Chapter

Risk Analysis, a Fuzzy Analytic Approach

Mahmoud Shahrokhi, Majid Vaziri Sarashk and Alain Bernard

Abstract

One of the challenges in designing industrial systems is integrating accident risk analysis with the other technical analysis tools. In the face of this challenge, this paper introduces an analytic approach to defining the occupational risk entities in computer-aided design software by visualizing the risk entities as geometric shapes. It uses energy/barrier analysis and the fuzzy set theory to model the protective role of barriers and infer the effects of harmful agents on humans and assets (targets). It defines dangers and targets presence zones by fuzzy sets, the so-called "fuzzy spaces" demonstrated as geometric profiles. The barriers affect these geometric profiles, and fuzzy union and intersection aggregate the effects of several dangers and protective measures. The model calculates the quantitative risk indexes for the various workplace points. The proposed model is adapted to evaluate the risk in the computer-aided design platform during the workplace simulation. An example illustrates the model application in a one-dimensional space.

Keywords: fuzzy theory, risk analysis, computer-aided design

1. Introduction

Järvinen et al. emphasized the potential of three-dimensional (3D) simulation models for implementing risk analysis without presenting any specific model [1]. Wang et al. developed an enhanced automated 3D visualization ergonomic analysis integrated with a proposed fuzzy logic-based joint-level ergonomic risk assessment methodology for work modification and workplace design [2]. Ojstersek et al. used the modeling and simulation method and ergonomic analyses in workplaces and presented potential opportunities for improving productivity and cost [3].

Despite many efforts, researchers have failed to develop practical risk management approaches in 3D platforms; implementing the new concurrent engineering approaches requires integrating safety-engineering techniques into the 3D design applications [4]. One of the significant challenges in this domain is the complexity of risk analysis due to the need to consider many system parameters that are very difficult to quantify. These parameters explain the characteristics of the harmful factors, their effect on vulnerable targets (humans, assets, and the environment), and the role of the safety barriers [5]. In the face of these challenges, this paper proposes an integrated risk analysis approach to develop the appropriate 3D risk analysis modeling tools for use through the design process by introducing geometric methods for modeling risk in computer-synthesized three-dimensional and virtual reality platforms.

Shahrokhi and Bernard use the "fuzzy space" concept to model danger zones, target presence zones, and physical and perceptual barriers by geometrical profiles [6]. This model visualizes and identifies the risk concentration points in the simulated workplace. The present paper uses fuzzy spaces to illustrate the risk distribution in the workplace and applies fuzzy operations to calculate a quantitative risk index.

2. Background

Risk is a function of the probability and the consequence of an unwanted top event in terms of possible damage to a target (i.e., property, environment, and people) [7]. Many researchers attempt to integrate risk analysis into computer-aided design applications. Määttä studied the applications of the virtual environment to analyze the safety of new designs in a steel factory [8]. Abshire and Barron review real-world applications of virtual maintenance and present the provided facilities using the virtual environment and digital prototypes for Failure Mode Effect Analysis (FMEA) during the design process [9]. Gallego et al. implemented an interesting geometric risk assessment method using the linguistic variables for occupancy degree and occupancy time to model the number of people exposed to a harmful agent (HA) [10]. Hendershot uses contour maps to calculate the risk by superposing the impact zones and population distribution for 11 regions [11].

Many efforts are taken to model barriers as an essential concept that, due to their variety, is very difficult to be modeled in geometric forms. The barrier concept was initially based on the successive works of domino theory back in the 1930s, Haddon in 1966 and Gibson in 1961, which developed the idea of an accident as an abnormal or unexpected release of energy [12]. It identifies and evaluates the associated hazards of the harmful agents [13]. Barrier analysis contributes to the energy analysis and represents the barrier as the protector of the target from dangers [14]. When avoiding or eliminating the dangerous agent and hazards is impossible, the designer adds a series of safety barriers to reduce the risk of the undesired outcomes to an acceptable level [15]. Polet and Zhang et al. state that the barriers prevent events or accidents, resurrect the target, and mitigate the severity of adverse consequences [16, 17]. Hollnagel distinguishes the protector and the preventive barriers. It defines a barrier as the "equipment, constructions, or rules that can stop the development of an accident" [18]. The same idea is the origin of the bow-tie diagram when categorizing the barrier effects by prevention and mitigation effects [19].

Tinmannsvik et al. modeled an accident that occurs by failing control barriers, controlling the hazards, and defense barriers that protect the target due to the transformation of the latent failures to the realized losses [20]. Fithri et al. conducted occupational safety and health risk analysis in manufacturing companies using FMEA and FTA methods [21]. The proposed model by Choe and Leite describes accident causation and improves accident investigation methods [22]. With construction domain knowledge, they offered a safety risk generation and control model representing the dynamic safety risk.

Despite many efforts, modeling the material and immaterial barriers reminds the fundamental challenges of modeling the risk in 3D computer applications.

