw material or intermediate is used [3, 4].

Mining is the largest source of income for many developing countries today. Around 30 million people work in mines around the world [5, 6]. One of the sectors with the highest accident and death risks is mining. Although only 1% of the workers in the world work in mines, 10% of serious accidents occur in the mining sector [7, 8]. Major accidents such as explosions, fires and dents in mines result in the death of many people. Although the high technologies used today have made great strides in preventing such accidents, mining is one of the sectors with the highest risk of accident and death [9, 10].

It also has high occupational accident numbers as a result of unpreventable and undesirable situations. Mining is different from other working branches in terms of its basic structure, because it is essential to work according to the ever-changing environmental conditions in mining, that is, to produce within the limits that nature constantly changes. This shows how important it is to correctly perceive and evaluate risks in mining. In mines with many specific and uncertain hazards, risk assessment and modeling of a system to simulate these hazards is very difficult [11, 12]. In this study, a computer software has been developed by creating a fuzzy logic-based risk assessment analysis model, taking into account many hazards in occupational health and safety in mines.

2. RISK ASSESSMENT AND ANALYSIS

It is defined as Risk Evaluation and Analysis, which is necessary to determine the hazards that exist in the workplace or may come from outside, to rank the risks arising from the hazards, to decide on the control measures, to implement them and to monitor their applications [13, 14]. In the mining sector, mine gases, ventilation, excavation works, thermal comfort, fire, dust, noise, vibration, lighting, fortification and mine collapses, use of explosives, electricity, flooding, mechanization and use of machinery, material and human transportation and psychological factors doing studies on such issues will help identify hazards [15, 16].

In order to determine the dangers that may arise in the mines, first of all, the mine workers should be talked to and the dangers they see should be listed, the reports of the accidents that have occurred should be examined, the information and instructions regarding the tools and equipment used should be examined, all existing and various hazards should be determined, and the risks that may arise from these hazards should be determined [17, 18].

Matrix Method, Fine-Kinney Method, Energy Analysis, Hazard and Operability Method (HAZOP), Fault Tree Analysis, Fault Mode and Effects Analysis (FMEA), Event Tree Analysis, Cause-Effect Diagrams, Deviation Analysis, Initial Hazard Analysis in analyzing risks, Checklists, If-Then Analysis, etc. [19, 20]. There are many methods available, the most commonly used method is the matrix method, which is a method of analyzing risk by separating severity and probability into components [21-23]. In this method; The risk posed by a hazard is analyzed over how often the probability of its occurrence can be seen and how serious the negative result can be. How to perform risk assessment and analysis is shown in Figure 1.

