IJRRS
International Journal of Reliability, Risk Safety: Theory and Application

Online ISSN: 2676-3346

Vol. 5/ Issue 2/ 2022/ pp. 33-40
DOI: 10.30699/IJRRS.5.2.4
Received: 2022.10.13, Accepted: 2023.01.13

Case Study

Safety assessment of people in public building fire incidents using harmony search algorithm

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Abstract

As we know, people are primarily at risk of different incidents during their life, especially when they encounter unpredictable accidents. For example, fires in public places such as governmental or trade centers during their daily activities make them obliged to evacuate the building rapidly. This research deals with the fire safety of mentioned people by means of the probabilistic method. For this purpose, fire safety is addressed by modeling the egress of the people from the fire to a safe zone. A trade center building with a common layout has been chosen for safety analysis and a limit state function has been developed according to the timeline evacuation model and fire scenario. To define the safety of building visitors, the safety index method has been selected for computing the probability of trapping in fire (fatality) and safety index (beta index). The harmony search algorithm has been used to obtain Hasfoer and Lind reliability index. A sensitivity analysis of the model's variables has been done to find the most important and effective parameters for fire safety. Results show response time to the fire, area of buildings and length of escape route are more critical in buildings. In other words, the safety of people will improve with decreasing response time and length of evacuation route and increasing dimensions of interior space of buildings.

Keywords: Fire safety; Public Buildings; the probabilistic method; optimization; Harmony Algorithm.

Nomenclature and Units

PDF	Probability Density Function
SLSF	Safety Limit State Function
$F_X(x)$	Probability Distribution Function
G	Performance Function
PF	Probability of Failure
FORM	First Order Reliability Method
SORM	Second Order Reliability Method
ASET	Available Safe Egress Time
REST	Required Safe Egress Time
SFT	Smoke Filling Time
DAT	Detection and Alarm Time
β_{HL}	Hasofer-Lind Reliability Index
CDF	Cumulative Distribution Function
HSA	Harmony Search Algorithm
IHS	Improved Harmony Search
HMS	Harmony Memory Size
HMCR	Harmony Memory Considering Rate
PAR	Pitch Adjustment Rate
MET	Movement Time
RPT	Response and Premovement time
COV	Coefficients of Variation

1. Introduction

Fire has been known for a long time as one of the main causes of death happening in building accidents [1] for example, in 2020, there were 3,500 civilian deaths caused by fires in the United States. This is a slight decrease from the previous year when fires in the country caused 3,704 civilian deaths. [2]. Recently, there have been many fire accidents at malls, restaurants, marriage halls, exhibitions, shopping complexes, and other public places so far. Fire safety in public places is the last thing we would have in mind when we visit these places mostly for entertainment. Being more careful could help you avert any tragedies and make your family more aware of the safety concerns. But, for the fire safety of people in a public building, crucial features of the capability to act include the ability to perceive, comprehend and evacuate. So, these items must be considered in the building design process, construction, and fire safety active and passive planning.

Over the past several years, efforts have been made within the fire protection community to develop and implement performance-based code [3]. It is noteworthy that the design purpose is the reducing risk of fire in terms of the probability of trapping in fire and its consequences that can be obtained using reliability theory [4]. Generally, safety and reliability theory is based on the comparison of pairs of two parameters: strength and stress that insufficient strength leads to a sort of failure [5]. Regarding fire safety, and the evacuation model, required safe egress time (RSET) and available safe egress time (ASET) can be considered as a pair of parameters in the same way as stress and strength [6]. The event of RSET exceeding ASET is considered a failure event or fatality event and quantifying mentioned probability has a significant impact on fire safety engineer decisions. Fire safety assessment of buildings consists of modeling every design variable of the egress timeline model on which there are uncertainties by using random vector X. Then, a failure criterion is defined by a safety limit state function (SLSF), G(X), that defines the failure domain d. To assess the fire safety of the building's occupants, the joint density probability function, $f_x(x)$, should be known and its vector is X [7]. To attain the probability there is a wide range of methods [8]. When it comes to taking a decision for improving the current level of safety, sensitivity analysis also can be utilized as a tool to find the most important parameters and their variations will have a significant impact on the fire safety of buildings occupants.

2. Building fire safety assessment problem

Generally, the main aim of the fire safety of buildings' occupants is verifying the possibility of escaping from a burning building toward a safe zone. So, there is some sort of models which are based on the spread of fire in buildings and people's behavior while evacuating their homes. In fact, these models are used in fire safety engineering to investigate the safety conditions of a given building or other infrastructures.

