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# Abstract

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*Keywords:* TBD

Title

# Introduction

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# Methods

**Overview**

As implemented in the systematic perspective, WUI fire safety performance is influenced by fire characteristics, weather conditions, vegetation, road access, building, fire protection measurements, etc. For example, the dimensions and design of emergency vehicle access as prescribed requirements by code can ensure enough volume for the transportation of emergency vehicles, like fire trucks and ambulances, and excavation for people. However, the interrelationships among these risk factors are still ambiguous and there are a great number of other factors that cannot be prescribed in the code, like weather conditions and human behaviors.

Based on the aforementioned challenges, the presented paper will adopt a combined technique of qualitative and quantitative methods, namely integrated characteristic interaction models (ICIM) to build a conceptual framework for risk factors and hierarchy methods and weighted sum methods to rank the factors and illustrate the hierarchy of attributes for WUI fire safety performance.

**Quantitative Model**

The aforementioned conceptional framework is helpful to indicate the cause-effect relationships among various characteristics of risk factors in revising the code and aiding the fire safety design solution. However, deeper insight from a quantitative perspective is more practical in governmental decision-making. To this end, a qualitative model is developed to rank the relationship between risk factors and their rankings based on the analytical hierarchy process, weighted sum methods, and other post-processing methods.

To build the quantitative model and reflect the relative importance of characteristics of risk factors illustrated in ICIM, the AHP is used. To the best of our knowledge, AHP is a decision-making technique for multiple factors introduced by Saaty (Saaty, 1990). During the processing of evaluating the relative contribution of lower-level risk factors in a different layer, the contribution of upper levels is quantified by the weighted sum method and eigenvector method(EVM). Due to the nature of the multiple risk factors, this approach is proper for the quantitation of the ICIM and it has been used by other researchers for the fire safety performance assessment in previous studies (Shields & Silcock, 1986) (Meacham, 2000).

In general, AHP can be divided into four steps (Subramanian & Ramanathan, 2012).

1. Reconstruct the ICIM into the decision matrix
2. Form the judgmental matrix from pair-wise comparisons.
3. Determine the local weight and consistency of the judgment matrix
4. Rearrange local weight and calculate final weight with normalization

To be more specific, in step 1, the ICIM model will be broken down into multiple sections, so that the size of the decision matrix is not too large or too small. Different sections can be classified into different categories according to their shared traits and hierarchy if possible. A standard AHP model consisted of three layers namely goal, criteria, and alternatives (Subramanian & Ramanathan, 2012). However, in the presented paper, the layers can be roughly divided into the ultimate goal(life safety and property safety), regulation items, specific items, parameters, and others.

In step 2, the risk factors of the lower layer are compared with the elements of the upper layer. By definition, the collective weight of risk factors in a layer should be added up to 1, which is called the local weight. And this rule applies to the upper level and so as to any layer. Pair-wise comparisons of the elements are made, and ratings on their relative attractiveness are recorded using a rating scale (1–9 scale in traditional AHP). Typically, an entry with a higher value of rate is thought to contribute more to (or more attractive than) an entry with a lower rating. The weight or relative importance of different risk factors can simply be assigned by experts or derived from interviews with local authorities, which is widely applied by researchers (Brzezinska & Bryant, 2021). In the present study, the weight of risk factors will also take the frequency of specific risk factors in WUI fire incidents reports to reduce the subjectivity.

In step 3, local weights will be calculated by the eigenvector methods (EVM). Technical details will be introduced in the example later. Then, we need a consistent test. Pair-wise comparison, which is usually made by experts, reflects the relative importance of factors and thus is used by AHP to quantify the weight factor. However, if the matrix is not consistent, indicating that there is something wrong with the pair-wise comparison, step 2 should be repeated until the consistency test is passed. However, it is worth noting that the criteria CR<0.1 is given by Saaty (Saaty, 1990) as a rule of thumb. Scientists are not sure whether the consistency test is useful or whether the given CR criteria are valid.

In the final step, the final weights of the choice alternatives (entries at the lowest level) are determined by averaging the local weights of the elements at various levels as described in Step 3 once they have been obtained. The following hierarchical (arithmetic) aggregation rule, for instance, is used to determine the final weight of alternative L1. Since the weight is normalized, the final weight could be computed from the general weight and the local weight, which represents the contribution and the local contribution to the higher levels.

To indicate the formulation and detailed calculation procedure, an example of the determination of WUI fire risk weight is given below.

According to the International Wildland Urban Interface Code, the safety performance of water supply is influenced by three attributes or characteristics, namely the earthquake, the water resources, and the power system. Assuming each value has an absolute importance value to the safety performance of water supply as in [Table 1](#_Table_1_–), then the relative importance of each element can be driven by the ratio of their weight.