Guimaraes and Lapa (a) and Guimarães and Lapa (b) used fuzzy inference systems to estimate risk priority numbers by aggregating the expert opinions in the failure mode and effects analysis (FMEA) method [23, 24]. Huang et al. developed a fuzzy set approach to integrating human error evaluation results in the event tree analysis [25]. Sadeghi et al. review the applications of design theories and methodologies and design tools and techniques to analyze and identify work situations to improve human safety in manufacturing system design [26]. Echeverri et al. (a) developed a design process's risk analysis models by considering technological and human factors and using essential functions and the production system's internal energy flow [27]. The proposed model integrated elements from the different design approach, considering cost, time, and performance, incorporating safety factors through energy functions and organizational rearrangements. Echeverri et al. (b) developed a multi-criteria design framework considering energy flow through components to characterize its behavior via Energetic Technical Functions [28]. Fargnoli reviewed the research addressing design for safety in the industrial context, focusing on those research approaches to integrate human factors within design activities [29]. He concluded that there is a research gap between theory and practice. He proposed a unified design for the safety process to support integrating human factors in design activities more practically.

The present paper introduces an analytic risk analysis approach by defining the danger, the target zones, and the effects of the barriers by geometric shapes.

3. Methodology

The presented method defines danger and target zones by fuzzy membership and probability density functions, illustrating them by geometric profiles in the 3D model.

3.1 Defining danger zones

A danger zone (DZ) is a portion of space where a harmful event may occur [10]. Shahrokhi and Bernard define fuzzy space to calculate every point x's membership in the danger zone [6]. According to the fuzzy sets notification, the following formula uses the integral and division symbols to explain that $\widetilde{DZ}$ is a continuous fuzzy set and assigns membership $\mu_{\widetilde{DZ}}(x)$to each x in the workplace.

$$\widetilde{DZ} = \int_x \frac{\mu_{\widetilde{DZ}}(x)}{x} \quad 0 \le \mu_{\widetilde{DZ}}(x) \le 1 \quad \forall x \in X$$

As **Figure 1** presents, in contrast to the classic definition, a member (e.g., a point) is not just inside or outside of a fuzzy danger zone ($\widetilde{DZ}$); it may also have a degree of membership. Function $\mu_{\widetilde{DZ}}(x)$ indicates the membership of point x in danger zone $\widetilde{DZ}$.

Figure 2 illustrates a mono-dimensional danger zone and shows how a HA decreases by increasing the distance from the danger source.

A dangerous source can be an explosion, radiation, or a toxic gas leak. In all cases, a $\widetilde{DZ}$ assigns a membership value $\mu_{\widetilde{DZ}}(x)$ to each point, x. The $\widetilde{DZ}$ form is a function of the physical characteristics of the danger and the environmental conditions. For

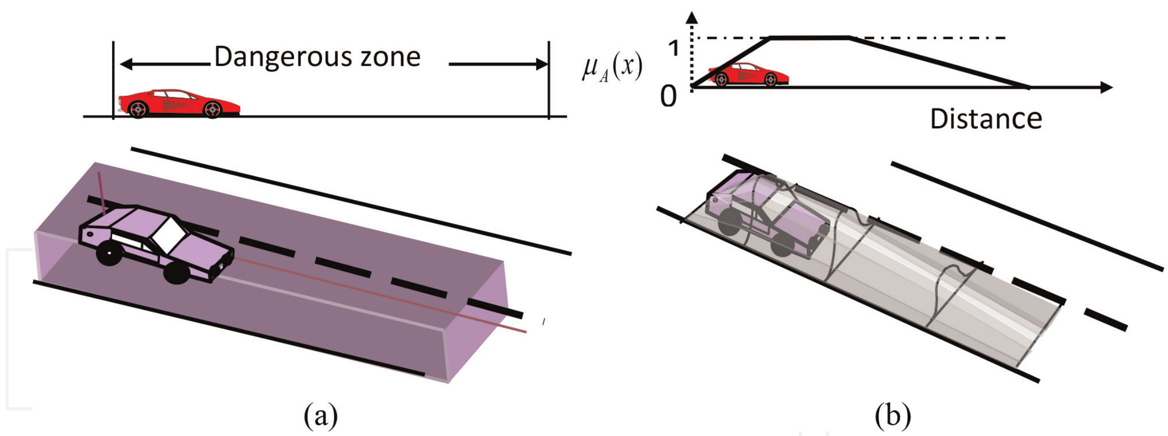

Figure 1.
Demonstration of the dangerous zone around a moving car using (a) the traditional and (b) the fuzzy space definitions [6].

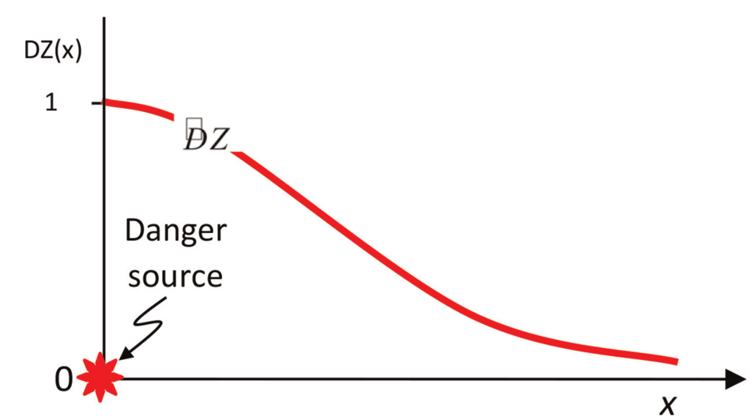

Figure 2.
Schematic demonstrations of a one-dimensional $\widetilde{DZ}$.

example, for a punctual radioactive material, the radiation in a uniform environment decreases proportionally to the distance squared from the danger source.

