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A Fuzzy Approach for Risk Analysis with Application in Project Management

Sina Khanmohammadi[1] and Javad Jassbi[2]
[1]*Faculty of Science, Technology and Creative Arts, School of Engineering and Technology, University of Hertfordshire, Hertfordshire,*
[2]*Department of Industrial Management, Islamic Azad University, Science and Research Branch, Tehran,*
[1]*UK*
[2]*Iran*

1. Introduction

The Critical Path Method (CPM) and its development to probabilistic environment, the Program Evaluation and Review Technique (PERT), are the most common tools for predicting and managing different short time or long time projects. However, one of the main difficulties in using mathematical models in real world applications is the vagueness and uncertainty of data and parameters such as activity durations and risky conditions. The constructed network for project management (as a mathematical model) is an aid for control of project implementation with deterministic time durations. However, realization of this approach is difficult in the situation where most of activities will be executed for the first time. One solution offered for this difficulty is the assignment of probabilistic values for estimated durations of activities. In PERT, three estimations called pessimistic, most likely and optimistic values are assigned for each activity. Then the mean duration and its standard deviation are calculated by

$$D = \frac{a + 4m + b}{6} \tag{1}$$

and

$$\sigma = \frac{b - a}{6} \tag{2}$$

Where a, m and b are the optimistic, most likely and pessimistic values respectively. D is the expected (weighted mean) duration of activity and σ is the standard deviation of the three values (Kerzner, 2009). The project duration (sum of durations of critical path) is estimated by using the estimated durations of activities. Also, the probability of finishing the project before a predicted time (by using PERT) is calculated based on the standard deviations without considering other real world factors such as probability of impacts on project (such as inflation or stagnation) , impact threat and ability to retaliate. Hence a new approach based on fuzzy inference system and fuzzy decision making is introduced to have more realistic procedure for project management in real world applications. Fuzzy set is introduced by Zadeh in 1965 (Zadeh, 1965). Different applications of fuzzy sets are studied by researches in different fields (Jamshidi et al., 1993). T. J. Ross has published an interesting book on fuzzy sets theory and its applications in engineering (Ross, 2010). Several papers are also published on applications of fuzzy sets in project management (Chanas et al., 2002; Shipley et al, 1997). M. F. Shipley et al. have used the fuzzy logic approach for determining probabilistic fuzzy expected values in a project management application (Shipley et al, 1996). An extension of their method is introduced and used for determination of expected values for estimated delays of activities in (Khanmohammadi et al., 2001). The procedure introduced here deals with defining multi-purpose criticalities for activities where some other features such as probability of impact, impact threat and ability to retaliate are considered as criticality factors of activities in project management process. In this way the risky situations (vulnerabilities) of activities are calculated using a fuzzy inference system which will be used for calculating the risky situation for each activity as a main criticality factor.

Considerable quantitative models have been introduced in literature to calculate the level of risk; which is simply defined as the rate of threat or future deficit of any system imposed by controllable or uncontrollable variables (Chavas, 2004; Doherty, 2000). Several factors such as probability of occurrence, impact threat and ability to retaliate are introduced as affecting factors on the risk. Then it is tried to find the mathematical relation between affecting factors and the value (level) of the risk (Li & Liao, 2007; McNeil et al., 2005). The concept of risk is considerably wide. It can contain strategic, financial, operational or any other type of risk.

The concept of fuzzy risky conditions for activities is introduced in sections 2 and 3. In section 4 the concept of Multi-Critical PERT by considering risky levels for activities is introduced and a typical project network is considered as a case study for analyzing the effect of imposing the risky level of activities to criticality. The results are compared to classic PERT by means of Mont Carlo simulation using random variables. Another typical example, project management of rescue robot that provides preliminary processes for helping injured people before the arrival of rescue teams, is studied in section 5. Analysis of obtained results and conclusions are presented in section 6.

2. Classic and fuzzy risk analysis

Fig. 1 shows a classic and simple model of risk analysis. It consists of two factors: Impact threat and ability to retaliate. In this model the risk value is classified in four groups. Each group represents a risky condition for the system (organization, project, activity …). Fig. 2 shows the points (situations) with identical risky levels. The distributions of points with the identical risks (contours of different levels) are also presented in Fig. 2. Points O and + represent the risky situations for two systems with ability to retaliate and impact threats of (1,8) and (4.9,5.1) respectively.

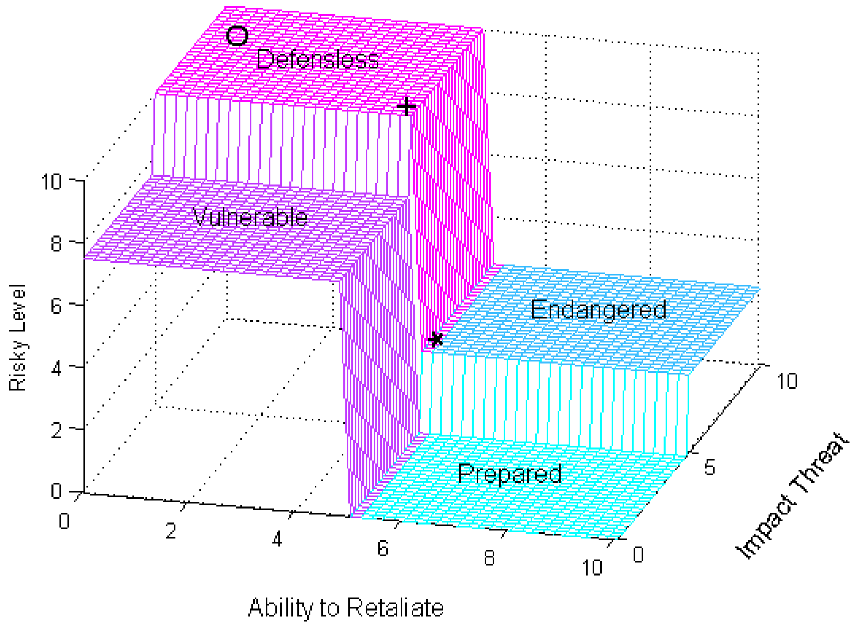


Fig. 1. Risky situations classified in 4 levels

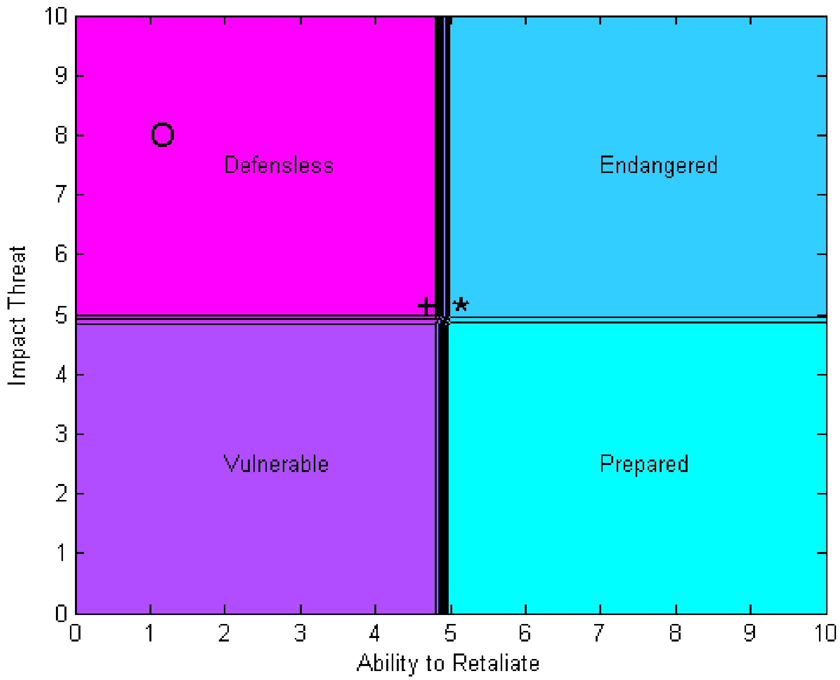


Fig. 2. Different levels of situations (contours of Fig. 1.)