Among these models, the timeline model is a simplified method to represent the phases of an evacuation. The model includes detect and alarm times, pre-movement time, and the movement phase or needed time to reach a safe place [9]. All the mentioned times can be considered as REST for each one of the buildings' residents to egress from the fire zone (see Figure 1). Also, based on the fire's properties and buildings' characteristics, there is ASET that gives the occupants of the building the chance of escape. The greater difference between these times indicates a higher level of safety during the evacuation process and an increment in the margin of safety of occupants against fire incidents.

Many aspects of our daily lives involve the comparison of pairs of two variables: supply and demand, strength, stress, etc. As mentioned above, in fire safety engineering the egress timeline model is currently used for occupants' life safety assessment. The parameters of interest are ASET and RSET and the event of RSET exceeding ASET is regarded as a failure event or trapping people in the fire which might lead to death or life injuries. An egress timeline can be utilized to describe occupants' activities observed during evacuation phases. It consists of detection and alarm time, response or pre-movement time, and movement time. The recognition time that consists of detection and alarm times is demonstrated implicitly within the pre-movement phase [9,10].

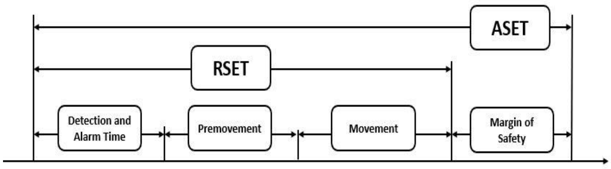

Figure 1. Time-line model of buildings' occupants' fire safety

2.1 People's fire safety limit state function

Fire safety assessment of buildings includes creating a model based on every design variable of the egress timeline model on which there are uncertainties by using a random vector of variables. A safety limit state equation (SLSF) would be formulated as below:

$$SLSF = SFT - DAT - RPT - MET \quad (1)$$

Where SFT is critical time (s) for smoke-filling to a certain threshold (average of people height of 1,6 + 0,1 H (m)); DAT is detection and Alarm time(s); PRT denotes response and pre-movement time-consuming behaviors prior to evacuation (s); and MET is movement or evacuation time (s). According to an empirical equation is suggested in NFPA92B for the smoke layer height during the t^2-fires [$Q = \alpha t^2\ (Kw)$]:

$$\frac{z}{H} = 0.91\left[tH^{-4/5}\left(\frac{1000}{\alpha}\right)^{-1/5}\left(\frac{Area}{H^2}\right)^{-3/5}\right]^{-1.45} \quad (2)$$

Where z is the height of the smoke layer above the fire [m], H is the ceiling height of the building [m], t is the time [s], Area is the floor area [m2], α is the growth rate of fire (kW). The critical time for smoke filling, S, is defined as the time at which the smoke layer comes down to 1.6 +0.1H meters above the floor of the building [11]. Rounding 1.6 0.1H + to 2 meters, we get

$$SFT = (2.32\,\alpha^{-0.2}H^{0.3}Area^{0.6}) \quad (3)$$

The detector has the following characteristics: detection temperature is 60 °C. The proposed equation for detection time is as follows [12]:

$$DAT = 5.36\,\alpha^{-0.478}H^{0.7} \quad (4)$$

The response or pre-movement time (RPT) depends on the evacuation alarm and the dimension and plan of the home. The input data normally are chosen with engineering judgment made by a fire safety expert. In this research, a triangular probability distribution function with recommended parameters based on people's behaviors in fire situations has been selected [13]. The evacuation time, (MET), is the time it takes to travel to and through an exit door. It relates to the width of available exit doors and the number of people in the building which depends on the type of building and its area. The following formula can be considered for the required time of movement after taking a purposive decision to evacuate the building:

$$MET = \frac{L}{V} + \frac{P}{F \times W} \tag{5}$$

Where L is the distance to the exit doors, V denotes the speed of movement, P is the number of people in the building, F is the number of persons going through a door per second per door width in meters (m-1) and W denotes the width of the door (m). Assuming the average number of people to be 1 person/m2. So, the limit state function is [11]:

$$SLSF = SFT - DAT - RPT - MET \tag{6}$$

$$SLSF = (2.32\ \alpha^{-0.2} H^{0.3} Area^{0.6}) - \cdots$$
$$(5.36\ M_D \alpha^{-0.478} H^{0.7}) - RPT - (\frac{L}{V} + \frac{P}{W}) \tag{7}$$