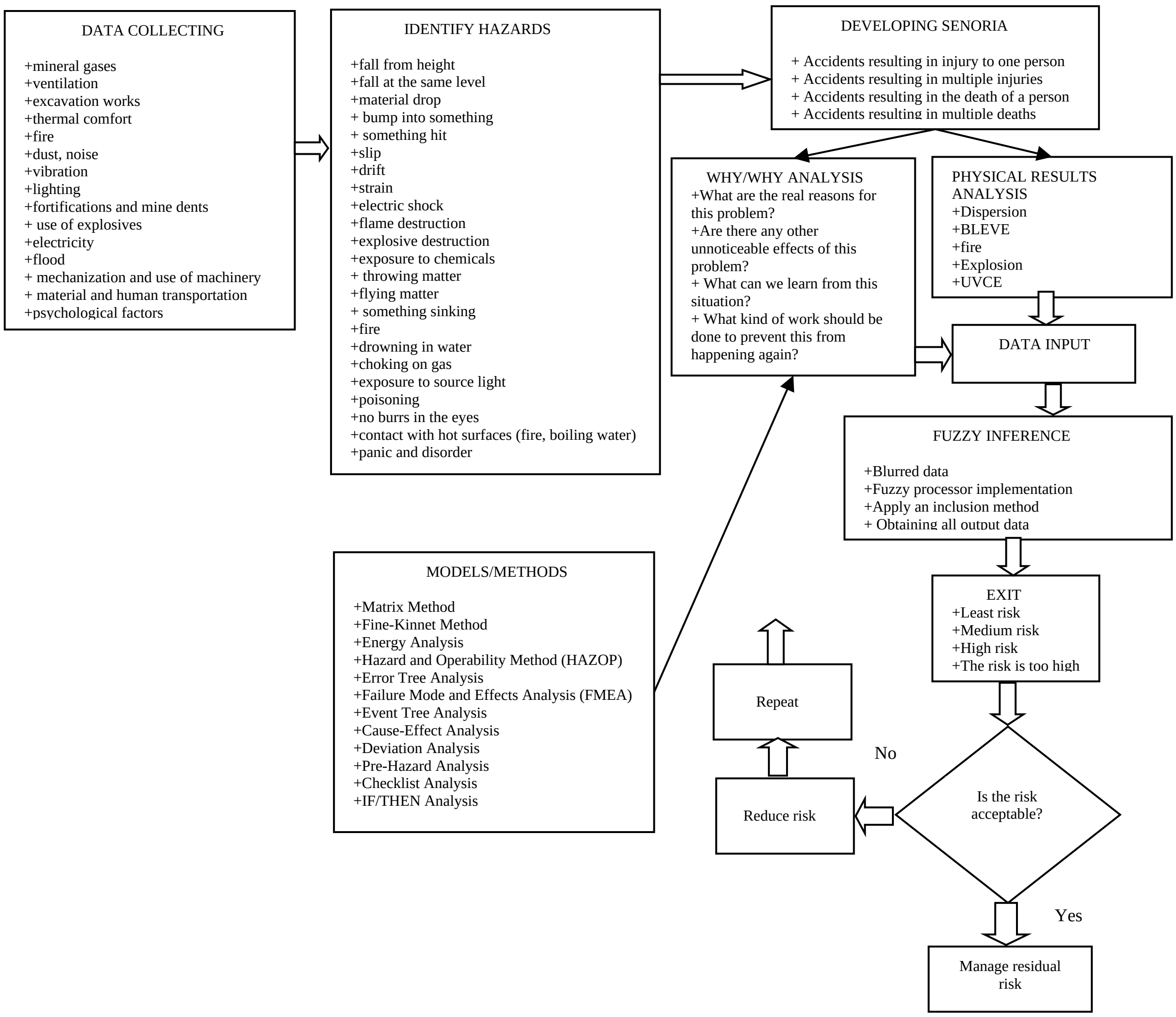

Figure 1. How to perform risk assessment and analysis

3. APPLICATION OF FUZZY LOGIC TO OCCUPATIONAL SAFETY RISK ASSESSMENT

It can be given to people in workplaces;

t: hazard (from 1 hazard to number *T*)

d: value,

d^{max}: maximum value of hazard

Nd: no hazard value (membership degree $m_{VIOLENCE}$=0)

dd: very low hazard value (membership degree $m_{VIOLENCE}$=0.2)

Dd: low hazard value (membership degree $m_{VIOLENCE}$=0.4)

Od: middle hazard value (membership degree $m_{VIOLENCE}$=0.6)

yd: high hazard value (membership degree $m_{VIOLENCE}$=0.8)

Yd: very high hazard value (membership degree $m_{VIOLENCE}$=1.0)

As a workplace environment;

t (1): workplace ambient temperature (when it goes below 15 °C and rises above 25 °C

d_1^{min} = 10 °C and d_1^{max} =35 °C

t (2): air flow velocity (when it goes below 0.5 m/s and goes above 1 m/s)
d_2^{min} = 0.4 m/s
d_2^{max} =1.1 m/s
t (3): relative humidity (over 60%)
d_3^{max} =60%

As a suffocating gas in the workplace environment;
t (4): carbon monoxide
d_4^{max} = 50 ppm
t (5): hydrogen cyanide
d_5^{max} = 10 ppm
t (6): hydrogen cyanide acid
d_6^{max} = 10 ppm

As harmful metals in the workplace environment;
t (7): lead
d_7^{max} = 0.15 mg/m^3
t (8): mercury
d_8^{max} = 0.075 mg/m^3
t (9) : arsenic
d_9^{max} = 0.5 mg/m^3
t (10): sulphureous hydrogen
d_{10}^{max} = 20 ppm
t (11): beryllium
d_{11}^{max} = 2 mg/m^3