This model is very simple, but it has some structural drawbacks. For example the system + which is in Defenseless situation will change to entirely different condition (Endangered), point (*), with infinity small deviation in ability to retaliate. Also because of its geometrical structure, this model suffers from the lack of considering additional parameters for risk analysis. Another method which has gained more attraction in the risk analysis literature is the model presented by Eq. (3), based on the linear combination of ability to retaliate and impact threat.

$$\text{Risk} = (\text{ability to retaliate}) \times (\text{impact threat}) \quad (3)$$

Fig. 3 represents the continuous increasing surface (risk levels) generated by means of Eq. (3). Two particular levels are shown by the cutting planes K1 and K2. Positions O, + and * are also presented in this figure. Fig. 4 shows some contours of risky surface. As it is seen, by using this model any small change in the values of impact threat and ability to retaliate will cause a very small deviation on the risky level of system. This model is more realistic than the one presented by Figs. 1 and 2. However, it also has its limitations for real world applications because it simplifies the complicated relation between different factors to a linear relation.

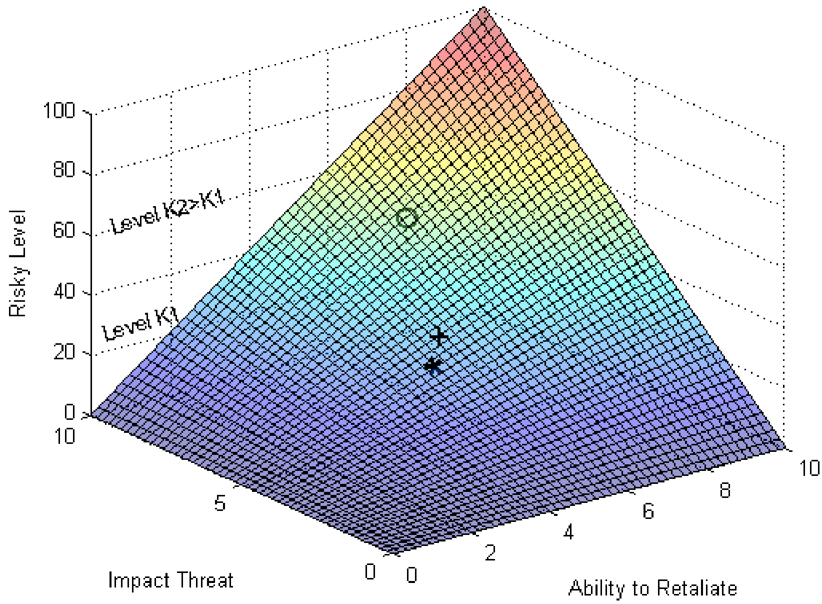


Fig. 3. Continuous surface for risk levels

To have a more applicable model, we can formulate our problem as an input output system by:

$$R=F(X) \quad (4)$$

Where X is the set of input variables which affect the level of the risk, R is the level of the risk and F(.) is a nonlinear function (Kreinovich et al., 2000).

The problem here is to find an appropriate model by which the level of risk of the system can be determined in complex situations where there is no access to all data, or the historical data is useless. This problem may be solved by using Fuzzy inference system.

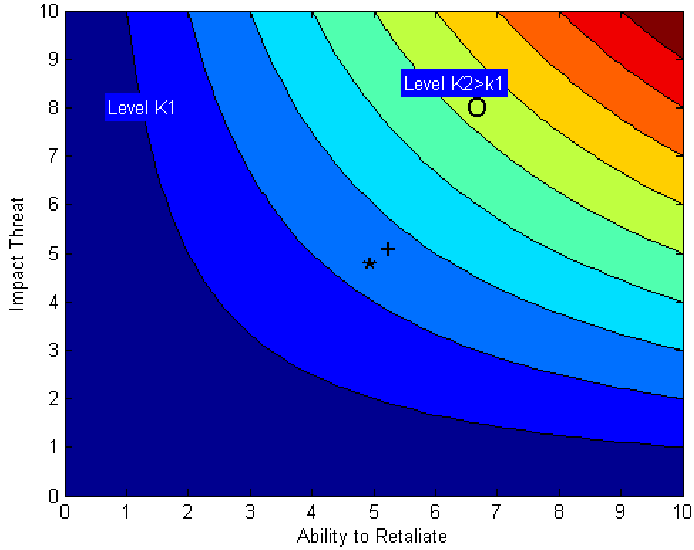


Fig. 4. Some contours of Fig. 3.

3. Fuzzy model

Fuzzy inference systems (FIS) are rule-based systems with concepts and operations associated with fuzzy set theory and fuzzy logic (Mendel, 2001; Ross, 2010). These systems map an input space to an output state; therefore, they allow constructing structures that can be used to generate responses (outputs) to certain stimulations (inputs), based on stored knowledge on how the responses and stimulations are related. The knowledge is stored in the form of a rule base, i.e. a set of rules that express the relations between inputs and the expected outputs of the system. Sometimes this knowledge is obtained by eliciting information from specialists. These systems are known as fuzzy expert systems (Takács, 2004). Another common denomination for FIS is fuzzy control systems (see for example (Mendel, 2001)).

FIS are usually divided in two categories (Mendel, 2001; Takagi & Sugeno, 1985): multiple input, multiple output (MIMO) systems, where the system returns several outputs based on the inputs it receives; and multiple input, single output (MISO) systems, where only one output is returned from multiple inputs. Since MIMO systems can be decomposed into a set of MISO systems working in parallel, all that follows will be exposed from a MISO point of view (Mamdani & Assilian, 1999). In our risk analysis model a fuzzy inference system is introduced for calculating the risky situations of systems by considering different factors such as probability, impact threat and ability to retaliate (Cho et al., 2002; Nguene & Finger, 2007). Fig. 5 shows the block diagram of a multi input single output fuzzy risk analysis system for the mentioned factors (Carr & Tah, 2001).

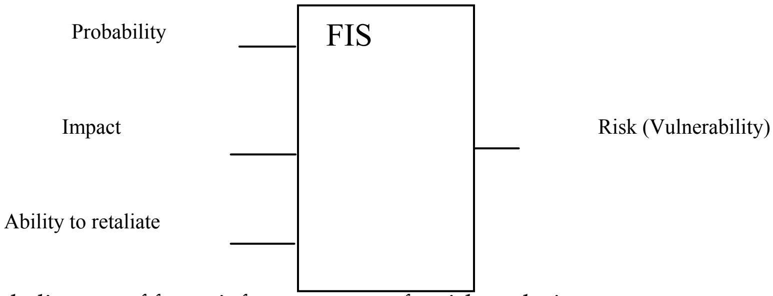


Fig. 5. Block diagram of fuzzy inference system for risk analysis

In this work the following Bell shape membership function is used to determine the fuzzy values of inputs for determining the risky levels of activities by FIS.

$$\mu_A(x) = \frac{1}{1 + d(x - c)^2} \tag{5}$$

Where $\mu_A(x)$ is the membership of variable x in fuzzy value A, c is the median of the fuzzy value and d is the shape parameter. Fig. 6 shows the bell shape membership functions for different fuzzy verbal values.