3.2 Aggregating several danger zones

Fuzzy union apples on several dangers to form a total danger zone, as follows:

$$\widetilde{DZ} = \bigcup_{i=1}^{n} \widetilde{DZ}_i$$

The selection of an appropriate union method among standard union (max(a,b)), bounded sum (min(1,a + b)), and other fuzzy union operations are essential to simulate the actual effect of accumulated dangers on the target.

3.3 Defining the target zone

A fuzzy target zone ($\widetilde{TZ}$) is also a fuzzy space, indicating the geographical distribution of the presence of the target:

$$\widetilde{TZ} = \int_x \frac{\mu_{\widetilde{TZ}}(x)}{x}$$

The $\mu_{\widetilde{TZ}}(x)$ is the normalized target population density (P(x)) or the target presence probability f(X) in point x. The following normalization formula converts the population density to a membership value by ensuring that the maximum membership value is 1:

$$\mu_{\widetilde{TZ}}(x) = \left(\frac{P(x)}{\underset{x}{Sup}(P(x))} \right)$$

It divides the population density of every point to their maximum (supremum) value for every x. For a target with random movement or stochastic existence, the model normalizes the probability function of the target presence, f(X), by using the following formula:

$$\mu_{\widetilde{TZ}}(x) = \left(\frac{f(x)}{\underset{x}{Sup}(\ f(x))} \right)$$

The membership function of TZ (i.e., $\mu_{\widetilde{TZ}}(x)$) indicates the distribution of the targets in the workplace. A fixed target creates a singleton fuzzy set target zone.

3.4 Modeling the barriers

The barriers limit danger and target zone(s) in several ways:

- Danger barriers ($\widetilde{DBs}$) impede or diminish the hazard's harmfulness and affected area by modifying $\widetilde{DZ}$.

- Target barriers ($\widetilde{TBs}$) modify $\widetilde{TZs}$ by impeding or decreasing the target membership in the danger zone or separating the target and HA by time.

The proposed approach models the above barriers by using geometric shapes. Fuzzy barriers (i.e., $\widetilde{TBs}$ and $\widetilde{DBs}$) illustrate the geographical distribution of barriers' capability to impede the danger and target presence.

3.5 Modeling danger barriers

Figure 3a–c exemplify danger barriers for the following cases, respectively:

a. A gas mask reduces 60% of danger harmfulness

b. A firewall that prevents 80% of the heat from passing through

c. A hazard neutralization system with a Gaussian local efficiency

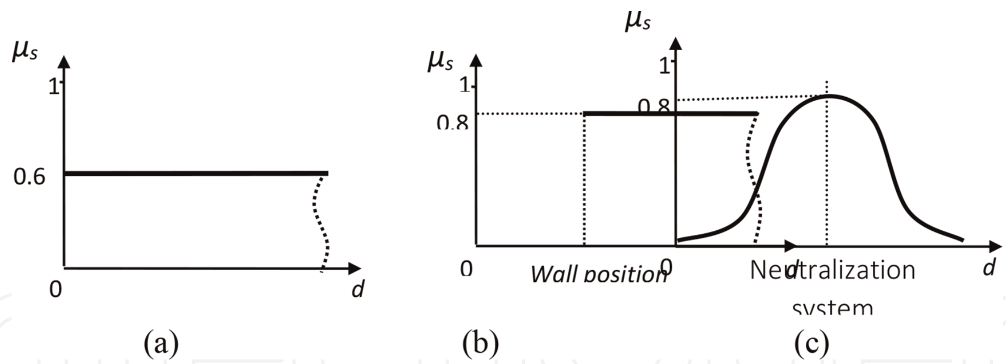

Figure 3.
Some schematic demonstration of danger barriers.

This approach uses fuzzy complement operation to transfer the danger barriers protection to danger barrier inefficiency ($\widetilde{DBI}$) as follows

$$\widetilde{DBI} = \neg\widetilde{DB} \qquad \mu_{\widetilde{DBI}}(x) = 1 - \mu_{\widetilde{DB}}(x) \qquad \forall x \in X$$

The risk exists when there is a danger and no barriers to neutralize the threat. Therefore, the practical (residual) danger zone equals the intersection of the original danger zone and the danger barrier inefficiency.

$$\widetilde{EDZ} = \widetilde{DZ} \cap \left(\neg\widetilde{DB}\right)$$

The following equation is applied when barrier effectiveness is proportional (e.g., using percentages). It means that the barrier reduces a specified portion of the danger.

$$\mu_{\widetilde{EDZ}}(x) = \mu_{\widetilde{DZ}}(x)\left(1 - \mu_{\widetilde{DB}}(x)\right) \qquad \forall x \in X$$

The following equation is valid when the barrier effectiveness is in absolute values (e.g., the barrier absorbs or filters a specified amount of the hazardous effects).

$$\mu_{\widetilde{EDZ}}(x) = Max\left(0, \mu_{\widetilde{DZ}}(x) - \left(1 - \mu_{\widetilde{DB}}(x)\right)\right) \qquad \forall x \in X$$

3.6 Modeling target barriers

The exemplified TBs affect the $\widetilde{TZ}$, For example, they may describe the following cases:

a detector, organizational measure or warning signs (**Figure 4a**), or a wall that prevents the presence of the target in a limited zone with specified reliability (**Figure 4b**), and a thermal protective cloth which controls 30% of the outside temperature from colliding with the wearer body (**Figure 4c**).