As an irritating gas in the workplace environment;
t (12): ammonia
d_{12}^{max} = 25 ppm
t (13): chlorine
d_{13}^{max} = 1 ppm
t (14): nitrogen dioxide
d_{14}^{max} = 5 ppm
t (15): sulfur dioxide
d_{15}^{max} = 0.1 ppm
t (16): ozone
d_{16}^{max} = 0.1 ppm

As a toxic gas in the workplace environment;
t(17): Arsine,
d_{17}^{max} = 0.05ppm
t(18): phosphine
d_{18}^{max} = 0.3 ppm
t(19) : stibin
d_{19}^{max} = 0.1 ppm
t (20): high pressure
t (21): low pressure
t (22): chemicals
t (23): noise
t (24): hand-arm vibration
t (25): whole body vibration
t (26): illumination
t (27): harmful rays and radiation
t (28): electromagnetic fields
t (29): hot or cold climate
t (30): irregular and slippery surfaces
t (31): movement of vehicles and machinery
t (32): machine movement and parts
t (33): hazardous surfaces
t (34): hot or cold surfaces
t (35): hand tools
t (36): electrical installations and equipment
t (37): fire
t (38): explosion
t (39): lifting and transport
t (40): posture disorders
t (41): biological hazards
t (42): stress, violence, harassment
is determined. The probability of occurrence of the hazard is given in Table 1.

Table 1. The probability of occurrence of the hazard

Probability Value	Probability of Occurred
Very high (5)	Very often (every day)
High (4)	Often (once a week)
Medium (3)	Few (once every three months)
Small (2)	Very little (once a year)
Too small (1)	Hardly ever

Table 2. The violence rating

Violence	Rating
Very Serious (5)	Death
Serious (4)	There is loss of limb
Middle (3)	Treatment in bed is required.
Light (2)	Outpatient treatment is required, work hours are lost.
Very light (1)	Outpatient treatment required, no loss of working hours.

Table 3. The risk analysis score

Violence / Probability	Very high (5)	High (4)	Medium (3)	Low (2)	Very low (1)
Very high (5)	25 Intolerable	20 High	15 High	10 Medium	5 Low
High (4)	20 High	16 High	12 Medium	8 Medium	4 Low
Medium (3)	15 High	12 Medium	9 Medium	6 Low	3 Low
Low (2)	10 Medium	8 Medium	6 Low	4 Low	2 Negligible
Very low (1)	5 Low	4 Low	3 Low	2 Negligible	1 Negligible

Table 4. The risk analysis score

Acceptable Risks (1)	It is a risk that has been reduced to a tolerable level.
Low Risk (2,3,4,5,6)	It is a risk that does not require immediate action. However, long-term control is applied to reduce the risk to acceptable risk
Medium Risks (8,9,10,12)	These risks should be reduced to a low risk level by implementing measures as soon as possible.
High Risks (15,16,20)	These risks should be reduced to a low risk level by taking immediate measures. If necessary, work should be stopped until occupational health and safety measures are taken.
Unacceptable Risks, Very High Risks (25)	Work should be stopped until occupational health and safety measures are taken. The work should be started after the precautions are taken.

id=5 'danger occurring per day' (membership degree $u_{Probable}$=1.0)
id=4 'the occurrence of the danger in a week' (membership degree $u_{Probable}$=0.8)
id=3 'the occurrence of the danger in the month' (membership degree $u_{Probable}$=0.6)
id=2 'the danger occurs in three months' (membership degree $u_{Probable}$=0.4)
id=1 'the occurrence of the hazard per year' (membership degree $u_{Probable}$=0.2)
id=0 'no danger ever arises' (membership degree $u_{Probable}$=0.0)
is expressed. The violence rating is determined in Table 2.