To consider the model uncertainty related to each one of mentioned times, uncertainty parameters, C_1, C_2, and C_3, have been introduced into the calculation, transforming Eq. (6) to equation (8). In other words, C_1 is the model uncertainty for the smoke-filling model; C_2 is the model uncertainty for the detection system and C_3 is the uncertainty for the evacuation model.

$$SLSF = C_1 SFT - C_2 DAT - RPT - C_3 MET \tag{8}$$

2.2 Probability of fatality

To define the safety of buildings visitors, the problem of calculating the probability of trapping in a fire should be solved. For this purpose, one can use the theory of reliability. Let x denote random variables of SLSF defining the fire, building, and people properties. And $f_X(x)$ is the probability density function (PDF) of these variables. Also, failure state $SLSF$ is denoted with the following characteristics [7]:

if $SLSF > 0$ RSET is less than ASET for the safe evacuation of the building.

if $SLSF = 0$ RSET is exactly equal to ASET and they can evacuate the building on time,

if $SLSF < 0$ ASET is less than RSET and they will be trapped in the fire.

In nutshell, it means that when the safety margin is lower or equal to zero, the rescue process fails. Hence, the failure domain of people safety can be defined by $d = \{x \in R^n,\ G(x) \leq 0\}$. Therefore the probability of fatality or trapping in the fire, P_f can be formulated as follow:

$$Probability\ of\ Fatality = \int_d f_X(x)dx. \tag{9}$$

Solving Equation (9) is possible by using a wide range of approaches e.g., direct integration of PDF on the failure domain, Monte-Carlo simulation method [14], discrete approximation [16], and First and Second order reliability methods [15]. The first and second-order reliability methods are also known as the Hasofer-Lind Reliability Index developed by Hasofer and Lind [17]. The index has been recognized as an important step toward the development of contemporary methods to estimate safety effectively and accurately. The determination of this index needs first, transforming the uncertain variable x, into uncorrelated standard normal variable U. The design point is defined, in the standard normal space, as the design point that is located on the performance function $G(U) = 0$; it is the nearest point to the origin in the failure region $G(U) = 0$, is an optimum point at which to approximate the LSF. The Hasofer-Lind reliability index is defined by the distance from the origin to the design point in the standard normal space.

The mentioned safety index is proposed in a space where the vector components are Gaussian standard. The Hasofer–Lind reliability index β_{HL}, is defined as β_{HL}in the Gaussian normal standard space. But when the distribution of random variables is not normal, the equivalent normal value of the mean and standard deviation for each no normal random variable should be computed which is based on the proposed procedure by Rackwitz and Fiessler [18]. When the distribution of the random variable is non-normal, the equivalent normal value of the mean and standard deviation for each non-normal random variable should be computed. For this aim suppose that a particular random variable X with mean μ_X and standard deviation σ_X is described by a cumulative distribution function (CDF) $F_X(x)$ and a probability density function (PDF) $f_X(x)$. To obtain the equivalent normal mean μ_X^e and standard deviation σ_X^e, we require that the CDF and PDF of the actual function be equal to the normal CDF and normal PDF at the value of the variable x^* (design point) on the failure boundary described $g = 0$. Mathematically, these requirements are expressed as [19,20],

$$F_X(x^*) = \Phi\left(\frac{x^* - \mu_X^e}{\sigma_X^e}\right) \tag{10}$$

$$f_X(x^*) = \frac{1}{\sigma_X^e}\phi\left(\frac{x^* - \mu_X^e}{\sigma_X^e}\right) \tag{11}$$

Where Φ is the CDF for the standard normal distribution and ϕ is the PDF for the standard normal distribution. By manipulating these equations, we can obtain expressions for μ_X^e and σ_X^e as follows:

$$\mu_X^e = x^* - \sigma_X^e[\Phi^{-1}(F_X(x^*))] \tag{12}$$

$$\sigma_X^e = \frac{1}{f_X(x^*)}\phi\left(\frac{x^* - \mu_X^e}{\sigma_X^e}\right) \tag{13}$$

The main aim is calculating β_{HL} with Harmony Search evolutionary algorithm in space Λ [21]. To achieve this, one must solve a constrained optimization problem that is

$$\begin{cases} Min \sum_{i=1}^{n} u_i^2 \\ Subject\ to\ G(T^{-1}(u)) = 0. \end{cases} \tag{14}$$