Some protective measures may affect both the $\widetilde{DZ}$ and $\widetilde{TZ}$ simultaneously; for example, **Figures 3b** and **4b** model effects of the same protection wall on the $\widetilde{DZ}$ and $\widetilde{TZ}$, respectively.

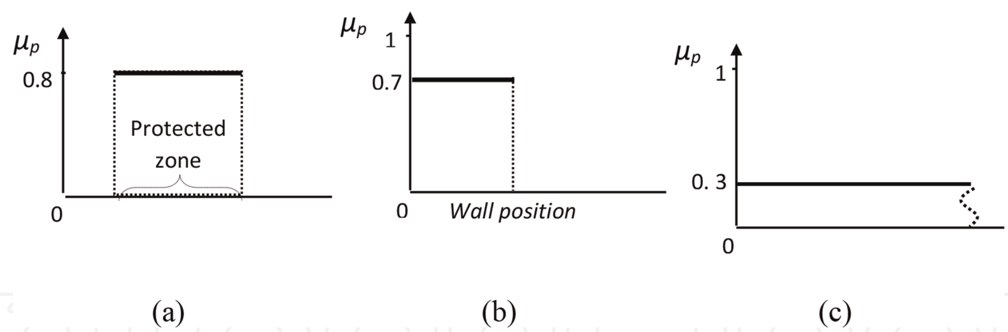

Figure 4.
Some schematic demonstration of target barriers.

3.7 Cumulative effects of several barriers

There are cumulative effects where two or several barriers are practical at the same place and time. The fuzzy union operator aggregates a set of J danger barriers and a set of K target barriers as effective danger barriers and practical target barriers, using the following formulas:

$$\widetilde{EDB}(x) = \bigcup_{j=1}^{J} \widetilde{DB}_j(x)$$

$$\widetilde{ETB} = \bigcup_{k=1}^{K} \widetilde{TB}_k$$

Fuzzy spaces $\widetilde{EDB}$ and $\widetilde{ETB}$ are the effective danger zone barrier and effective target barrier, respectively.

The definition of the fuzzy union in the above equations varies according to the cumulative barrier effects. The proposed approach defines serial and parallel barriers. In a serial barrier configuration, the danger must pass from all obstacles to impact the target (e.g., the consecutive antifire doors); in this case, the bounded sum (min(1, a + b)) is one of the appropriate s-norms if the danger reduced after passing from each barrier.

The standard union (i.e., max(a,b)) is a helpful s-norm when the most effective barrier is essential in limiting the danger zone or target presence zones.

In a parallel structure, it is sufficient for the threat to pass through one of the guards to impact the target. The analyst may consider the most unreliable barrier as the weakest link in the protection chain. A fuzzy intersection operator such as the standard intersection (e.g., min(a,b)) aggregates the parallel safety measures as effective danger follows:

$$\widetilde{EDB} = \cap \widetilde{DB}_j$$

$$\widetilde{ETB} = \cap \widetilde{TB}_k$$

3.8 Barriers inefficiency

Appling fuzzy compliment operator on "effective danger barriers" and "effective target barriers" results in "danger barriers inefficiency" and "target barriers inefficiency," respectively, as follows:

$$\widetilde{IDB} = \neg\widetilde{DB}$$
$$\widetilde{ITB} = \neg\widetilde{TB}$$

Operator ⌐ means fuzzy complement (fuzzy NOT) operation. The standard complement (⌐a = 1-a) is one of the most suitable fuzzy complementation methods. However, also there are other alternatives for this operator.

$$\mu_{\widetilde{IDB}}(x) = 1 - \mu_{\widetilde{DB}}(x) \qquad \forall x \in X$$
$$\mu_{\widetilde{ITB}}(x) = 1 - \mu_{\widetilde{TB}}(x) \qquad \forall x \in X$$

3.9 Apply barrier effects to the danger zone

Danger remains in dangerous places, but there is not enough protection; this means that the residual (effective) hazard at each point equals the intersection of the threat and the barriers inefficiency at that point. Therefore effective danger for every danger zone is:

$$\widetilde{EDZ} = \widetilde{DZ} \cap \widetilde{IDB}$$

In the same way, a practical target presence zone is:

$$\widetilde{ETZ} = \widetilde{TZ} \cap \widetilde{ITB}$$

Using the $\widetilde{EDZ}$ and $\widetilde{ETZ}$, the fuzzy risk zone is:

$$\widetilde{RZ} = \widetilde{EDZ} \cap \widetilde{ETZ}$$

In this case, multiplication is one of the alternatives for fuzzy intersection operation.

3.10 Determining the fuzzy risk zone

The proposed risk analysis approach uses the fundamentals of energy analysis and considers an accident resulting from the impact of a harmful agent (energy) on a target. Therefore, the fuzzy risk zone ($\widetilde{RZ}$)is an intersection area of a $\widetilde{DZ}$and a $\widetilde{TZ}$. The risk analyst should select the most appropriate fuzzy intersection operator (i.e., triangular norms (t-norm)) to reflect the accident consequence best. Triangular norms are indispensable for interpreting the conjunction in the intersection of fuzzy sets. One of the simplest choices is the product intersection, defined as:

$$\widetilde{RZ} = \widetilde{DZ} \cap \widetilde{TZ}$$
$$\mu_{\widetilde{RZ}}(x) = \mu_{\widetilde{DZ}}(x)\mu_{\widetilde{TZ}}(x) \qquad \forall x \in X$$

This formula uses the concept that the accident importance equals the multiplication of the hazard amplitude and the target presence probability or density. Other t-norms may be more appropriate for specific cases.