'Death, permanent incapacity' (membership degree $u_{Violence}$=1.0)
'Serious injury, long-term treatment, occupational disease' (membership degree $u_{Violence}$= 0.8)
'Mild injury, inpatient treatment/injury' (membership degree $u_{Violence}$=0.6)
'No lost workday, outpatient treatment with no lasting effect' (membership degree $u_{Violence}$=0.4)
'No loss of working hours, remediable immediately, requiring first aid' (membership degree $u_{Violence}$=0.2)
'No danger' (membership degree $u_{Violence}$=0.0)
is expressed. The score matrix of risk is in Table 3. The score of risk is given in Table 4.

Risk assessment score and degree of membership;
Risk = violence x probability
Risks with a score of 25 are very high risk. The membership level is u_{RISK} = 1.0.
Risks with a score between 15 and 25 are high risk. The membership level is u_{RISK} = 0.8.
Risks with a score between 8 and 12 are medium risk. The membership level is u_{RISK} = 0.6.
Risks with a score between 3 and 6 are low risk. The membership level is u_{RISK} = 0.4.
Risks with a score of 1 and 2 are very low risk risk. The membership level is u_{RISK} = 0.2.
If the score is 0, there is no risk. The membership level is u_{RISK} = 0.0
is defined as [24, 25].

Firstly, the per unit values of the identified hazards are calculated as $d_t^n = d_t/d_t^{\max}$, t=1,…,T', then the per unit values of the unidentified hazards are calculated as $d_t^n = d_t/d_t^{\max}$, $t=T'+1,\ldots,T$, each a fuzzy number scale, d_t^n, r_t, $t=T'+1,\ldots,T$ is defined by the maximum method, the fuzzy definition of each identified hazard is $c_t=W_t$ for each t=1,…,T'. The d_t^n is calculated and all linguistic hazards are $c_t=W_t$ for each $t=T'+1,\ldots,T$. By calculating r_t, the order of hazards is based on the comparison method of fuzzy numbers. The linguistic variable table is given in Table 5. The probability-severity assessments of risks determined by three different occupational safety experts using fuzzy decision-making approach and matrix method in an applied mining quarry is shown in Table 6. The risk membership degrees of these assessments are given in Table 7. The conversion of probability-severity membership degrees of the risks obtained in the study to linguistic variables are shown in Table 8. The risk membership degrees obtained are given in Table 9.

Table 5. Linguistic variables

Linguistic variant	Fuzzy value
O *Nd:* non-dangerous value	(0, 0, 0)
● *dd*: very low dangerous value	(1, 1, 2)
● *Dd*: low dangerous value	(1, 2, 3)
● *Od*: medium dangerous value	(2, 3, 4)
● *yd*: high dangerous value	(3, 4, 5)
● *Yd*: very high dangerous value	(4, 5, 5)

Table 6. Probability-severity assessments of risks using fuzzy decision making approach and matrix method in an applied mine

	Risks	Probability	Violence
1	Dent	0.6, 0.4, 0.4	1.0, 0.8, 0.8
2	Slide Down	0.4, 0.6, 0.6	1.0, 1.0, 0.8
3	Fall From Height	0.4, 0.6, 0.4	0.8, 0.8, 0.8
4	Fall at The Same Level	0.2, 0.2, 0.2	0.2, 0.2, 0.2
5	Material Drop	0.6, 0.6, 0.4	0.8, 0.6, 0.8
6	Bump into Something	0.4, 0.6, 0.4	0.6, 0.6, 0.8
7	Something Hit	0.4, 0.6, 0.6	0.4, 0.6, 0.4
8	Slip	0.8, 0.6, 0.8	1.0, 1.0, 1.0
9	Drift	0.2, 0.4, 0.2	0.4, 0.2, 0.6
10	Strain	0.4, 0.2, 0.2	0.2, 0.2, 0.2
11	Electric Shock	1.0, 1.0, 1.0	1.0, 1.0, 1.0
12	Flame Destruction	0.4, 0.6, 0.6	0.6, 0.6, 0.8
13	Explosive Destruction	0.4, 0.6, 0.6	0.6, 0.6, 0.8
14	Exposure To Chemicals	0.4, 0.4, 0.6	1.0, 0.8, 0.8
15	Throwing Matter	0.4, 0.2, 0.2	0.2, 0.2, 0.4
16	Flying Matter	0.6, 0.6, 0.4	0.4, 0.2, 0.2
17	Something Sinking	0.2, 0.2, 0.2	0.2, 0.2, 0.2
18	Fire	0.2, 0.4, 0.2	1.0, 0.8, 0.8
19	Drowning in Water	0.2, 0.4, 0.2	0.8, 0.8, 0.8
20	Choking on Gas	0.4, 0.4, 0.6	1.0, 1.0, 1.0
21	Poisoning	0.4, 0.4, 0.6	1.0, 1.0, 1.0
22	No Burrs in The Eyes	0.2, 0.2, 0.2	0.2, 0.2, 0.2
23	Contact with Hot Surfaces (Fire, Boiling Water)	0.6, 0.4, 0.4	0.2, 0.2, 0.4
24	Panic and Disorder	0.6, 0.4, 0.4	0.2, 0.2, 0.4