Solve Eq. 14 is equivalent to solving the relaxed form obtained by the penalty method

$$\left\{ \underset{u}{Min} \sum_{i=1}^{n} u_i^2 + \lambda\zeta(G(T^{-1}(u)) = 0)\right., \tag{15}$$

Where ζ is the penalty function and λ is the penalty coefficient (strictly positive). The solution u^* of Eq. (14) or (15) is called the design point and enables to calculate of the reliability index as

$$\beta_{HL} = \|u^*\|. \quad (16)$$

The choice of the penalty coefficient λ in Eq. (15) is crucial for the convergence of the search toward the solution of Eq. (14). In the case of equality constrained as it is addressed in this paper, the penalty coefficient will be searched by an iterative process from a low value because the search space is a hyper-surface. According to [7], an appropriate sequence of λ is λ_i, such that $\lambda_{i+1} = 2\lambda_i$ and $\lambda_0 = 0.1$. The value of λ will be considered suitable when the quantity $\xi(G(T^{-1}(u)))$ in Eq. (15) is enough small (<10^{-4} for example).

3. Harmony Algorithm

HS algorithm is based on natural musical performance processes that occur when a musician searches for a better state of harmony, such as during jazz improvisation. Jazz improvisation seeks to find musically pleasing harmony (a perfect state) as determined by an aesthetic standard, just as the optimization process seeks to find a global solution (a perfect state) as determined by an objective function [22].

The pitch of each musical instrument determines the aesthetic quality, just as the objective function value is determined by the set of values assigned to each decision variable. The HS algorithm works as follows:

Step 1. Initialize the problem and algorithm parameters.

The optimization problem is defined as Minimize $f(x)$ subjected to $X_{iL} \leq X \leq X_{iU}$ $(i = 1,\ldots,N)$. X_{iL} and X_{iU} are the lower and upper bounds for decision variables. The HS algorithm parameters are also specified in this step. They are the harmony memory size (HMS), or the number of solution vectors in the harmony memory; harmony memory considering rate (HMCR); bandwidth (bw); pitch adjusting rate (PAR); and the number of improvisations (K) or stopping criterion.

Step 2. Initialize the harmony memory (HM).

The initial harmony memory is generated from a normal distribution in the ranges $[X_{iL}, X_{iU}]$, $(i = 1,2,\ldots N)$ as shown in Eq. (17):

$$M = \begin{pmatrix} x_1^1 & \ldots & x_N^1 \\ x_1^2 & \ldots & x_N^2 \\ \vdots & \ddots & \vdots \\ x_1^{HMS-1} & \cdots & x_N^{HMS-1} \\ x_1^{HMS} & \ldots & x_N^{HMS} \end{pmatrix} \quad (17)$$

Step 3. Improvise a new harmony.

Generating a new harmony is called improvisation. The New Harmony vector $x' = (x_1', x_2', \ldots, x_3')$ is determined by three rules: memory consideration, pitch adjustment, and random selection. The procedure works as follows:

```
for each i ∈ [1,N] do
   if rand() ≤ HMCR then
      x'_i = x_i^j (j = 1,2,...,HMS)% memory consideration
      if rand ≤ PAR then
         x'_i = x'_i ± r × bw %Pitch adjustment
         if x'_i > x_iU
            x'_i = x_iU
         else if x'_i < x_iL
            x'_i = x_iL
         end
      end
   else
      x'_i = x_iL + rand() × (x_iU − x_iL)%Random selection
   end
end
```

$x_i'(i = 1,2,\ldots,n)$ is the ith component of x', and $x_i^j(j = 1,2,\ldots,HMS)$ is the ith component of the jth candidate solution vector in HM. Both r and $rand()$ are uniformly generated random numbers in the region of [0,1], and bw is an arbitrary distance bandwidth.

Step 4. Update harmony memory.

If the fitness of the improvised harmony vector $x' = (x_1', x_2', \ldots, x_3')$ is better than that of the worst harmony, replace the worst harmony in the HM with x'.

Step 5. Check the stopping criterion.

If the stopping criterion (maximum number of iterations K) is satisfied, the computation is terminated. Otherwise, Step 3 is repeated.