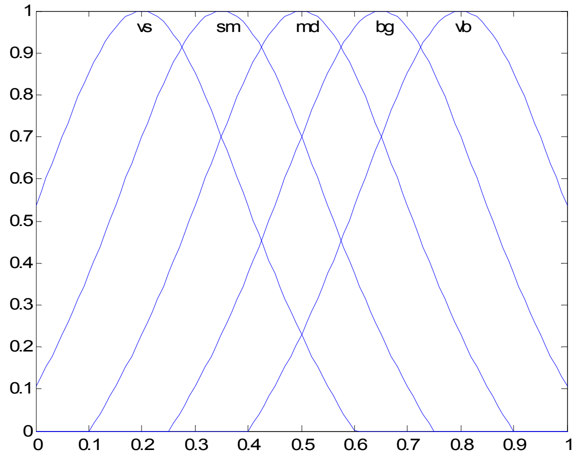


Fig. 6. Membership functions of different fuzzy verbal values vs: Very Small, sm: Small, md: Medium, bg: Big, vb: Very Big

The reason for implementing bell shape membership function is that because of its smoothness (comparing Triangular memberships), and simple formula (comparing Gaussian memberships) it is more appropriate for getting qualitative data from experts.

This model is implemented to the simple model of risk analysis, presented in section 2, to have an idea on the main difference between the classic and fuzzy risky levels. Fig. 7 shows the surface and counters of risky levels of organizations +, and O for 50% probability of impact.

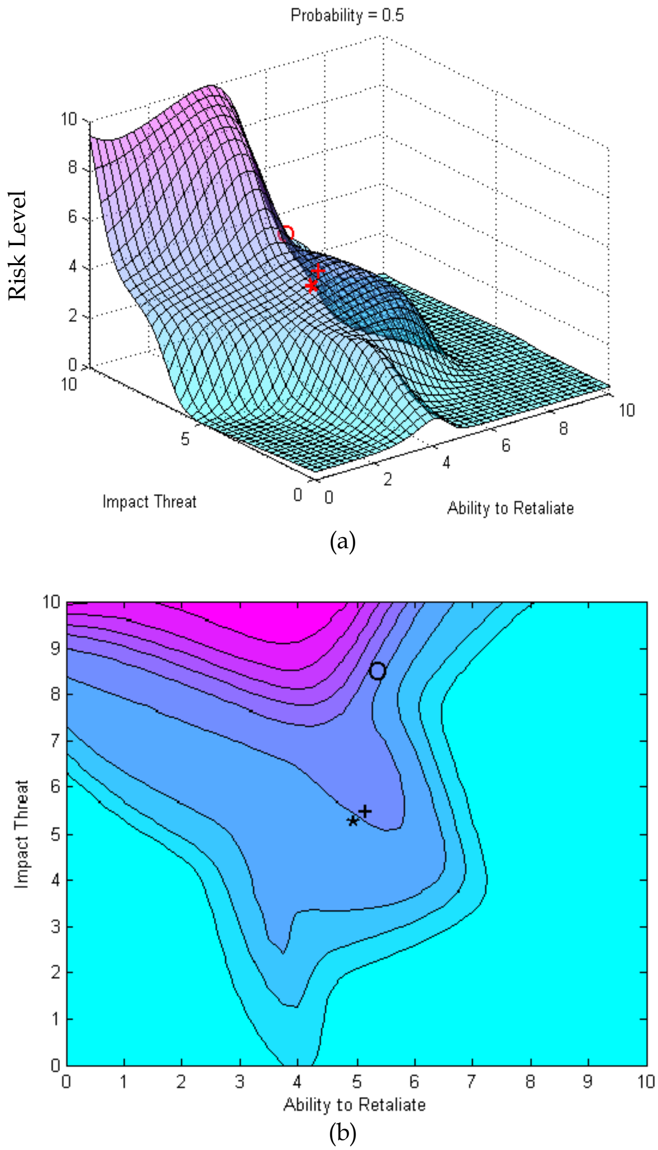


Fig. 7. (a) Risky surface and (b) Counters of the simple example by using fuzzy inference system

As it is seen in Fig. 7, organization + which is in appropriately Defenseless situation will change to appropriately Endangered situation, point **(*)**, with infinity small deviations in ability to retaliate and in impact threat, which is more realistic comparing to the classic one. To have an idea on utilization of risk management on criticality of activities besides other criticality criteria, the multi critical PERT is introduced in section 4.

4. Multi critical PERT by considering risky levels

The multi critical PERT uses the data presented by table 1 to define the multi-purpose criticality of activities.

Activity	a	m	b	V	PFA	RLA	SFA	SCA	COR	MPC

Table 1. Data used by Multi-Critical PERT

The procedure for using these data to calculate the multi-purpose criticalities of activities is as follows:

Algorithm

Step 1. Perform classic PERT to calculate Durations of activities D, variances V, Earliest Start Times ES, Latest Finish times LF, Free slack times FS and Total slack times TS, where scheduled times ST may be imposed to different events.

Step 2. Calculate the Duration Range of activities DR=LF-ES.

Step 3. Calculate the Probability of Finishing each Activity PFA in duration range DR, by considering duration D and standard deviation $\sigma = \sqrt{V}$.

$$PFA = p(D \le DR) \tag{6}$$

Step 4. Use the fuzzy inference system to calculate the Risky Level of each Activity RLA by using the fuzzy values of probability of impact pr, impact treat im, and ability to retaliate ar.

The following experimental data gathered from experts are fed to ANFIS (Artificial Neural Fuzzy Inference System) in MATLAB and 14 appropriate FIS rules (Fig. 8) are generated by means of “genfis3” for the case study.

Probability = [1 .5 1.2 .8 .4 1.7 .8 .2 .2 .7 .5 .5 1 1 .6 .1 .3 .4]
Impact = [10 0 5 5 5 2 7 0 8 8 9 3 10 10 10 8 2 10 2 6 .8]
Ability to retaliate = [4 10 5 5 2 3 3 5 2 7 5 5 3 2 10 0 8 4 6 8 1]
Risky level = [7.5 0 1 3 0 5 1 0 4 2 .5 0 4.5 2.5 0 10 .5 3 0 0 0]

Step 5. Normalize the free slack times of activities by dividing them to their maximum value. Calculate the Severity of Free slack times of Activities SFA based on durations of activities by:

$$\text{SFA} = 1\text{- normalized FS} \tag{7}$$

Step 6. Normalize the total slack times of activities by dividing them to their maximum value. Calculate the Severity of Criticalities of Activities SCA based on durations of activities by:

$$\text{SCA} = 1\text{- normalized TS} \tag{8}$$

Step 7. Perform CPM to calculate total slacks of activities where RLAs are used instead of durations for activities to calculate the criticalities based on risky levels (COR). Normalize CORs by dividing them to their maximum value.

Step 8. Use V, SFA, SCA, PFA, RLA and COR as criteria with corresponding weighs W_i (defined by experts), to calculate Multi-Purpose Criticalities (MPC) of activities, where for each activity:

$$MPC = w_1 \times V + w_2 \times PFA + w_3 \times RLA + w_4 \times SFA + w_5 \times SCA + w_6 \times COR \quad (9)$$

Step 9. Classify activities based on MPCs.

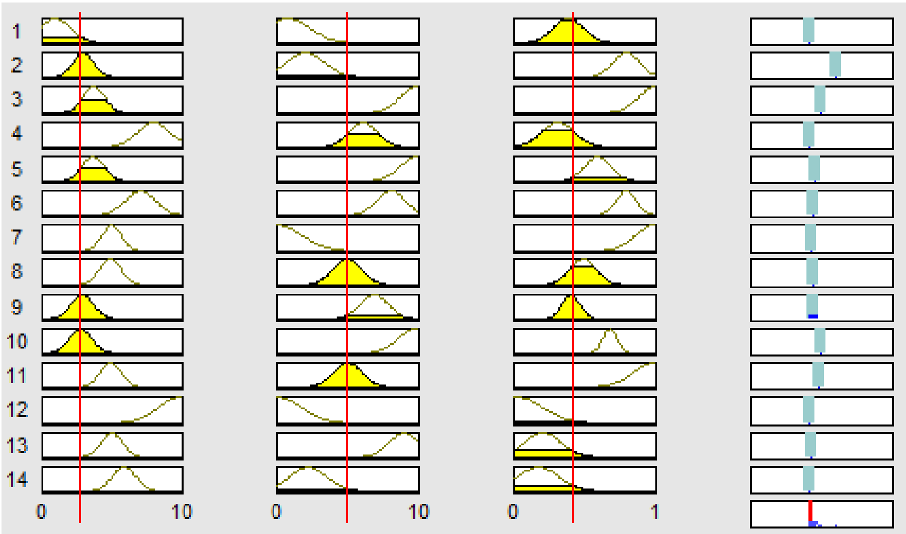


Fig. 8. Rule base generated by ANFIS

Fig. 9 shows the network representation of a typical project. The data for activities is represented in table 2.