Table 7. Risk membership degrees of risk assessments using fuzzy decision making approach and matrix method in an applied mine

	Risks	Risk Membership Degree
1	Dent	0.60, 0.32, 0.32
2	Slide Down	0.40, 0.60, 0.48
3	Fall from Height	0.32, 0.48, 0.32
4	Fall at The Same Level	0.04, 0.04, 0.04
5	Material Drop	0.48, 0.36, 0.32
6	Bump into Something	0.24, 0.36, 0.32
7	Something Hit	0.16, 0.36, 0.24
8	Slip	0.80, 0.60, 0.80
9	Drift	0.08, 0.08, 0.12
10	Strain	0.08, 0.04, 0.04
11	Electric Shock	1.00, 1.00, 1.00
12	Flame Destruction	0.24, 0.36, 0.48
13	Explosive Destruction	0.24, 0.36, 0.48
14	Exposure To Chemicals	0.40, 0.32, 0.48
15	Throwing Matter	0.08, 0.04, 0.08
16	Flying Matter	0.24, 0.12, 0.08
17	Something Sinking	0.04, 0.04, 0.04
18	Fire	0.20, 0.32, 0.16
19	Drowning in Water	0.16, 0.32, 0.16
20	Choking on Gas	0.40, 0.40, 0.60
21	Poisoning	0.40, 0.40, 0.60
22	No Burrs in The Eyes	0.04, 0.04, 0.04
23	Contact with Hot Surfaces (Fire, Boiling Water)	0.12, 0.08, 0.16
24	Panic and Disorder	0.12, 0.08, 0.16

Table 8. Transforming probability-severity membership degrees of risks into linguistic variables using fuzzy decision making approach and matrix method in an applied mining quarry

	Risks	Probability	Violence
1	Dent	Od, Dd, Dd	Yd, yd, yd
2	Slide Down	Dd, Od, Od	Yd, Yd, yd
3	Fall from Height	Dd, Od, Dd	yd, yd, yd
4	Fall at The Same Level	dd, dd, dd	dd, dd, dd
5	Material Drop	Od, Od, Dd	yd, Od, yd
6	Bump into Something	Dd, Od, Dd	Od, Od, yd
7	Something Hit	Dd, Od, Od	Dd, Od, Dd
8	Slip	yd, Od, yd	Yd, Yd, Yd
9	Drift	dd, Dd, dd	Dd, dd Od
10	Strain	Dd, dd, dd	dd, dd, dd
11	Electric Shock	Yd, Yd, Yd	Yd, Yd, Yd
12	Flame Destruction	Dd, Od, Od	Od, Od, yd
13	Explosive Destruction	Dd, Od, Od	Od, Od, yd
14	Exposure To Chemicals	Dd, Dd, Od	Yd, yd, yd
15	Throwing Matter	Dd, dd, dd	dd, dd, Dd
16	Flying Matter	Od, Od, Dd	Dd, dd, dd
17	Something Sinking	dd, dd, dd	dd, dd, dd
18	Fire	dd, Dd, dd	Yd, yd, yd
19	Drowning in Water	dd, Dd, dd	yd, yd, yd
20	Choking on Gas	Dd, Dd, Od	Yd, Yd, Yd
21	Poisoning	Dd, Dd, Od	Yd, Yd, Yd
22	No Burrs in The Eyes	dd, dd, dd	dd, dd, dd
23	Contact with Hot Surfaces (Fire, Boiling Water)	Od, Dd, Dd	dd, dd, Dd
24	Panic and Disorder	Od, Dd, Dd	dd, dd, Dd

