A PROPOSED METHODOLOGY FRAMEWORK TO ASSESS THE FIRE RISK IN EXISTING BUILDINGS

S. P. Bhattacharya

ABSTRACT

Fire is one of the major causes of the manmade disaster. A simple fire-related accident may lead to a complete devastation due to the nature of the built forms and practices of the inhabitancies. Fire constitutes a significant threat to life and property mostly in urban setups. In the recent past, in India and abroad, numerous numbers of fire-related accidents broke out. Other than the life and built properly, a huge amount of local and regional economic loss has been recorded. The norms and guidelines are given in National building code (NBC) of India suitable for a new building design. The old buildings and the building is used to undergo certain addition-alteration. The used pattern and the habits of the occupants are also changed during the passage of time. Many times, it has been witnessed that these changes lead to fire hazards. There is an urgent need to supplement those norms and provide a systematic approach to evaluate the fire risk. In this context, this paper proposed a comprehensive framework to assess the fire risk of an existing building. A two-fold approach is considered in the proposed method. The evaluation of risk is based on rapid visual surveys. Two separate parametric matrices are considered to calculate the potential of fire hazard. Certain physical parameters are evaluated in each building zone and a Space-Physical parameter Matrix (SPM) is established. Similarly, a Space-Socio economical parameter Matrix (SSM) is also established from a group of chosen socio-economic parameters. All the parameters are normalized based on the weighted factor obtained from an expert opinion survey. The statistical hypothesis tests are proposed to be conducted to screen the effective parameters. Finally, an inclusive mathematical approach will provide the total risk assessment index of the building. Further, the analysis of the risk index will provide the scope of capacity building and the reduction of fire disaster vulnerability of the building.

Introduction

Fire is an essential element of energy transformation. It is very crucial for the human civilization and development process. However, in another hand, fire is treated as one of the major causes of the manmade disaster. A simple fire-related accident due to certain disorders may lead to a complete devastation due to nature of the built forms and practices of the inhabitancies. Fire constitutes a significant threat to life and property mostly in urban setups. In India and abroad, numerous numbers of fire-related accidents broke out in the recent past. Other than the life and built properly, a huge amount of local and regional economic loss has been recorded. With the technological advance on all fronts, not only the factor of susceptibility but the complexity of fires, explosions and other hazards which these buildings are exposed to, have also increased manifold (Hansen et.al, 2018). These hazards have been instrumental in causing heavy losses in lives and property, throwing up fresh challenges to planners, architects and fire protection services in evolving better and improved methods of design and fire protection in order to mitigate such losses.

The National building code (NBC, 2005) of India had a separate section and provisions for fire safety. The norms and guidelines are basically suitable for a new building design. The buildings are used to undergo certain addition-alteration. The used pattern and the habits of the occupants are also changed during the passage of time. Many times, it has been witnessed that these changes lead to fire hazards. There is an urgent need to supplement those norms and provide an extension and systematic approach to evaluate the risk due to fire (Xin and Huang, 2013). In this context, a comprehensive framework to assess the fire risk of an existing building is urgently needed.

1Assistant Professor, Dept. of Architecture and Regional Planning, Indian Institute of Technology Kharagpur, West Bengal, India
spb@arp.iitkgp.ac.in
Need and Objective of the Study

Since, independence, India has lost several lives and property in fire-related disasters. Fire hazards become very common incidences, particularly in the urban areas. The April 2016 fire destroyed several items in the National Museum of Natural History located in New Delhi, India. Almost 20 million archive items Brazil’s oldest and most important historical and scientific museum at Rio de Janeiro has been consumed by fire recently in September 2018. The loses impart to a discontinuation of the nation’s history and beyond repair.