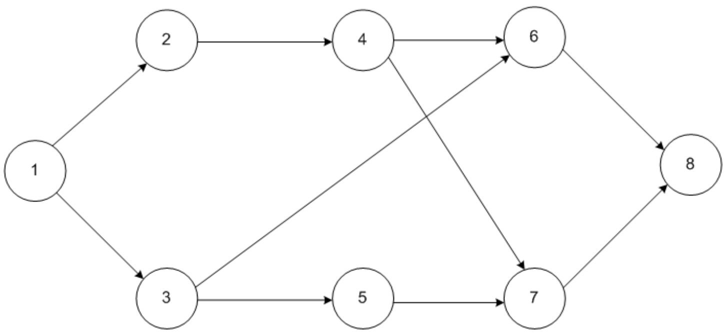


Fig. 9. Network representation of typical project

To compare the efficiency of multi critical PERT with the classic one, 1000 tests are performed using Mont Carlo simulation by generating uniform distributed random numbers r to be used in Equations (10) and (11). For each activity, two costs of impact are calculated where:

a. SCA is considered as a factor of criticality (Expense_on_SCA), by using Eq. (10)

$$\text{Expense\_on\_SCA} = \max\{0, r - \text{SCA}\} \quad (10)$$

b. MPC is considered as a factor of criticality (Expense_on_MPC), by using Eq. (11)

$$\text{Expense\_on\_MPC}=\max\{0, r-\text{MPC}\} \tag{11}$$

Activity	Durations			V	DR	PFA	RLA	SFA	SCA	COR	MPC
	a	m	b	Step 1 W_1=0.3	Step 2	Step 3 W_2=0.7	Step 4 W_3=0.9	Step 5 W_4=0.5	Step 6 W_5=0.9	Step 7 W_6=0.7	Step 8
1-2	2	3	4	0.3906	3.0000	0.5003	0.0071	0.00	0.00	0.0000	0.1503
1-3	1	3	4	0.8789	4.8333	0.9842	0.5840	0.00	0.80	0.4691	0.8806
2-4	1	3	5	1.5625	3.0000	0.5003	1.0000	0.00	0.00	0.0000	0.5356
3-5	1	2	3	0.3906	4.0000	1.000	0.0006	0.00	0.80	1.0000	0.8054
3-6	2	5	7	2.4414	7.3333	0.9458	0.0024	1.00	1.00	0.4691	1.0000
4-6	3	4	6	0.8789	4.1667	0.5003	0.0008	0.00	0.00	0.0000	0.1704
4-7	3	4	5	0.3906	4.5000	0.7887	0.0787	0.00	0.20	0.4421	0.4310
5-7	1	4	5	1.5625	5.6667	0.9458	0.0000	0.60	0.80	1.0000	0.9560
6-8	2	5	6	1.5625	4.6667	0.5003	0.4829	0.00	0.00	0.0000	0.3628
7-8	3	4	7	1.5625	4.8333	0.6559	0.0077	0.40	0.20	0.4421	0.4633

Table 2. Activities with appropriate data generated in different steps

Considering that the expense of each unit of impact is 1000$, the mean values of the obtained expenses for 1000 iterations are
Mean value of Expense_on_SCA = 2720.3 $
Mean value of Expense_on_MPC = 1356.3 $

It means that in real world applications, with probabilistic and non precise situations for finishing activities, if we consider MPC as the criticality of activities our project managements will be more realistic causing less expenses.

Fig. 10 represents the two Expenses, for 1000 tests.

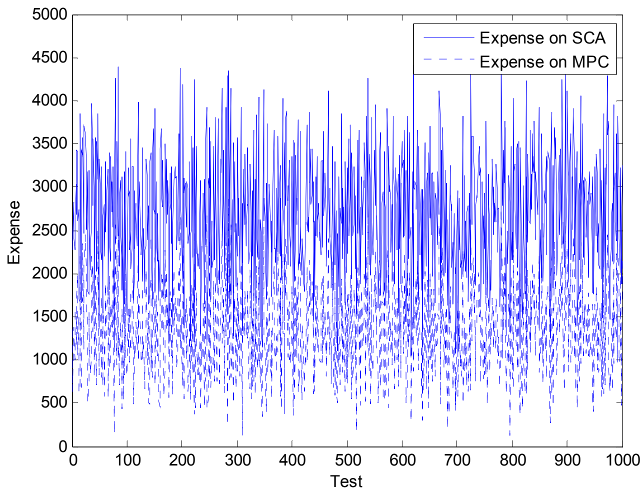


Fig. 10. Two Expenses, for 1000 tests

As another interesting application, a heuristic method for simultaneous rescue robot path-planning and mission scheduling is introduced based on Graphic Evaluation and Review Technique (GERT) (Alan & Pritsker, 1966), along with multi criteria decision making and artificial potential fields path-planning.

5. Rescue robot path planning

Consider some groups of injured people who are trapped in a disastrous situation. These people are categorized into several groups based on the severity of their situation. A rescue robot, whose ultimate objective is to reach injured groups and provide preliminary aid for them through a path with minimum risk, has to perform certain tasks on its way towards targets before the arrival of rescue team. A decision value is assigned to each target based on the whole degree of satisfaction of the criteria and duties of the robot in the way toward the target, and the importance of rescuing each group based on their category and the number of injured people. The resulted decision value defines the strength of the attractive potential field of each target. Dangerous environmental parameters are defined as obstacles whose risk determines the strength of the repulsive potential field of each obstacle. Moreover, negative and positive energies are assigned to the targets and obstacles respectively. These energies vary with respect to different environmental factors.

5.1 Potential feld path planning

The potential field method has been studied extensively for mobile robot path planning (Latombe, 1990). The basic idea behind the potential field method is to define an artificial potential field (energy) in the robot's workspace in which the robot is attracted to its goal position and is repulsed away from the obstacles (Alsultan & Aliyu, 1996; Khanmohammadi & Soltani, 2011). Despite the problems in architecture of potential field such as local minima and oscillation in narrow passages, this method is particularly attractive because of its mathematical elegance and simplicity (Casper & Yanco, 2002; Chadwick, 2005; Tadokoro et al, 2000). For simplicity, we assume that the robot is of point mass and moves in a two-dimensional (2-D) workspace. Its position in the workspace is denoted by $q = [x\ y]^T$. The most commonly used attractive potential U_{att} and the corresponding attractive force F_{att} takes the form:

$$U_{att}(q) = \frac{1}{2}\xi\rho^{m}(q_{goal}, q) \tag{12}$$

$$F_{att} = -\nabla U_{att} = \xi(q_{goal} - q)$$

Where ξ is a positive scaling factor, $\rho(q_{goal}, q) = \|q_{goal} - q\|$ is the distance between the robot q and the goal q_{goal}, and m = 1 or 2. For m = 1, the attractive potential is conic in shape and the resulting attractive force has constant amplitude except at the goal, where U_{att} is singular. For m = 2, the attractive potential is parabolic in shape. Also, the attractive force converges linearly toward zero as the robot approaches the goal.