Table 9. Obtaining risk membership degrees using fuzzy decision making approach and matrix method in an applied mine

	Risks	Risk Membership Degree
1	Dent	0.413
2	Slide Down	0.493
3	Fall from Height	0.373
4	Fall at The Same Level	0.040
5	Material Drop	0.386
6	Bump into Something	0.306
7	Something Hit	0.253
8	Slip	0.733
9	Drift	0.093
10	Strain	0.053
11	Electric Shock	1.000
12	Flame Destruction	0.360
13	Explosive Destruction	0.360
14	Exposure To Chemicals	0.400
15	Throwing Matter	0.066
16	Flying Matter	0.146
17	Something Sinking	0.040
18	Fire	0.226
19	Drowning in Water	0.213
20	Choking on Gas	0.466
21	Poisoning	0.466
22	No Burrs in The Eyes	0.040
23	Contact with Hot Surfaces (Fire, Boiling Water)	0.120
24	Panic and Disorder	0.120

After the fuzziness sets have been defined and assigned their membership functions, rules are written for each combination of the control variable. These rules establish a relationship between input variables and output variables by using If–Then statements in decision making. The If condition is a proposition that leads to the Then result of each rule. In general, each rule is shown as If (suggestion) Then (result) Else, and when the equivalent result expressions are removed, 1024 rules with combinations are created. The screenshot of the software has been created as shown in Figure 2. The priority order of the risks has been obtained as in Table 9.

Table 10. Ranking of risks using fuzzy decision making approach and matrix method in an applied mine

1	2	3	4	5	6	7	8
H11	H8	H2	H20	H21	H1	H14	H5

9	10	11	12	13	14	15	16
H3	H12	H13	H6	H7	H18	H19	H16

17	18	19	20	21	22	23	24
H23	H24	H9	H15	H10	H4	H17	H22

4. CONCLUSION

In the workplace environment with many specific and uncertain hazards, risk assessment and modeling of a system to simulate these hazards is very difficult. In this study, a fuzzy logic-based risk assessment analysis model has been created and software has been developed by considering many hazards in occupational health and safety in mines. An alternative approach to risk assessment is proposed using the fuzzy decision approach and the matrix method. With this approach, Occupational health and safety experts were enabled to make evaluations with fuzzy linguistic expressions without making calculations with exact numbers, and the inconsistencies in decision making were reduced by taking the arithmetic averages of these evaluations. As a result of the study by creating a fuzzy logic-based occupational safety risk analysis model and software using fuzzy decision-making approach and matrix method to increase occupational safety in mines, it has been seen that the three most prioritized risks are electric shock, landslide and slipping. It has been determined that these risks create high risks on extremely wet ground where the electrical cables used in the installation are very old and have lost their insulating properties. Cables that are found to be damaged or deteriorated in a way that poses a danger, should be immediately repaired or replaced with good ones. Excavations in the mine should be carried out from top to bottom by giving a slope proportional to the durability of the soil. In the ground that can hold itself such as hard rock, hard shale, concreted gravel, hard limestone, clayey schist rock, sandstone and conglomerate, it is fortified by supporting or shoring the side faces appropriately. The slopes of the ramps should not be more than 35 degrees, which will allow the vehicles to carry the excavated soil outside to the excavation site easily, should not be more than 35 degrees, should be thrown to the distance required by the soil type or shoring should be made to prevent the soil from the excavation, necessary measures should be taken against subsidence and falling of pieces and flooding in underground works.