The most important step of the HS algorithm is Step 3, which includes memory consideration, pitch adjustment, and random selection. PAR and bw have a profound effect on the performance of the HS. (Mahdavi et al. 2007) proposed a new variant of the HS, called the improved harmony search (IHS) [23]. The IHS dynamically updates PAR and bw according to Eqs. (18) and (19):

$$PAR(k) = PAR_{\min} + \frac{PAR_{\max} - PAR_{\min}}{NI} \times k \quad (18)$$

$$bw(k) = bw_{\max} \exp\left(\frac{\ln\left(\frac{bw_{\min}}{bw_{\max}}\right)}{NI} k \right) \quad (19)$$

Where NI is the maximum number of iterations, and k is the current number of iterations; PAR_{min} and PAR_{max} are the minimum adjusting rate and the maximum adjusting rate, respectively; bw_{min} and bw_{max} are the minimum bandwidth and the maximum bandwidth, respectively. Table 1 shows the selected Parameters of the algorithm in this research for fire safety assessment of people in a public building based on the defined scenario.

Table 1. IHS parameters used for considered fire scenario

Parameter	Value
PAR	0.3
HMCR	0.9
PAR_min	0.35
PAR_max	0.99
bw_min	1e-6
bw_max	1
NI	1000
HMS	120

4. Result and Discussion

To define the safety of a public building's occupants and its visitors an example has been considered and the probability of trapping in fire or residents' injuries has been computed. The following fire scenarios have been considered to occur for the building occupants and visitors. The layout for a public building is shown in Figure 2. The floor has two corridors that lead to two exit doors with adjoining rooms that serve here as offices. The height of the rooms and the corridor is 2.8 m. The total size of the floor is 500 m2. The building is a single-floor building. Two fire hoses are placed near the exit doors on both ends of the corridors. There are no emergency openings in the offices. No alarm is connected in the office as it is not required by the regulation.

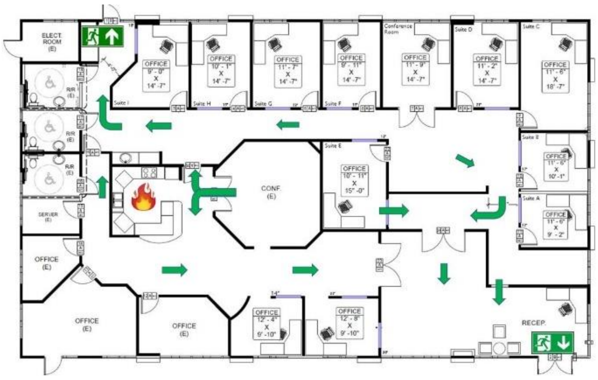

Figure 2. The layout of the public administrative building and its available escape routes

Scenario: it's a normal day and in the mentioned public administrative building there is a lot of staff work there who have a great number of clients. Most of the offices and corridors have been occupied by staff and visitors respectively. A fire breaks out in the kitchen. Someone has forgotten to turn off the Electric Kettle. The kettle contains no water and overheats, igniting the plastic and the napkin beside the kettle. At that moment smoke detector is activated and the staff smells something burning, and the person working in the room next to the kitchen rushes in. By that time, the fire has spread to a pile of papers next to the kettle, generating a lot of smoke. The staff begins to evacuate the floor after an attempt to extinguish the fire with a fire extinguisher fails. The safety limit state function in consideration is as follows:

$$SLSF = C_1\left(\left(2.32\,\alpha^{-0.2}H^{0.3}Area^{0.6}\right)\right) - \cdots$$
$$C_2(5.36\,\alpha^{-0.478}H^{0.7}) - RPT - C_3\left(\frac{L}{V} + \frac{P}{W}\right) \quad (20)$$

Table 2 shows the statistical properties of the limit states function's probabilistic variables which are taken from different references.

Table 2. Statistical properties of SLSF variables

Variable	Probability Distribution	Statistical parameters	unit
α[22]	triangular	0.0028,0.0034,0.01	Kw/sec2
RPT[16]	triangular	60,90,120	sec
L[23,24]	rectangular	5,50	m
V[25,26]	rectangular	0.4,1.3	m/sec
P	Normal	50,25	n/m2
W[23]	rectangular	0.9,1.8	m
H	Normal	3.0,0.2	m
$Area$	Normal	500,50	m2
C_1[15]	Normal	1.25,0.1	-
C_2[15]	Normal	1,0.2	-
C_3[15]	Normal	1,0.1	-

The adopted SLSF from the probabilistic model in the preceding sections has been inputted into the computer codes which are prepared for assessment of the safety index, probability of trapping in fire, and design point. The results of mentioned parameters are given in Table 3 below.