One commonly used repulsive potential function and the corresponding repulsive force is given by:

$$U_{rep} = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho(q,q_{obs})} - \frac{1}{\rho_0}\right)^2, & if\, \rho(q,q_{obs}) \le \rho_0 \\ 0 \quad\quad\quad\quad\quad\quad\quad\quad , & if\, \rho(q,q_{obs}) > \rho_0 \end{cases} \tag{13}$$

$$F_{rep} = -\nabla U_{rep} = \begin{cases} \eta\left(\frac{1}{\rho(q,q_{obs})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q,q_{obs})}\nabla\rho(q,q_{obs}), & if\, \rho(q,q_{obs}) \le \rho_0 \\ 0 \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad , & if\, \rho(q,q_{obs}) > \rho_0 \end{cases}$$

Where η is a positive scaling factor, ρ (q,q_{obs}) denotes the minimal distance from the robot q to the obstacle, q_{obs} denotes the point on the obstacle such that the distance between this point and the robot is minimal between the obstacle and the robot, and ρ_0 is a positive constant denoting the distance of influence of the obstacle. The total force applied to the robot is the sum of the attractive force and the repulsive force which determines the motion of the robot (Jacoff et al., 2000).

$$F_{total} = F_{att} + F_{rep} \tag{14}$$

5.2 Graphic evaluation and review technique

In fact GERT is a generalized form of PERT, where the probability of occurrence of activities of the project is taken into consideration. In other words in PERT, either an activity occurs (probability=1) or it does not occur (probability=0); however, in GERT the probability of occurrence of each activity can be a real number between zero and one. GERT approach addresses the majority of the limitations associated with PERT/CPM technique and allows loops between tasks. The fundamental drawback associated with the GERT technique is that a complex program (such as Monte Carlo simulation) is required to model the GERT system.

5.3 Proposed methodology

Given the graph representing the sequence of activities in a disastrous situation, the first step is to obtain necessary information for making decision. The mentioned information consists of: a) parameters affecting the decision making, which are mostly predefined and weighted, and b) estimating approximate durations of activities which may occur during the mission. The mentioned parameters are categorized in two main classes; one of them deals with the degree of satisfaction of the criteria defined in tasks of the robot, and the other one is concerned with importance of targets. These parameters are listed in table 3.

Having gained the necessary data via a questionnaire of experts, PERT algorithm is used for the process of durations of activities. The resulted output is a part of the data needed for Multiple Criteria Decision Making (MCDM) analysis which consists of: standard deviation, free slack and total slack for activities, and the probability of occurrence of activities before a certain time.

The outputs of PERT and the degree of satisfaction of criteria defined for intermediate actions of robot, along with the importance of each criterion are given to MCDM algorithm as inputs. MCDM makes a decision and assigns a decision value for each activity. These values are treated as the virtual durations of activities and are given to CPM. It is obvious that output E_s (Earliest starts representing the decision indexes of missions) of CPM can be interpreted as the degree of fulfillment of the activities leading to a certain event. By comparing the E_s of the last events of several missions, we can deduce which mission fulfills our criteria better than the other ones.

Human factors		Environmental parameters		Parameters Concerning the robot	
H1	Capacity for reducing the life risk of the rescue team	E1	Prevention of air positioning in the surroundings	R1	Destruction of accessories
H2	Rescuing and preventing personal damage to the injured person	E2	Prevention destruction of path for the rescue team	R2	Annihilation of the robot
		E3	Prevention of fire danger in the peripheries	R3	Repairable damage to the robot
				R4	Damage negligible for the robot to be able to continue its task

Table 3. Main criteria for choosing the path

The ultimate objective of rescue mission is to help the injured people. The injured situations are divided into four groups: endangered, vulnerable, defenseless and prepared. To compare different groups of injured people four criteria are considered (refer to Table 6). The weights of criteria along with the degree of satisfaction of different criteria are given to MCDM algorithm and a decision value is calculated for each group of injured people as targets. In fact ξ (the positive scaling factor for attractive force) for each target is calculated as follows:

$$\xi_i = \text{norm}\ (E_{si}) + \text{norm}\ (ADV_i) \tag{15}$$

Where *norm* is normalization operator and ADV_i is the Attraction Decision Value of the i^{th} target.

Considering environmental situation and defining certain criteria for degree of danger of each obstacle, a similar approach is possible for determining the scaling factor η of the repulsive force. The degree of satisfaction of each criterion is fed into MCDM and the resulting decision value equals the positive scaling factor of repulsive force:

$$\eta_i = \text{norm}\ (RDV_i) \tag{16}$$

Where RDV_i is the Repulsive Decision Value of the i^{th} obstacle.

Having obtained the corresponding strength of the attractive and repulsive potential field, the path planning algorithm is established and the optimal path with respect to least time, least risk and most help to injured people is achieved.

5.4 Case study and simulation

Assume that two groups of injured people with different number of people and different categories of injuring are identified. One of the groups is located near a gas station, where people are endangered by the threat of explosion and the other group is next to a building and is threatened by the collision risk of the building. The rescue robot must choose one of the groups as the priority of its mission. Also it is expected that the rescue robot accomplishes several intermediate tasks such as searching for any injured person isolated from other members of identified group, taking picture of the surroundings and sending it to the rescue team, sensing the environmental factors that can signify explosion, etc. Fig. 11 demonstrates the GERT network for rescue mission.

The list of activities for the network represented in Fig. 11, are listed in table 4. The criteria for intermediate actions of robot in choosing the path are listed in Table 5.

The three optimistic, most likely and pessimistic values for the duration of each activity and the fulfillment of the main criteria (by performing each activity) which are listed in Table 5 are estimated based on the experts' opinions. In this table H, E and R indicate parameters concerning human, environment and the robot, respectively (Khanmohammadi & Soltani, 2011).

Durations of activities (first column of Table 5) are given to the PERT algorithm and standard deviation, free slack and total slack for activities, and the probability of performing activities in the range DR are obtained as the outputs of PERT. The output of the PERT and the degree of the satisfaction of the criteria by intermediate actions (H_1, H_2, E_1, E_2, E_3, R_1, R_2, R_3 and R_4 columns) are fed to MCDM algorithm which yields a decision value for each activity. These decision values are treated as the virtual durations of activities and comprise the inputs of the CPM algorithm. Since there is the possibility of obtaining negative decision values, to avoid assigning negative inputs to CPM, the values are normalized in the range [1,10]. E_s in the output of the CPM represents the degree of satisfaction of each activity in each network (mission index). The following values are obtained for the networks of the gas station (target 1) and building (target 2), respectively.

$$E_{s1}= 52.9434,\ E_{s2}= 27.0122.$$

As defined in the previous section, a set of criteria is defined for the injured people to be able to distinguish which group of injured people are more at risk. These criteria are described in Table 6.

The degree of satisfaction of these criteria along with the weight (importance) related to each criterions are the inputs of MCDM and the decision value for each target is the value assigned to ADV_i.

Similar to the procedure above, a set of criteria is defined for the degree of danger of the obstacles based on the environmental situation. Consider three kinds of obstacles consisting: Risk of fire, Risk of electric shock and Risk of building collision. Table 7 summarizes the factors involved.

Similar to obtaining ADVs, RDVs (Repulsive Decision Values) are simply obtained by using MCDM algorithm on the importance of each criterion and the degree of satisfaction of them for each obstacle. For comparison purpose, consider two scenarios with different environmental situations and different groups of troubled people.