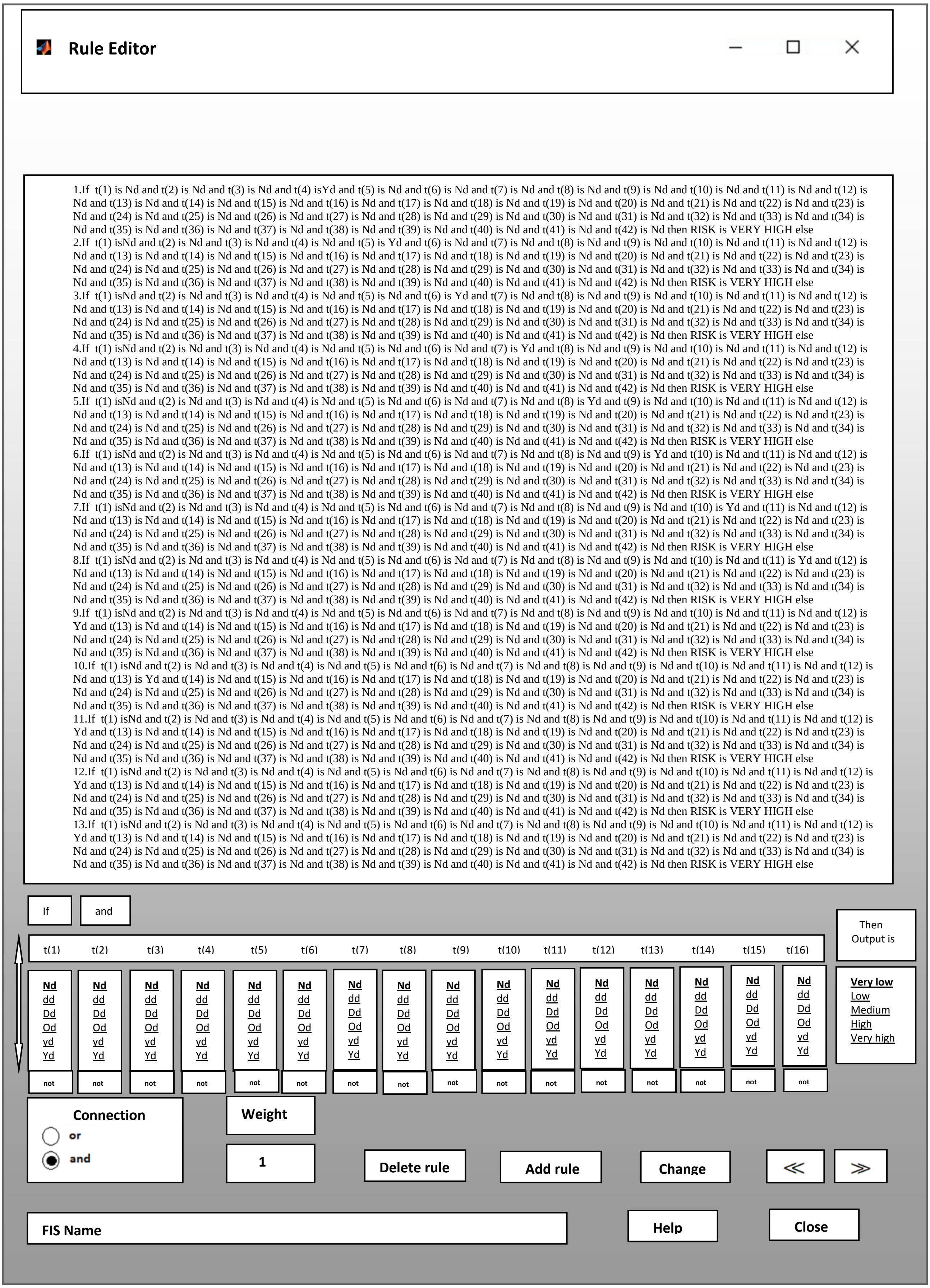

Figure 2. The screenshot of software

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BIOGRAPHY

Mehmet Zile was born in Ankara, Turkey, 1970. He received the B.Sc. degree from University of Yildiz (Istanbul, Turkey), the M.Sc. degree from University of Gazi (Ankara, Turkey) and the Ph.D. degree from University of Yildiz (Istanbul, Turkey), all in Electrical and Electronic Engineering, in 1992, 1999 and 2004, respectively. Currently, he is an Associate Professor of UTIYO at University of Mersin (Mersin, Turkey). He is also an academic member of UTIYO at University of Mersin and teaches information systems and control systems. His research interests are in the area of control systems and electrical machines. He is a member of IEEE.