The so-called city of joy Kolkata also experiences many fires of a different character in recent past. A fire broke out at 2:00 pm at Stephen Court, near Park Street on 23 March 2010, 43 people died in the blaze. The initiation of fire is due to a short circuit from a lift between the fifth and sixth floors. In 9th December 2011 early morning, the annexe building of AMRI Hospital at Dakuria gets fire and smoke. The fire was due to alleged negligence, which caused flammable substances kept in the basement of the building to catch fire after a short circuit in the electrical system. It is reported that 95 people, including members of the staff, died (Murali and Vijayalakshmi, 2014). Surya Sen street market fire took place in 27th February 2013. An estimated 19 people, who were mostly labourers working in the market were killed in the accident. The accident occurred at around 3:50 in the morning. Very recently, Bagri market, one of the largest and oldest wholesale markets of Eastern India, comes under huge fire in the early hours 2:45 am on 16th September 2018. Losses due to the fire are expected to be ₹20-25 crore, Restrictions on daily trade around the affected areas are likely to be imposed. This will lead to a further loss of ₹3-4 crore a day.

The change in the socio-economic stratum, enormous development of building and interior finish materials, building an integrated service system provides an extremely high potential for fire-related vulnerability (Yang and Chen, 2014). The proposed fire risk assessment methodology outlines the various causes of fire and provides an overview of building fire hazards. It can be applied to various buildings and marketplaces in urban areas.

To establish a proper framework for assessment techniques following three objectives are suggested.

1. Selection of physical and socio-economic parameters responsible for the fire vulnerability in buildings.
2. Establish the building level data collection survey format to evaluate the selected parameters in response to the fire disaster in building
3. Analysis of the collected data to achieve an index system to assess the fire risk of a building.

Based on the above objectives, the outline of the proposed risk assessment model is discussed in the subsequent paragraphs.

Outline of Risk Assessment Model

The proposed research is executed through parallel steps. A methodology flowchart is established to achieve the research objectives and mentioned in Fig 1. Initially, a space matrix is established based on the building layout. The whole building is segregated based on various activity areas (cell) and the circulation areas (links). The links will create the boundaries or the edge elements. The different zones of the space within a building layout will be formed by a collection of cells and the boundary edges. The physical and socio-economic parameters that responsible for fire disasters are then selected from the literature surveys. The selection of the parameters is accomplished by frequency analysis (Groner, 2016). The nature of the risk due to fire hazard will change with time due to the use of the building and occupancy profile. So, a survey is needed to read this risk pattern.

A Rapid Visual Survey (RVS) is to be conducted to assess the potential vulnerability due to physical parameters. Whereas, a Stakeholder’s Questioner Survey (SQS) is planned to measure the socio-economic vulnerability character of the building user group. Seven physical parameters are evaluated in each building zone and a Space-Physical parameter Matrix (SPM) is established. Similarly, a Space-Socio economical Matrix (SSM) is established from the six chosen socio-economic parameters over each building zones. The assessment and allocation of rating points to all the parameters are proposed through the rapid visual and questioner survey respectively. The parameters in each group can be screened through T-test. The parameters having relatively less importance can be eliminated by the T-test. The overall weight of all the selected parameters are also proposed through an expert opinion survey. The overall weight can be assigned by an
Analytical Hierarchy Process (AHP) method.

![Diagram of Fire Risk Assessment Methodology]

A composite score of physical vulnerability can be obtained by multiplying the respective parameter weight with the Space-Physical parameter Matrix values. Similarly, the composite score of socio-economic vulnerability can also be obtained. Finally, the fire hazard risk index can be achieved by adding both the composite score.

**Evaluation of Space-Physical Matrix (SPM)**

The physical environment of any space has a direct role to play in terms of fire risk. Seven such physical parameters are recognized from the literature review for assessment (Ibrahim et. al, 2011). The description of the parameters is mentioned below.

1. **Fire Load**: It is a derivative of physical nature of the building interior stored items. This is also depending on the calorific value of all individual materials.
2. **Effective Area**: It indicates the amount of net area in any particular building zone containing the material having certain fire load. It can be calculated by deducting the circulation area from the total area of the specific zone.
3. **Fire Hazard Hot Spots**: Certain location in building zone can act as a potential fire hazard source. Example: unprotected and old electrical cable, Electrical overloading points, unsafe uses of LPG or stove burner for shops inside the building, Smoking area.
4. **Existing Fire Control System**: The placement, distribution and maintenance standards of fire detection and extinguished system installed in the building (if any).
5. **Means of Access**: The special arrangement of horizontal circulation routes to exit. The placement and distribution of staircases in the building.
6. **Floor Position**: Floor level of different zones. Higher the floor level, the risk of fire will be increased proportionally.
7. The degree of Encroachment: The means of access many times blocked due to the storing of material and furniture placement. It effectively reduces the emergency evacuation efficiency during a fire event.