Table 3. Safety index, Probability of fatality obtained by HA and MC, and design point of SLSF of Building Occupants

Safety Index	$HA\ P_f$	$MC\ P_f$	Design Point
0.26	0.397	0.401	(C_3, C_2, C_1, Ar, H, A, R, L, W, P, V, F,) = (0.850, 1.0047, 1.002, 1.245, 231.297, 3.000, 0.005, 91.621, 27.991, 1.194, 50.947, 1.185, 1.000)

As shown in the table 3, the safety of mentioned scenario shows that building occupants are at high risk of fire fatality regarding building layout, fire properties, and people characteristics. Results show that obtained probability of trapping in the fire is about 40%. it means that according to the defined scenario, the building's staff or clients will trap on the floor before leaving the building by mentioned likelihood which is a high risk of fatality, especially for those who suffer from disabilities. Therefore, preparing an appropriate plan to reduce the evacuation time such as embedding more exit doors to decrease the length of the evacuation route and the required time of pre-movement is crucial and has a key role in occupant safety. To verify the impact of fire, building, and people characteristics variables in SLSF, a sensitivity analysis has been carried out. It gives a useful overview of their impact on the fire safety index of people. Figure 3 shows the results of the sensitivity analysis of each limit state function's variables on the safety index of home occupants.

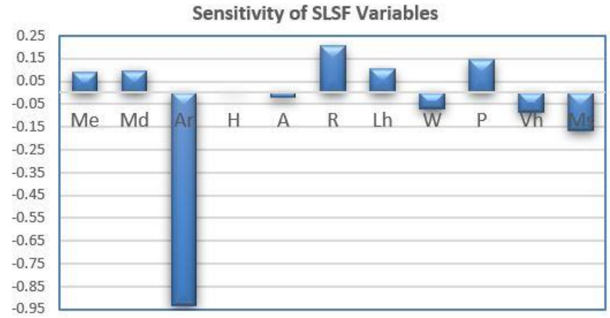

Figure 3. Sensitivity analysis of SLSF variables

Sensitivity analysis of random variables demonstrates that the area of the building's corridors has the greatest impact on the safety index and is the most sensitive parameter compared to other variables. It means that by increasing the interior space which can be resulted from opening or closing offices' doors, ones can have more time for evacuation. In other words, the smoke takes more time reaches to the mentioned threshold in section 2 and it gives extra time to building occupants to evacuate the building. The second sensitive parameter that has a considerable effect on the safety index is response time or pre-movement time. As shown, by increasing response time, the probability of trapping in the fire will increase. The next place of sensitive variables belongs to the number of people inside the building and the length of the escape route. Whatever these variables get greater, the probability of being trapped in the fire will increase. On the other hand, the width of exit doors (W) and rate of movement (Vh) have an inverse effect on the probability of fatality. They have the same importance as the variable sensitivity analysis and any increment of these variables leads to improving the safety of people. It is worth noting that the sensitivity of model uncertainties is around 2% of the total values for the considered evacuation model.

As is clear from the sensitivity analyses of the above scenario, the area of the building, the number of people, and the length of the escape route are the most important parameters for the safety of people's homes. Figures 4 to 6 show the effect of mentioned variables' variation on the safety index and probability of being trapped in the fire.

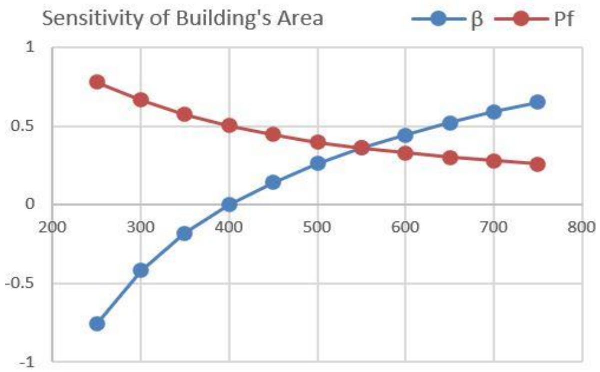

Figure 4. Safety index and Probability of trapping in fire vs. building area

Since the area of the home has the greatest importance among the SLSF variables, variation of the safety index and probability of trapping in the fire vs area of the building have been investigated. Figure 4 shows how the area's increment effect on mentioned safety parameters. As it is clear, the safety index increases with the increment of the building's area. Also, the probability of being trapped in fire decreases significantly vs. increasing area. It can be concluded that if the number of offices with open door get increases, the interior space of the building for smoke propagation will be and it leads to increasing ASET for the building occupants. Because it needs more time to reach the aforementioned certain threshold of height. So people have extra time to escape from the hazard zone toward the exit doors and safe zone.