The matrix shows the relative importance of the risk factors can be written as



Right multiplying the importance vector , we then have



Which is similar to the eigenvalue/eigenvector format. Then, it is found that the eigenvector, indicating the relative importance of each risk factor can thus be calculated to show the relative importance of risk factors in a normalized manner.

[Table 2](#Table2) shows how the relative weight between the three contributes to the safety performance of the water supply listed in the IWUIC.

It should be noticed that the construction of the matrix should follow the following three rule.



Where  means the element in the i row and j column of the matrix. The three rules indicate that each element should be larger than 0, the elements of diagonal symmetry are reciprocals of each other, and the elements on the diagonal are 1 for any i. With the three rules, the normalized matrix is able to provide local weights that add up to 1.

The rationales for such relative importance will be discussed below. However, it is noticeable that such rationales are just the researchers’ personal views, and the weighting might be changed by different code interpreters, and it may also be modified over time.

1. Power System versus Water Resources

Both power systems and water resources will influence the safety performance of the water supply in the life safety and property safety of WUI fire. The suppression system will not be able to work if the water supply is insufficient. While the power system, usually equipped with some emergency or secondary power, is more reliable than the water resources. Therefore, it is concluded that water resources are three times more significant than the power system in the safety performance of the water supply.

1. Power System versus Earthquake

Compared with an earthquake, the influence of the potential failure of the power system is much more likely but will result in less significant outcomes. For example, the failure of the power system might be recovered in several minutes or even seconds and will not ruin the water supply system. Not to mention with regular maintenance, the risk to power system can be effectively reduced. However, an earthquake is unpredictable and will damage the water supply system. For this reason, it is concluded that earthquake contributes five times more to the safety performance of water supply.

Based on the reciprocal Matrix listed in [Table 2](#Table2), the corresponding eigenvalue and eigenmatrix can be computed as [Table 3](#Table3). It can be found that the eigenvalue which is closest to the number of elements is 3.0385, indicating that the corresponding eigenvector is what we need, namely the first column, 0.9161, 0.3715, 0.1506. Then, the local weight can be computed by the formula below and the results are shown in [Table 4.](#Table4)



Then, the local weights of each risk factor under the lower layer are reconstructed, and their relative importance is represented by the local weights.

To reduce the subjectivity and to ensure the consistency of the local weight, a consistency test should be made (Leung & Cao, 2000).

First, the coefficient of consistency is defined by (Saaty, 1990) as  where the  is the max eigenvalue in [Table 3](#Table3).

In the given example, .

Where RI is the consistency index from the random matrix given by Saaty. The value of RI can be found in the [Table 5](#Table5), where n is the number of risk factors in the matrix.

So the reciprocal matrix in the given example is consistent. However, if the CR is larger than 0,1, then we should go back to step 2 of AHP to revise the local contributions to the upper level until the consistent test is passed.

However, for further application, a weighted term called performance (Park, Meacham, & Dembsey, 2013) value should be taken into consideration before the quantitative model can be utilized.

It should be noted that the ICIM and the quantitative model diagrams serve different objectives: the former for the holistic understanding of the building performance during fires and the latter for the quantitative performance evaluation.

# Results

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# Discussion

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# References

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# **Table 1 –** Influencing Variables for WUI Fire Safety Evaluation

|  |  |
| --- | --- |
| Attributes | Weight |
| Power System | w1 |
| Water Resources | w2 |
| Earthquake | w3 |

# Table 2 **–** Example Reciprocal Matrix for WUI Fire Safety Evaluation

|  |  |  |  |
| --- | --- | --- | --- |
|  | Power System | Water Resources | Earthquake |
| Power System | 1 | 3 | 5 |
| Water Resources | 1/3 | 1 | 3 |
| Earthquake | 1/5 | 1/3 | 1 |

# Table 3 – Eigenvalues and Eigenmatrix of the Example

|  |  |  |  |
| --- | --- | --- | --- |
| Eigenvectors | | | Eigenvectors |
| 0.9161 | 0.9161+0i | 0.9161 - 0i | 3.0385 |
| 0.3715 | -0.1857+0.3217i | -0.1857 - 0.3217i | -0.0193+0.3415i |
| 0.1506 | -0.0853-0.1304i | -0.0753 + 0.1304i | -0.0193-0.3415i |

# Table 4 – Local Weights of Contributes to the Water Supply

|  |  |  |  |
| --- | --- | --- | --- |
|  | Power System | Water Resources | Earthquake |
| Local Weight | 0.637 | 0.258 | 0.105 |

# Table 5 – Random Consistency Index

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

# Figure 1.Title