Figure 5 illustrates the distribution of targets in the neighborhood of a supposed hazard source.

Figure 6a shows both $\widetilde{DZ}$ and $\widetilde{TZ}$, and **Figure 6b** illustrates the resulting risk zone using the algebraic product t-norm as the fuzzy intersection operator. The horizontal axis corresponds to the distance from the hazard source. The vertical axis illustrates the risk index function; thus, risk zone ($\widetilde{RZ}$) presents the geographic distribution of the risk amplitude.

If the hazardous effects of several dangers are not similar, $\widetilde{RZ}$ should be calculated separately for different hazards.

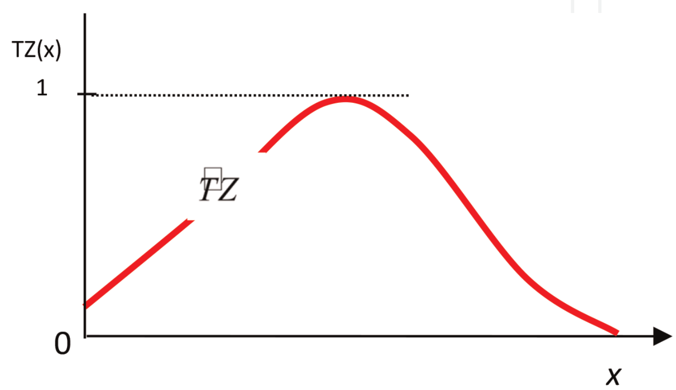

Figure 5.
Schematic demonstrations of a one-dimensional $\widetilde{TZ}$.

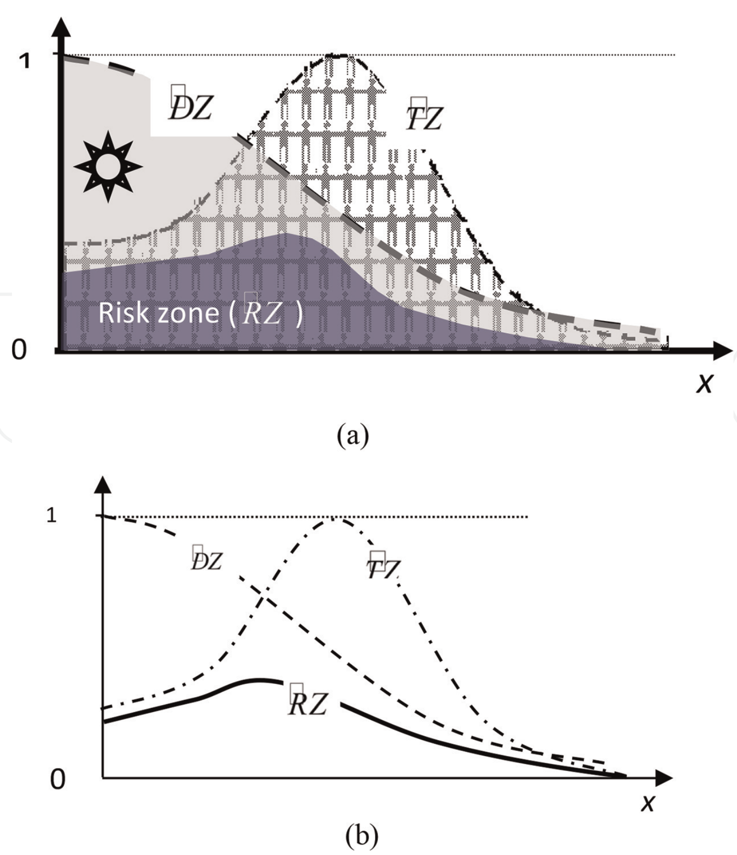

Figure 6.
Schematic demonstrations of one-dimensional $\widetilde{DZ}$, $\widetilde{TZ}$, and $\widetilde{RZ}$.

4. Examples

This section presents a numerical example using fuzzy discrete sets.

4.1 Numerical example

Suppose three similar dangers produce danger zones DZ1 to DZ3, limited by three serial danger barriers DB1 to DB3 with the following parameters (**Tables 1** and **2**):

Because the danger barriers are supposed on serial, the model accumulates their effects. For this example, using bounded sum fuzzy union ($\mu_{\widetilde{DB_1} \oplus \widetilde{DB_2}}(x) = \min\left(1, \mu_{\widetilde{DB_1}}(x) + \mu_{\widetilde{DB_2}}(x)\right)$), the effective danger barrier is:

Therefore, the danger barriers inefficiency zones are (**Table 3**).

Suppose the barriers reduce some specific proportion of the danger, so the residual danger zones after applying the above barriers, by using $\widetilde{EDZ} = \widetilde{DZ} \cap \widetilde{IDB}$ and the Algebraic product ($\mu_{\widetilde{EDZ}}(x) = \mu_{\widetilde{DZ}}(x)\mu_{\widetilde{IDB}}(x)$) intersection are (**Table 4**).

Consider 4 targets, using the following protective barriers for targets T1 to T4 (**Table 5**).

The above values indicate the protectives proportion of targets barriers used by different targets in different places. Using the fuzzy complement, the Inefficiency of the above protective measures is (**Table 6**).