Activity	Description	Activity	Description
0-2	Building	2-4	Applying the sensor to detect poisonous gas
4-6	Gas detected	6-8	Evaluating the probability of explosion by means of thermal sensors
8-10	Possibility of explosion present	10-26	Signaling warning to the rescue team for possibility of explosion
8-12	No Possibility for explosion	12-14	Considering the data of the sensor for CO2 and respiration
14-18	Human life detected	18-20	Providing the living person with oxygen
20-24	Dummy activity	18-24	Signaling assistance message to the rescue team
18-22	Signaling warning to the rescue team to wear gas masks	22-24	Dummy activity
24-26	Aggregated tasks	14-16	No Human life detected
16-26	Signaling warning to the rescue team to wear gas masks	4-26	No dangerous gas detected
26-80	----------	2-28	Applying the sensor to detect CO2
28-36	No CO2 detected	28-30	CO2 detected
30-32	Signaling assistance message to the rescue team	32-34	Dummy activity
30-34	Providing the living person with oxygen	34-36	----------
36-80	----------	2-38	Noise detection
38-46	No Noise detected	38-40	Noise detected
40-42	Providing the living person with oxygen	42-44	Dummy activity
40-44	Signaling assistance message to the rescue team	44-46	----------
46-80	----------	2-48	Applying the sensor to measure temperature
48-60	Low temperature	60-62	Signaling message to the rescue team to evaluate the place for possible conflagration
48-50	High temperature	50-54	Signaling assistance message to the rescue team

Activity	Description	Activity	Description
50-52	Applying the extinguisher	52-54	Dummy activity
54-62	----------	48-56	Extremely high temperature
56-62	Applying the extinguisher	62-80	----------
2-64	Detecting bumpy plains	64-76	No Roughness detected
64-66	Roughness detected	66-68	Considering the data of the sensor of CO2 and Respiration
68-70	No alive Human detected	70-72	Leveling the path
72-74	Dummy activity	70-74	Signaling message to the rescue team responsible for leveling the path
74-76	----------	68-76	Human life detected
76-80	----------	2-78	Taking photos of the surroundings
78-80	Sending the photos		
0-1	Gas Station	1-3	Taking photos of the surroundings
1-5	Detecting the temperature of the surroundings with sensor	5-7	Moving to the point with highest temperature
7-33	Using nitrogen to cool down the surroundings	7-13	Applying the extinguisher
13-33	Dummy activity	7-9	Applying the sensor to detect gas leakage
9-11	gas leakage detected	11-15	Signaling warning to the rescue team
15-29	Dummy activity	11-17	Using nitrogen to cool down the surroundings
17-29	Dummy activity	11-29	Applying the extinguisher
11-19	Applying the sensor to detect CO2	19-27	No CO2 detected
19-21	CO2 detected	21-23	Providing the living person with oxygen
23-25	Dummy activity	21-25	Signaling assistance message to the rescue team
25-27	----------	27-29	----------
29-31	----------	31-33	----------
9-31	----------	3-33	Sending photos

* Activities with the dashed lines in the description do not signify any specific activity. They represent the priority considered in making decision

Table 4. List of activities for Network of Fig. 11.

Activity Numbers	Duration(sec)			H1			H2			E1			E2			E3			R1			R2			R3			R4		
	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b
0-2	0	0	0	0.75	0.8	0.95	0.75	0.8	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-4	2	5	8	0	0	0	0.75	0.8	0.95	0.5	0.6	0.7	0	0	0	0.5	0.6	0.7	0	0	0	0	0	0	0	0	0	0	0	0
2-28	2	6	10	0	0	0	0.75	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-38	2	6	10	0	0	0	0.8	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-48	2	6	8	0.65	0.8	0.85	0.65	0.8	0.85	0.3	0.5	0.6	0.2	0.4	0.5	0.5	0.6	0.8	0	0	0	0	0	0	0.4	0.25	0.1	0.5	0.3	0.2
2-64	3	7	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-78	3	6	10	0	0	0	0.25	0.35	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6-8	6	9	15	0.75	0.9	0.95	0.35	0.5	0.6	0	0	0	0	0	0	0	0	0	0.6	0.5	0.3	0.6	0.4	0.3	0.7	0.5	0.3	0.7	0.6	0.4
8-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12-14	3	4	7	0	0	0	0.5	0.7	0.85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-20	20	35	45	0	0	0	0.65	0.8	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-22	2	4	8	0.65	0.8	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-24	2	4	8	0	0	0	0.65	0.8	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-32	2	3	7	0	0	0	0.75	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-34	15	25	40	0	0	0	0.75	0.85	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34-36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38-46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60-62	2	4	7	0	0	0	0.65	0.8	0.9	0.6	0.8	0.95	0.6	0.8	0.9	0.8	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0
62-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64-66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66-68	3	4	7	0	0	0	0.5	0.6	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68-76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76-80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78-80	2	4	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Activity Numbers	Duration(sec)			H1			H2			E1			E2			E3			R1			R2			R3			R4		
	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b
0-1	0	0	0	0.6	0.8	0.9	0.65	0.8	0.9	0.7	0.85	0.95	0.5	0.6	0.8	0.7	0.85	0.95	0.9	0.85	0.75	0.95	0.9	0.75	0.95	0.9	0.75	0.65	0.5	0.4
1-3	6	15	25	0.1	0.15	0.4	0.1	0.15	0.25	0	0.05	0.15	0	0.05	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-5	5	6	10	0	0.05	0.2	0.1	0.15	0.25	0.15	0.25	0.3	0.1	0.15	0.3	0.15	0.25	0.3	0	0	0	0	0	0	0	0	0	0	0	0
3-33	1	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-7	3	10	20	0.05	0.1	0.25	0.1	0.25	0.4	0.15	0.25	0.3	0.05	0.15	0.2	0.2	0.25	0.35	0.95	0.8	0.7	0.9	0.8	0.75	0.95	0.9	0.8	0.9	0.8	0.75
7-9	3	8	12	0.6	0.8	0.95	0.75	0.9	0.95	0.65	0.8	0.85	0.6	0.75	0.85	0.6	0.75	0.85	0.4	0.3	0.1	0.4	0.2	0.1	0.4	0.3	0.25	0.6	0.5	0.3
7-13	18	24	40	0.25	0.4	0.6	0.6	0.8	0.9	0.65	0.8	0.9	0.7	0.75	0.85	0.65	0.8	0.9	0.8	0.6	0.5	0.8	0.6	0.5	0.9	0.7	0.6	0.95	0.9	0.75
7-33	20	28	40	0.4	0.6	0.75	0.75	0.9	0.95	0.75	0.9	0.95	0.75	0.9	0.95	0.75	0.9	0.95	0.6	0.4	0.3	0.7	0.5	0.4	0.95	0.8	0.65	0.95	0.9	0.75
9-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11-15	2	3	6	0.75	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11-17	20	25	35	0.65	0.8	0.9	0.65	0.8	0.9	0.7	0.85	0.95	0.7	0.85	0.95	0.6	0.75	0.8	0.5	0.3	0.15	0.5	0.3	0.25	0.6	0.5	0.3	0.65	0.5	0.3
11-19	3	8	12	0	0	0	0.75	0.9	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11-29	14	20	30	0.4	0.6	0.75	0.6	0.75	0.8	0.65	0.8	0.9	0.1	0.25	0.4	0.6	0.7	0.85	0.5	0.4	0.25	0.4	0.25	0.1	0.65	0.5	0.35	0.8	0.75	0.55
13-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15-29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19-27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27-29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29-31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Values other than durations of activities are normalized in the range [0,1]

Table 5. Durations of activities and satisfaction levels of criteria by performing each activity