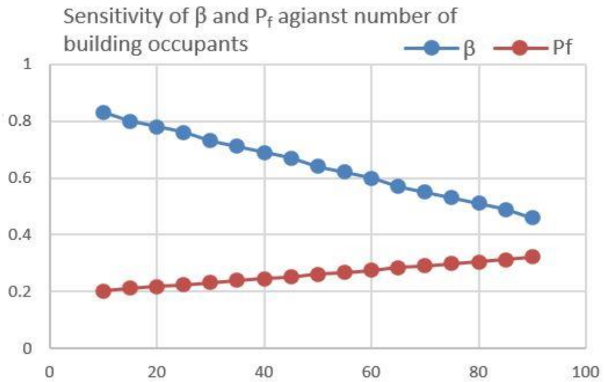

Figure 5. Safety index and probability of trapping in fire vs number of buildings visitors

Figure 5 shows the comparison between the safety index of occupants and the number of buildings' visitors indicating that increasing the number of buildings' occupants leads to reducing in the safety index and consequently the probability of trapping in the fire before the evacuation will be increased. Regarding the length of the escape route as a sensitive variable, figure 6 illustrates variations of the safety index and Pf against the length of the evacuation route which can be a combination of the horizontal and inclined length of an escape route. As it is clear by increasing the length of the escape route, the safety index of occupants decreases and pf increases accordingly.

5. Conclusion

This paper presents the fire safety of building occupants by means of calculating the safety index and probability of trapping people in fire based on the egress timeline model. An appropriate safety limit state function was developed regarding a common type of public building layout, fire properties, and people characteristics. Uncertainty of SLSF random variables and model uncertainties have been addressed by selecting the proper probability distribution function of variables according to the last experimental data from the literature. The safety index of building occupants and the probability of fatality due to the fire have been calculated by using the Hasofer and Lind safety index in conjunction with the harmony search algorithm. The Rackwitz and Fiessler procedure has been used due to different types of probability distribution functions of design variables to deal with this issue. Results of proposed methods for safety index and probability of life injuries of buildings visitors and resident staff indicated a high risk and probability of trapping in a fire during the evacuation phase. Sensitivity analysis of design variables showed that the most important and effective parameters on the fire safety of at-risk groups are the area of the buildings, the number of people in the building, and the length of escape routes. By increasing the interior space of the building which can be the result of the addition of office space with open doors to the corridor space, it can be expected that ASET increases and building occupants would have a bit more time to escape the building. Also, by scheduling the number of building visitors during the hour's work of public building. Furthermore, embedding new exit doors in the building layout leads to decreasing the length of the escape route and accordingly reducing the required time for the building evacuation. However, further research is needed to address the role of the elevators, staircases, and people with specific kinds of impairment in developing, which could lead to developing a more realistic fire egress model based on the occupants' behaviors and the characteristics of the buildings.

6. References

[1] A. P. Harpur, K. E. Boyce, and N. C. McConnell, "An investigation into the circumstances surrounding elderly dwelling fire fatalities and the barriers to implementing fire safety strategies among this group," in *Fire Safety Science*, International Association for Fire Safety Science, 2014, pp. 1144–1159. doi: 10.3801/IAFSS.FSS.11-1144.

[2] Usfa, "A Profile of Fire in the United States 2003-2007," 2003. [Online]. Available: www.usfa.dhs.gov

[3] E. Almgren and P. Hansson, "Finding the Performance in Performance Based Codes-Lesson Learned from the Pre-Study for the Renewal of the Swedish Fire Safety Code due to 2010", *Proc. of the 8th Performance-Based Codes and Safety Design Methods Society of Fire Protection Engineers*, 2010.

[4] T. Tanaka, "Integration of fire risk concept into performance-based evacuation safety design of buildings," in *Fire Safety Science, Proceedings of the 10th International Symposium* 2011, pp. 3–21. doi: 10.3801/IAFSS.FSS.10-3.

[5] F.J. Samaniego, "System signatures and their applications in engineering reliability" in International Series in Operation Research and Management Science, New York: Springer, 2007. [Online]. Available: https://link.springer.com/book/10.1007/978-0-387-71797-5

[6] E. Ronchi, "Developing and validating evacuation models for fire safety engineering", *Fire Safety Journal*, vol. 120, p. 103020, 2021, doi: https://doi.org/10.1016/j.firesaf.2020.103020.