The impacted dangers 1 to 3 to target 1, to target 1, after applying target barrier 1 is (**Table 7**).

In the above table, the model uses the bounded sum union to calculate the accumulated danger in each position.

In the same way, the total impacted danger for all the targets is (**Table 8**).

Parameter	Parameter description	Values					
x	**One-dimensional coordinates (x)**	**0**	**1**	**2**	**3**	**4**	**5**
$\mu_{\widetilde{DZ_1}}(x)$	Membership of x in DZ1	1	0.8	0.6	0.4	0.2	0.1
$\mu_{\widetilde{DZ_2}}(x)$	Membership of x in DZ2	0.8	0.9	1	0.5	0.4	0.1
$\mu_{\widetilde{DZ_3}}(x)$	Membership of x in DZ3	0.2	0.6	0.8	0.8	0.5	0.4
$\mu_{\widetilde{DB_1}}(x)$	Membership of x in DB1	0.1	0.2	0.3	0.2	0.1	0.1
$\mu_{\widetilde{DB_2}}(x)$	Membership of x in DB2	0.1	0.1	0.1	0.1	0.1	0.1
$\mu_{\widetilde{DB_3}}(x)$	Membership of x in DB3	0.0	0.0	0.2	0.0	0.0	0.0

Table 1.
The risk entities parameters.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$\mu_{\widetilde{EDB}}(x)$	Membership in Effective Danger Barrier	0.2	0.3	0.6	0.3	0.2	0.2

Table 2.
Membership of different coordinates in effective danger barriers fuzzy set.

x	One-dimensional coordinate (x)	0	1	2	3	4	5
$\mu_{\widetilde{IDB}}(x)$	Membership in Danger Barriers Inefficiency	0.8	0.7	0.4	0.7	0.8	0.8

Table 3.
Membership of different coordinates in effective danger barrier inefficiency fuzzy set.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$\mu_{\widetilde{EDZ_1}}(x)$	Membership in Residual DZ1	0.8	0.56	0.24	0.28	0.16	0.08
$\mu_{\widetilde{EDZ_2}}(x)$	Membership in Residual DZ2	0.64	0.63	0.4	0.35	0.32	0.08
$\mu_{\widetilde{EDZ_3}}(x)$	Membership in Residual DZ3	0.16	0.42	0.32	0.56	0.4	0.32

Table 4.
Membership of different coordinates in residual fuzzy danger zones.

x	One-dimensional coordinate (x)	0	1	2	3	4	5
$\mu_{\widetilde{TB_1}}(x)$	Target Barrier effect, used by T1	0.2	0.2	0.2	0.2	0.2	0.2
$\mu_{\widetilde{TB_2}}(x)$	Target Barrier effect, used by T2	0.3	0.3	0.3	0.2	0.1	0.1
$\mu_{\widetilde{TB_3}}(x)$	Target Barrier effect, used by T3	0.4	0.4	0.4	0.4	0.4	0.4
$\mu_{\widetilde{TB_4}}(x)$	Target Barrier effect, used by T4	0.1	0.1	0.1	0.1	0.1	0.1

Table 5.
Membership of different coordinates in fuzzy target barriers.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$\mu_{\neg\widetilde{TB_1}}(x)$	Inefficiency of target barrier 1	0.8	0.8	0.8	0.8	0.8	0.8
$\mu_{\neg\widetilde{TB_2}}(x)$	Inefficiency of target barrier 2	0.7	0.7	0.7	0.8	0.9	0.9
$\mu_{\neg\widetilde{TB_3}}(x)$	Inefficiency of target barrier 3	0.6	0.6	0.6	0.6	0.6	0.6
$\mu_{\neg\widetilde{TB_4}}(x)$	Inefficiency of target barrier 4	0.9	0.9	0.9	0.9	0.9	0.9

Table 6.
Membership of different coordinates in residual fuzzy target barriers Inefficiency.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$\mu_{\widetilde{EDZ_1}^{1}}(x)$	T1 membership in Residual FDZ1	0.64	0.448	0.192	0.224	0.128	0.064
$\mu_{\widetilde{EDZ_1}^{2}}(x)$	T1 membership in Residual FDZ 2	0.512	0.504	0.32	0.28	0.256	0.064
$\mu_{\widetilde{EDZ_1}^{3}}(x)$	T1 membership in Residual FDZ 3	0.128	0.336	0.256	0.256	0.32	0.256
Membership in Total Danger Zone for T1		1	1	0.768	0.76	0.704	0.384

Table 7.
Membership of different coordinates in residual fuzzy danger zones.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
	T1 Membership in Total Danger Zone	1	1	0.768	0.76	0.704	0.384
	T2 Membership in Total Danger Zone	1	1	0.672	0.76	0.792	0.432
	T3 Membership in Total Danger Zone	0.96	0.966	0.576	0.57	0.528	0.288
	T4 Membership in Total Danger Zone	1	1	0.864	0.855	0.792	0.432

Table 8.
Membership of different coordinates in total fuzzy danger zones.

Suppose the position of the targets is a random variable with the following 132probabilities (**Table 9**).

Therefore the total risk for every target at each position is (**Table 10**).

The following figure shows the distribution of the danger (**Figure 7**).

The above chart shows that the most dangerous place is point 2, with a total risk index of 1.382, and particularly the risk for target 4 is very high at this point.

In the continue consider a target presence barrier with the following reliabilities (**Table 11**).