The contribution of given physical parameters in various spatial zones is estimated with the help of a Rapid Visual Survey (RVS). The physical parameters are evaluated based on the actual value and normalised into the Likert scale (1-5). The selected seven parameters along with the special zones of the building can be represented through the Space-Physical matrix (SPM) as given in Table 1.

**Evaluation of Space-Socio economic Matrix (SSM)**

The socio-economic structure any habitat or a group of building occupancy also contribute to fire risk estimation. Six such physical parameters are obtained from the literature review for assessment (Sun and Lou, 2014). The description of the parameters is mentioned below.

1. Total Occupancy: It will provide the exposure level of risk. Corresponding the various zones and its physical fire risk should be overlain with the sectors of occupancy to calculate the risk level.
2. Floating Population: If the fire event occurs during pick hours, then the floating population in various zones will be affected. The proportion of floating population over the total occupancy will also indicate the overall control for any fire hazard to occur. If this ratio becomes higher, the level of control will reduce.
3. Age Group: The age grouping within the total occupancy and the floating population is also contributing to the exposure condition of fire risk estimation. The proportion of infant, old age and mother-child population will provide a more vulnerable situation.
4. Annual Turnover: This parameter can be an indicator to predict the amount of economic loss in terms of running investment may occur due to sudden fire.
5. Fixed Asset Value: The Fixed asset is also indicated the amount of economic loss in terms of capital investment may occur due to sudden fire.
6. Insurance Status: The status of the insurance will infer the capacity or resilience of the mass to any sudden event of a fire.

The six chosen socio-economic parameters are evaluated based on the Stakeholder’s Questioner Survey (SQS). The various stakeholder in the buildings and people from building administration should participate in the questioner survey. The socio-economic parameters are evaluated based on the actual value and normalized into the Likert scale (1-5). The selected six parameters along with the special zones of the building can be represented through Space-Socio economic Matrix (SSM) as given in Table 2.

**Risk Assessment Method**

The Rapid Visual Survey (RVS) and the Stakeholder’s Questioner Survey (SQS) will provide normalized Likert points for each building zones. Both the matrixes will show the relative marking against the zones. A T-test is proposed to evaluate the relative importance of the parameters of the two groups. The confidence level may be taken as 90 per cent to screen out the less important parameters. Not all the parameters in the final risk assessment model should have the same weight. Expert opinion surveys are conducted to constitute the parameter weight. The Analytical Hierarchy Process (AHP) method is proposed to assign the respective weight for the parameters. The selected parameters are then multiplied with a weightage factor.

Mathematically, the weight value of a space-physical parameter of each building zones can be defined as

\[ P^j_i \times wp_j \] (1)

Where,

- \( P^j_i \) is the normalized value of \( j^{th} \) physical parameter in \( i^{th} \) building zone
- \( wp_j \) is AHP based weightage factor the \( j^{th} \) physical parameter
Similarly, the weightage value of a space-socio economic parameter of each building zones can be defined as

$$S_k^i \times w_{sk}$$

Where,

$S_k^i$ is the normalized value of $k^{th}$ socio economic parameter in $i^{th}$ building zone

$w_{sk}$ is AHP based weightage factor the $k^{th}$ socio-economic parameter

If it is considered that, there are total ‘nz’ numbers of building zones, ‘np’ numbers of physical parameters and ‘ns’ numbers socio-economic parameters. Following two more relationships can be made out of those numbers. The Space-Physical Risk Factor (SPRF) is defined as the weighted sum score of all the physical parameter under any specific zone. It can be expressed mathematically as

$$SPRF_i = \sum_{j=1}^{np} P_{ij} \times w_{pj}$$

Similarly, the Space-Socio economic Risk Factor (SSRF) is defined as the weighted sum score of all the socio-economic parameter under any specific zone. It can be expressed mathematically as

$$SSRF_i = \sum_{k=1}^{ns} S_{ik} \times w_{sk}$$

Table 1. Space-Physical matrix (SPM) and Space-Physical Risk Factor (SPRF) evaluation