[7] N. Kazemi, S. Sanayee Mogahdam, S. Ghasemi, H. Abotorab, "Corrosion Reliability Assessment of underground Water Transmission Pipelines by IHS Algorithm", International Journal of Reliability, Risk and Safety: Theory and Application, vol. 1, no. 1, pp. 45-51, 2018.

[8] N. Shabakhty, N. Kazemi, M.A. Kia, "Structural reliability assessment using improved harmony search evolutionary algorithm", in Proc. of the 2nd Iranian Conf. on Reliability Engineering. (Reli2011), Aerospace Research Institute, Tehran, 2011, pp. 1–9.

[9] E. Ronchi, "Developing and validating evacuation models for fire safety engineering", *Fire Safety Journal*, vol. 120, p. 103020, 2021, doi: https://doi.org/10.1016/j.firesaf.2020.103020.

[10] Morgan J. Hurley, Daniel Gottuk, John R. Hall, Kazunori Harada, Erica Kuligowski. Et al, "SFPE Handbook of Fire Protection Engineering", 6th ed, New York, NY, Springer, 2016. [Online]. doi: https://doi.org/10.1007/978-1-4939-2565-0

[11] N. Fire, NFPA 92: standard for smoke control systems, 2021. Quincy, Massachusetts: National Fire Protection Association, 2021.

[12] Nordic Committee for Building Regulation: "Performance Based Fire-safety Requirements and Technical Guidelines for the Calculation Process", Working Rep: pp. 07, 1994.

[13] M. Forssberg, J. Kjellström, H. Frantzich, A. Mossberg, and D. Nilsson, "The Variation of Pre-movement Time in Building Evacuation," *Fire Technol*, vol. 55, no. 6, pp. 2491–2513, 2019, doi: 10.1007/s10694-019-00881-1.

[14] R. Y. Rubinstein and D. P. Kroese, "*Simulation and the Monte Carlo method*". Hoboken, N.J.: Wiley. Copyright, 2017, doi: https://doi.org/10.1002/9781118631980.

[15] Y.-G. Zhao and T. Ono, "A general procedure for first/second-order reliability method (FORM/SORM)," *Structural Safety*, vol. 21, no. 2, pp. 95–112, 1999, doi: https://doi.org/10.1016/S0167-4730(99)00008-9.

[16] D. Roy and T. Dasgupta, "A discretizing approach for evaluating reliability of complex systems under stress-strength model," in *IEEE Transactions on Reliability*, vol. 50, no. 2, pp. 145-150, June 2001, doi: 10.1109/24.963121.

[17] A. M. Hasofer and N. C. Lind, "Exact and Invariant Second-Moment Code Format," *Journal of the Engineering Mechanics Division*, vol. 100, no. 1, pp. 111–121, Feb. 1974, doi: https://doi.org/10.1061/jmcea3.0001848.

[18] R. Rackwitz and B. Flessler, "Structural reliability under combined random load sequences," *Comput Struct*, vol. 9, no. 5, pp. 489–494, 1978, doi: https://doi.org/10.1016/0045-7949(78)90046-9.

[19] A. S. Nowak and K. R. Collins, "*Reliability of structures*". Boca Raton: Crc Press, 2019.

[20] Ashgar B, "Nonlinear constrained optimization using penalty function", Mathematical developer Conference proceeding, 1999.

[21] K. Elaki, N. Shabakhty, M. A. Kia, and S. Moghaddam, "Structural Reliability: An Assessment Using a New and Efficient Two-Phase Method Based on Artificial Neural Network and a Harmony Search Algorithm," *Civil Engineering Infrastructures Journal*, vol. 49, no. 1, pp. 1–20, 2016, doi: 10.7508/ceij.2016.01.001.

[22] Zong Woo Geem, Joong Hoon Kim, and G. V. Loganathan, "A New Heuristic Optimization Algorithm: Harmony Search," *SIMULATION*, vol. 76, no. 2, pp. 60–68, Feb. 2001, doi: https://doi.org/10.1177/003754970107600201.

[23] M. Mahdavi, M. Fesanghary, and E. Damangir, "An improved harmony search algorithm for solving optimization problems," *Applied Mathematics and Computation*, vol. 188, no. 2, pp. 1567–1579, May 2007, doi: https://doi.org/10.1016/j.amc.2006.11.033.