It impedes particularly the targets presented in point 2. The Inefficiency of this barrier is (**Table 12**).

Using algebraic product fuzzy intersection, the presence probability of the targets is (**Table 13**).

By applying algebraic product fuzzy intersection on target presence probability and targets membership in danger zones, the total risk for the targets is (**Table 14**).

The following chart illustrates the risk after applying this barrier (**Figure 8**).

The results indicate a reduction in the risk significantly.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$P_1(x)$	Presence probability of T1	0	0.1	0.2	0.3	0.2	0.3
$P_2(x)$	Presence probability of T2	0.1	0.2	0.2	0.2	0.3	0
$P_3(x)$	Presence probability of T3	0	0	0.4	0.5	0.1	0
$P_4(x)$	Presence probability of T4	0	0	1	0	0	0

Table 9.
Presence probability of targets in different coordinates.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$\widetilde{RZ}_1(x)$	Total risk for T1	0	0.1	0.154	0.228	0.141	0.115
$\widetilde{RZ}_2(x)$	Total risk for T2	0.1	0.2	0.134	0.152	0.238	0
$\widetilde{RZ}_3(x)$	Total risk for T3	0	0	0.230	0.285	0.053	0
$\widetilde{RZ}_4(x)$	Total risk for T4	0	0	0.864	0	0	0
$\widetilde{RZ}(x)$	Total risk	0.1	0.3	1.382	0.665	0.431	0.115

Table 10.
Total risk for targets in different coordinates.

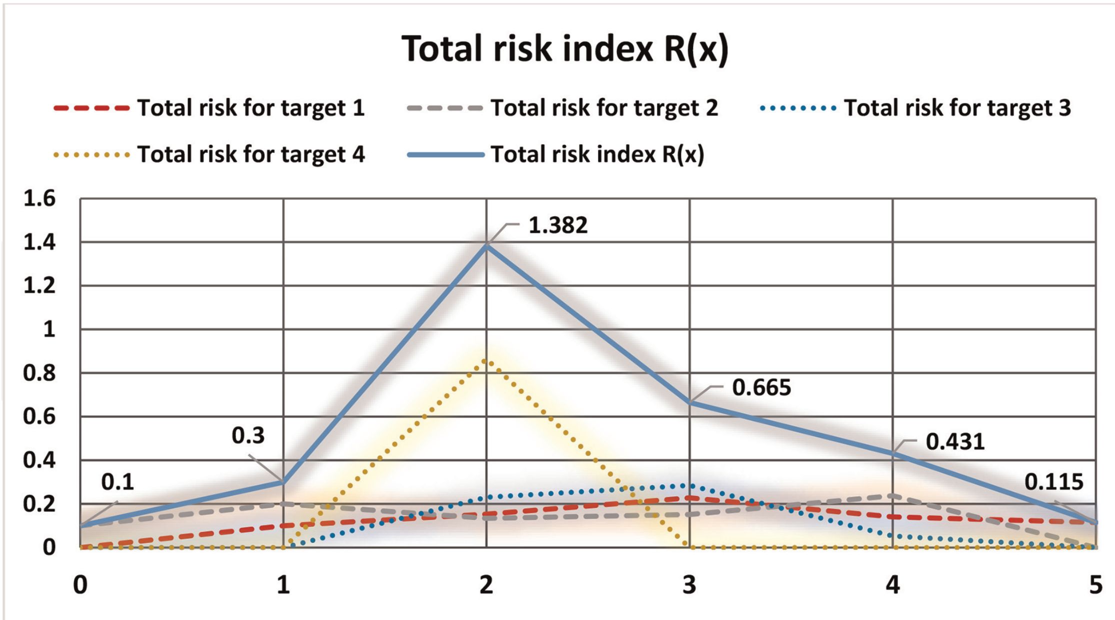

Figure 7.
The distribution of the risk for the targets.

x	One-dimensional coordinate (x)	0	1	2	3	4	5
$P_1(x)$	The presence barrier reliability for T1	0	0.1	0.3	0.1	0.1	0
$P_2(x)$	The presence barrier reliability for T2	0	0	0.2	0.2	0.2	0
$P_3(x)$	The presence barrier reliability for T3	0	0	0.4	0.1	0.1	0
$P_4(x)$	The presence barrier reliability for T4	0	0	0.8	0	0	0

Table 11.
The effects of presence barriers for targets in different coordinates.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$P_1(x)$	The presence barrier inefficiency for T1	1	0.9	0.7	0.9	0.9	1
$P_2(x)$	The presence barrier inefficiency for T2	1	1	0.8	0.8	0.8	1
$P_3(x)$	The presence barrier inefficiency for T3	1	1	0.6	0.9	0.9	1
$P_4(x)$	The presence barrier inefficiency for T4	1	1	0.2	1	1	1

Table 12.
The effects of presence barriers Inefficiency for targets in different coordinates

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$P_1(x)$	Modified presence probability of T1	0	0.09	0.14	0.27	0.18	0.3
$P_2(x)$	Modified presence probability of T2	0.1	0.2	0.16	0.16	0.24	0
$P_3(x)$	Modified presence probability of T3	0	0	0.24	0.45	0.09	0
$P_4(x)$	Modified presence probability of T4	0	0	0.2	0	0	0

Table 13.
The modified presence probability of targets in different coordinates.

x	One-dimensional coordinates (x)	0	1	2	3	4	5
$\widetilde{RZ}_1(x)$	Total risk for T1	0	0.09	0.108	0.205	0.127	0.115
$\widetilde{RZ}_2(x)$	Total risk for T2	0.1	0.2	0.108	0.122	0.190	0
$\widetilde{RZ}_3(x)$	Total risk for T3	0	0	0.138	0.257	0.048	0
$\widetilde{RZ}_4(x)$	Total risk for T4	0	0	0.173	0	0	0
$\widetilde{RZ}(x)$	**Total risk**	0.1	0.29	0.526	0.583	0.364	0.115

Table 14.
The total risk for targets in different coordinates.