<table>
<thead>
<tr>
<th>Physical Parameter</th>
<th>Weightage Factor</th>
<th>$z_1$</th>
<th>$z_2$</th>
<th>$z_{(nz)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>$w_{p1}$</td>
<td>$P_{11} \times w_{p1}$</td>
<td>$P_{21} \times w_{p1}$</td>
<td></td>
</tr>
<tr>
<td>$P_2$</td>
<td>$w_{p2}$</td>
<td>$P_{12} \times w_{p2}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...$P_j$</td>
<td>$w_{pj}$</td>
<td></td>
<td>$P_{ij} \times w_{pj}$</td>
<td></td>
</tr>
<tr>
<td>$P_{(np)}$</td>
<td>$w_{p(np)}$</td>
<td></td>
<td></td>
<td>$P_{(nz)(np)} \times w_{p(np)}$</td>
</tr>
</tbody>
</table>

Space-Physical Risk Factor (SPRF) = Sum of all columns (refer Eq. 3)

Table 2. Socio economic Matrix (SSM) and Space-Socio economic Risk Factor (SSRF) evaluation

<table>
<thead>
<tr>
<th>Socio economic Parameter</th>
<th>Weightage Factor</th>
<th>$z_1$</th>
<th>$z_2$</th>
<th>$z_{(nz)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>$w_{s1}$</td>
<td>$S_{11} \times w_{s1}$</td>
<td>$S_{21} \times w_{s1}$</td>
<td></td>
</tr>
<tr>
<td>$S_2$</td>
<td>$w_{s2}$</td>
<td>$S_{12} \times w_{s2}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...$S_j$</td>
<td>$w_{sj}$</td>
<td></td>
<td>$S_{ij} \times w_{sj}$</td>
<td></td>
</tr>
<tr>
<td>$S_{(ns)}$</td>
<td>$w_{s(ns)}$</td>
<td></td>
<td></td>
<td>$S_{(nz)(ns)} \times w_{s(ns)}$</td>
</tr>
</tbody>
</table>

Space-Socio economic Risk Factor (SSRF) = Sum of all columns (refer Eq. 4)

Finally, the Absolute Zonal Risk Factor (AZRF) is obtained from the square root of the sum of squares of Space-Physical Risk Factor (SPRF) and Space-Socio economic Risk Factor (SSRF). It is a zone-specific index number indicates the level of risk involves due to any fire hazard. The Absolute Zonal Risk Factor (AZRF) index can be utilized to rate the fire risk of any building. The building will be subdivided into many zones within a floor and different floors. It will provide as many AZRF index for total numbers of building zones. It is proposed that the AZRF index for all the building zones can be arranged in a descending (or ascending) order. To assess the overall nature of fire risk of the building following two statistical rules may be applied.

1. The range of the AZRF index of all building zones can be read as the difference between 75 and 25 percentiles of the obtained set value. It will give a clear understanding that the central 50 percentile of the zones fire risk character.
2. The mean AZRF index of all building zones can also be read with the above one to understand the central tendency of the grouped data.

**Conclusion**

Fire is one of the major causes of the destruction of our living and cultural heritage. It has become a common threat to establishments, organizations and individual. Most of the fire hazard related case studies in India reveals that fire occurred due to sheer negligence and building without proper fire preventive system. Many parameters are found responsible for fire phenomenon of the buildings. It makes the control mechanism complex in nature. Type of building, building activities, culture and behaviour of the people, maintenance of the building is few of those parameters. A survey-based assessment tool is proposed to evaluate the fire risk in the building. The Absolute Zonal Risk Factor can be an indication of the risk involved in the building. Further, the building zone wise parametric score can be used to plan the right strategy to improve the resilience to the fire disaster.

**References**


Guidelines for prevention detection and control of fire in archives and libraries, (1993), National archives of India, New Delhi.