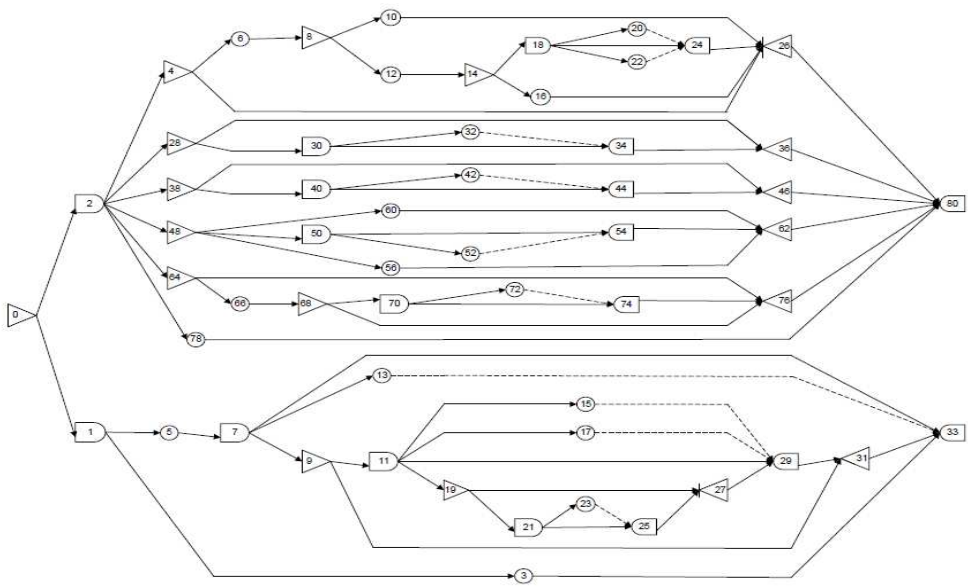


Fig. 11. Network of project activities

Category and Number of the troubled people	Exposure to dangerous situation
• Category of the troubled people: endangered, defenseless, vulnerable, prepared • Number of the people in each category Health status of the injured people	• Adjacency of the danger

Table 6. Criteria for calculating the priority values of injured groups

Type of the obstacle	Criteria and factors involved
• Fire • Building collision • Electric shock	- Temperature – existence of flammable material in the vicinity – rainy/dry weather - Humidity – fundamental robustness of building – possibility of building collision - Humidity – rainy/dry weather

Table 7. Criteria for measuring the danger level of obstacles

Scenario 1

group1: 25 people near gas station comprised of 15 endangered (injured) 5 vulnerable, 5 defenseless

group2: 15 people near a building with possibility of collision comprised of 4 injured and 11 defenseless.

The introduced procedure has been run twice, once for hot and dry and once for cold and rainy weather. Results are illustrated in Fig. 12. Priority is given to the first target (group1 near gas station) by robot. As it is seen in Fig. 12(a), the rescue robot tries to get as far as possible from the power electric station when it is rainy and it gets a shorter path (near electric power station) in dry conditions, Fig. 12(b).

Scenario 2

group1: 15 people near gas station comprised of 15 endangered (injured), 5 vulnerable, 5 defenseless

group2: 25 people near a damaged building with possibility of collision comprised of 4 injured and 11 defenseless.

We have considered the mentioned environmental conditions and the results are illustrated in Fig. 12.

The priority is given to the second target (group2 near damaged building) by rescue robot. In case one, when it is cold and rainy, the possibility of explosion is low, so the robot gets closer to the gas station, Fig. 13(a). But when it is hot, robot tries to be far from the gas

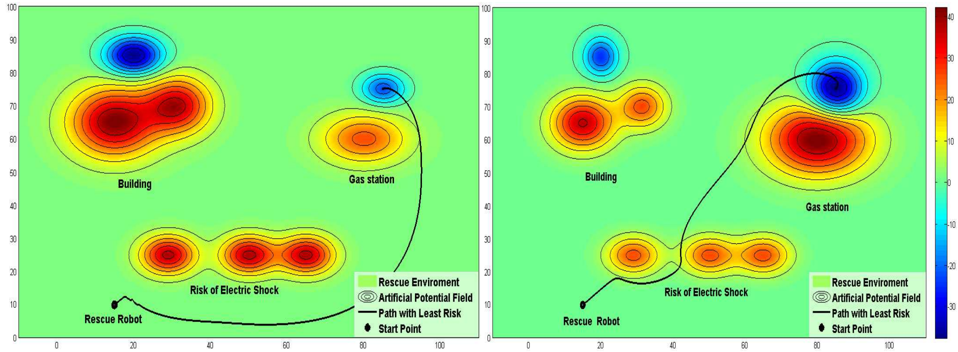


Fig. 12. Generated path for the first scenario: (a) cold and rainy condition, (b) hot and dry condition

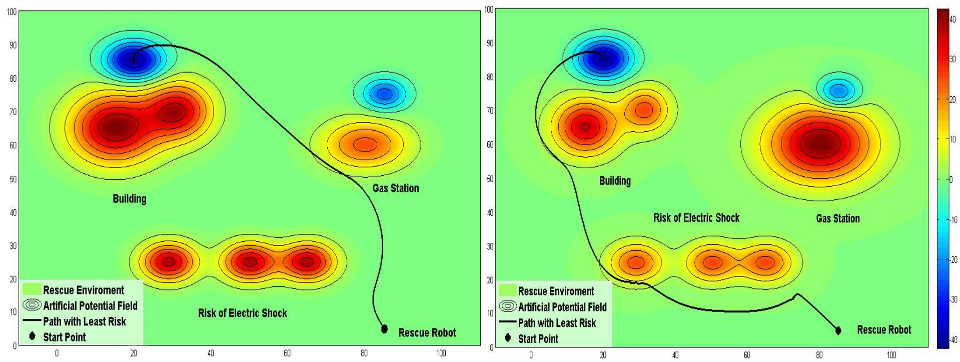


Fig. 13. Generated path for second scenario: (a) cold and rainy condition, (b) hot and dry condition

station where there is the risk of explosion, Fig. 13(b). The simulation results show the fact that the introduced algorithm is flexible in terms of the environmental conditions and the factors involved in targets.

To further illustrate the conceptual basis of the utilized potential field, a 3D representation of the risk potential function and the corresponding optimal path are represented in Fig. 14.

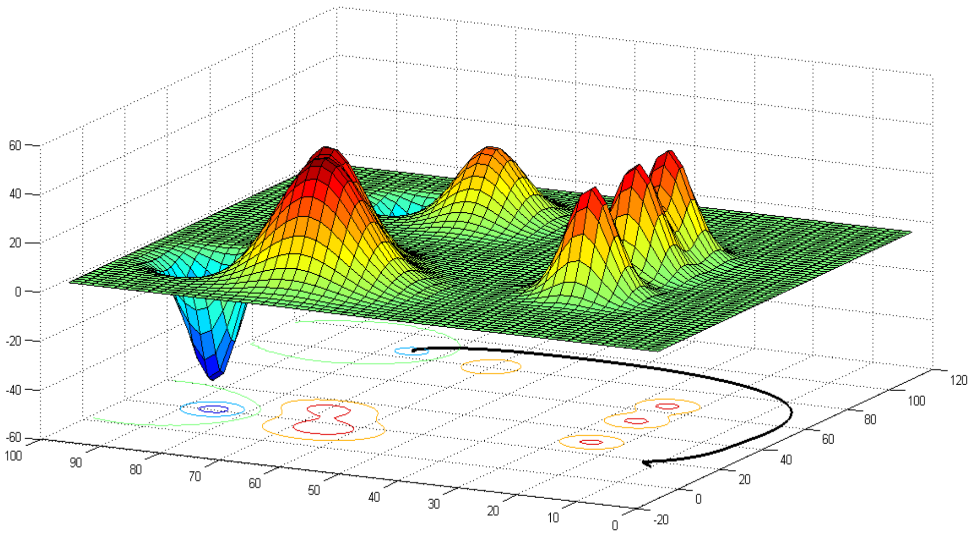


Fig. 14. Artificial potential field and the obtained path with minimum risk

6. Conclusion

A new fuzzy approach is introduced to perform a more applicable risk analysis in real world applications. This procedure is used to determine the multi-purpose criticalities of activities where six main factors V, SFA, SCA, PFA, RLA and COR are considered as criticality indexes. A fuzzy inference system with three inputs: probability of impact, impact treat, and ability to retaliate is used to calculate the values of RLA for activities. The output of FIS represents the risky level of each activity. The decision values obtained by classic multi criteria decision making problem are then considered as criticality indexes of activities. The obtained results are compared to classic PERT, from the view point of impact expenses, by using the Mont Carlo method. It has been shown that by considering the multipurpose criticalities (instead of total slacks) a considerable amount of expenses caused by different impacts may be saved. The introduced method is applied to simultaneous task scheduling and path planning of rescue robots. Simulation results show that project management technique along with risk analysis by means of artificial potential field path planning is an efficient tool which may be used for rescue mission scheduling by intelligent robots. The algorithm is flexible in terms of environmental situation and the effective factors in risk analysis. In fact the proposed method merges the path planning methods with rescue mission scheduling.