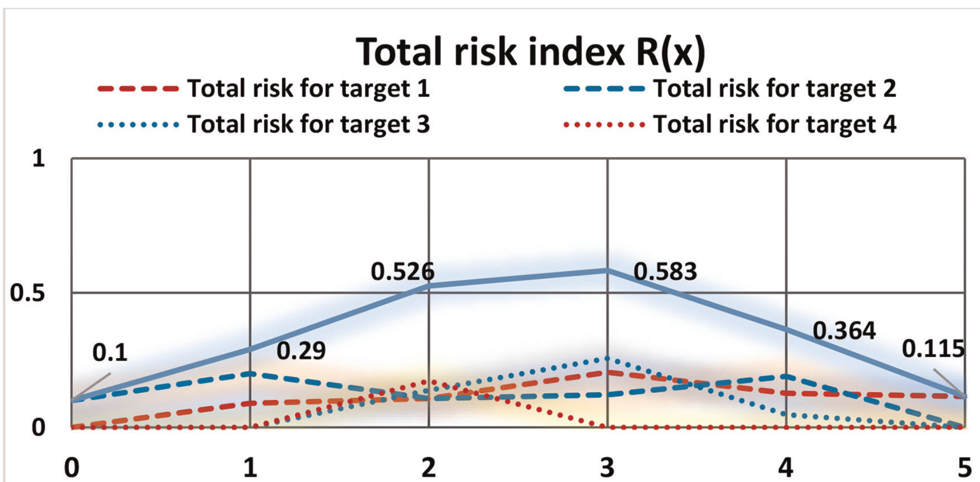

Figure 8.
The distribution of the risk for the targets, after applying the presence target.

5. Discussion

The proposed fuzzy analytical approach attempts to simplify the complexity of the traditional risk analysis by demonstrating the geometric profiles of risk analysis entities. This method models dangers, target presence, material, and immaterial barriers and provides a communication/analysis tool in graphical design platforms.

By using this approach in simulation applications, danger, target, and value attributes may vary during the simulated period. For instance, the magnitude of the HA and target position may vary according to the target and HA position. A software may calculate these parameters for each of the simulation sequences separately. The duration of simulation sequences is essential for calculating a total risk index for a simulated operation.

Shahrokhi and Bernard (2006) presented more discussion about the target vulnerability and worth. An event tree analysis may calculate the probability of occurrence of the simulated conditions. Defining the danger zone and target presence zone provided an index for quantitative risk analysis. The quantitative approaches require carefully scaling factors. For a fixed target, the presence zone will have infinite amplitude. The adaptability of fuzzy operations provides excellent flexibility to tailor the model according to typical situations. The method improves by considering several risks for a group of targets by applying fuzzy operations. Though the impact mode, including the impact duration and direction, is fundamental to estimating the accident severities, authors believe that in many risk analysis methods, including energy/barrier analysis, the assumptions related to the impact mode are not robust and sufficient.

Most of the barriers have not only protection effects; they relocate or reform DZ or TZ. For example, a protection wall increases the concentration of the DZ and TZ in a limited space.

Other fuzzy union operators can model the modification of the DZ/TZ by the barriers.

This model assumes a linear relationship between the damage and impact time because the presence zone demonstrates the duration of the target presence at each point. However, by defining the presence zone as the population density, the model ignores each target impact time. Like many other risk analysis methods, there is no assumption about other impact mode attributes. Therefore, the model's validity depends on the system's specifications. The model considers the danger zone as a stable and fixed region. In this case, the fundamentals theories are valid only for separated sequence times. A moving and dynamic danger zone is more appropriate if the danger source's harmfulness or position is unstable. Shahrokhi and Bernard (2006) discussed this case.

This model is applicable for calculating the cumulative risk indexes for a group of targets and hazards.

6. Conclusion

This paper presents a graphical approach to explain the geographical distribution of the danger and target presence to show the results of scientific calculations, experts' opinions, and observations. Using geographical risk attributes instead of their simple values provides a spatial risk analysis approach to present the workplace's danger concentration points and neighborhoods. The model introduces a geometric definition for the probability and severity of the professional risk and material/immaterial barriers using the fuzzy space concept. This definition lets to separate the barriers' severity and probability effects and use the fuzzy set operations to determine the risk and barrier effects. It assigns a risk membership to each workplace location and aggregates all points to provide a total risk index. The model is appropriate for calculating the cumulative risk indexes for a group of targets and hazards.

Author details

Mahmoud Shahrokhi[1]*, Majid Vaziri Sarashk[2] and Alain Bernard[3]

1 University of Kurdistan, Sanandaj, Iran

2 Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran

3 Laboratoire IRCCyN, Ecole centrale de Nantes, Nantes, France

*Address all correspondence to: shahrokhi292@yahoo.com

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