7. References

Alan, A., & Pritsker, B. (1966). GERT: *Graphical Evaluation and Review Technique*, Rand Corp

Alsultan, K. S., & Aliyu, M. D. S. (1996). A new potential field-based algorithm for path planning. *Journal of intelligent and robotic systems*, Vol. 17, No. 3, (November 1996), pp. (265–282)

Carr, V., & Tah, J. H. M. (2001). A Fuzzy approach to construction project risk assessment and analysis: construction project risk management system. *Advances in Engineering Software,* Vol. 32, No. 10-11, (October-November 2001), pp. (847-857)

Casper, J., & Yanco, H. (2002). AAAI/RoboCup-2001 Robot Rescue. *AI Magazine,* Vol. 23, No. 1, (Spring 2002)

Chadwick, R. A. (2005). The Impacts of Multiple Robots and Display Views: An Urban Search and Rescue Simulation. *Human Factors and Ergonomics Society, Annual Meeting Proceeding Cognitive Engineering and Decision Making,* (January 2005), pp. (387-391)

Chanas, S., Dubois, D., & Zielinski, P. (2002). On the Sure Criticality of Tasks in Activity Networks with Imprecise Durations. *IEEE Transactions on systems, man, and cybernetics part B,* Vol. 32, No. 4, (August 2002), pp. (393-407)

Chavas, J. P. (2004). *Risk Analysis in Theory and Practice,* Elsevier, ISBN – 10: 0121706214

Cho, H. N., Choi, H. H., & Kim, Y. B. (2002). A risk assessment methodology for incorporating uncertainties using fuzzy concepts. *Reliability Engineering & System Safety,* Vol. 78, No. 2, (November 2002), pp. (173-183)

Doherty, N. A. (2000). *Integrated Risk Management: Techniques and Strategies for Managing Corporate Risk*, McGraw-Hill Professional

Jacoff, A., Messina, E., & Evans, J. (2000). A Standard Test Course for Urban Search and Rescue Robots, *Proceeding of performance metrics for intelligent systems workshop,* August - 2000

Jamshidi M., Vadiee N., & Ross T. J. (1993). *Fuzzy Logic and Control,* Prentice Hall

Kerzner, H. (2009). *Project Management: A System Approach to Planning, Scheduling and Controlling*, Wiley

Khanmohammadi, S., Charmi, M., & Nasiri, F. (2001). Delay Time Estimating in Project Management Using Fuzzy Delays and Fuzzy Probabilities, *Proceeding of International ICSC Congress on Computational Intelligence: Methods and Applications,* Bangore - UK, June - 2001

Khanmohammadi, S., & Soltani, R. (2011). Intelligent path planning for rescue robot. *World Academy of Science, Engineering and Technology,* No. 79, (April 2011), pp. (764-769)

Kreinovich, V., Nguyen H. T., & Yam Y. (2000). Fuzzy Systems are Universal Approximators for a Smooth Function and its Derivatives. *International Journal of Intelligent Systems,* Vol. 15, No. 6, (June 2000), pp. (565-574)

Latombe, J. C. (1990). *Robot Motion Planning,* Springer

Li, Y., & Liao, X. (2007). Decision support for risk analysis on dynamic alliance. *Decision Support Systems,* Vol. 42, No. 4, (January 2007), pp. (2043-2059)

Mamdani, E. H., & Assilian, S. (1999). An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller. *International Journal of Human-Computer Studies,* Vol. 51, No. 2, (August 1999), pp. (135-147)

McNeil, A. J., Frey, R., & Embrechts, P. (2005). *Quantitative Risk Management: Concepts, Techniques and Tools,* Princeton University Press

Mendel, J. (2001). *Uncertain rule-based fuzzy inference systems: Introduction and new directions*, Prentice-Hall

Nguene, G. N., & Finger, M. (2007). A fuzzy–based approach for strategic choices in electric energy supply. The case of a swiss power provider on the eve of electricity market opening. *Engineering applications of Artificial Intelligence,* Vol. 20, No. 1, (February 2007), pp. (37-48)

Ross, T. J. (2010). *Fuzzy Logic with Engineering Applications*, Wiley

Shipley, M. F., De Korvin, A., & Omer, K. (1996). A fuzzy Logic Approach for Determining Expected values: A Project Management Application. *Journal of Operations Research Society,* Vol. 47, No. 4, (April 1996), pp. (562-569)

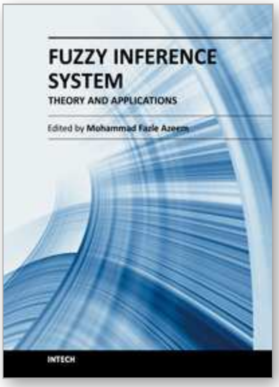
Shipley, M. F., De Korvin, A., & Omer, K. (1997). BIFPET methodology versus PERT in project management: fuzzy probability instead of the beta distribution. *Journal of Engineering and Technology Management,* Vol. 14, No. 1, (March 1997), pp. (49-65)

Tadokoro, S., Kitano, H., Takahashi, T., Noda, I., Matsubara, H., Shinjoh, A., Koto, T., Takeuchi, I., Takahashi, H., Matsuno, F., Hatayama, M., Nobe, J., & Shimada, S. (2000). The RoboCup-Rescue Project: A Robotic Approach to the Disaster Mitigation Problem, *Proceedings of IEEE international Conference on Robotics and Automation,* San Francisco - USA, April 2000

Takács, M. (2004). Critical Analysis of Various Known Methods for Approximate Reasoning in Fuzzy Logic Control, *Proceedings of 5th International Symposium of Hungarian Researchers on Computational Intelligence,* Budapest - Hungary, November 2004.

Takagi, T., & Sugeno, M. (1985). Fuzzy identification of systems and its applications to modelling and control, *IEEE Transactions on systems, man, and cybernetics,* Vol. SMC-15, No. 1, (January 1985), pp. (116-132)

Zadeh, L. A. (1965). Fuzzy Sets, *Information and Control,* Vol. 8, No.3, (June 1965), pp. (338-353)



Fuzzy Inference System - Theory and Applications
Edited by Dr. Mohammad Fazle Azeem

ISBN 978-953-51-0525-1
Hard cover, 504 pages
Publisher InTech
Published online 09, May, 2012
Published in print edition May, 2012

This book is an attempt to accumulate the researches on diverse inter disciplinary field of engineering and management using Fuzzy Inference System (FIS). The book is organized in seven sections with twenty two chapters, covering a wide range of applications. Section I, caters theoretical aspects of FIS in chapter one. Section II, dealing with FIS applications to management related problems and consisting three chapters. Section III, accumulates six chapters to commemorate FIS application to mechanical and industrial engineering problems. Section IV, elaborates FIS application to image processing and cognition problems encompassing four chapters. Section V, describes FIS application to various power system engineering problem in three chapters. Section VI highlights the FIS application to system modeling and control problems and constitutes three chapters. Section VII accommodates two chapters and presents FIS application to civil engineering problem.