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Developing a conceptual framework to quantitatively assess WUI fire risk based on code requirements and safety guides

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Author Note

A thank you note (optional).

# Abstract

In the present paper, we propose the use of the Integrated Characteristic Interaction Model (ICIM) and Analytical Hierarchy Process (AHP) to build an evaluation framework for the risk factors of the Wildland Urban Interface (WUI) fire from code and safety guide. The ultimate goal of our research is to aid the government decision-making on the prevention of and protection of WUI fire, with a focus on life safety performance and property safety performance. While ICIM and AHP have been utilized in the evaluation of fire safety performance, seldom research can be found in WUI fire. So the conceptual framework will be built based on the ICIM derived from code and safety code through grounded theory and content analysis, followed by the AHP which builds quantitative relationships. While ICIM and AHP have been used in the assessment of fire safety performance, its application on WUI fire research is rare. So the conceptual framework will be built based on the ICIM derived from code and safety code through grounded theory and content analysis, followed by the AHP which builds quantitative relationships. With the framework, a quantitative model utilizing the conditional probability and Bayesian network, which are frequently used in AHP, will be provided as a tool to assist in the development of national fire safety design solutions for WUI fire and to help with decision-making at the government levels.

*Keywords:* TBD

Title

# Introduction

1. Move 1:
   1. Step 1: (15%)
      1. This study will use Ground theory and (Analytic Hierarchical Process) to find relationships between risk factors for WUI fires from the International Wildland-Urban Interface Code (IWUIC) and the Safety Guide. Even though these factors have been mentioned by previous authors in their articles, the interactions between the factors have not been studied in detail. Exploring the relationship between the factors influencing WUI Fire can help improve the wildfire prevention capability of communities at the wild-urban interface with the orientation of protecting life safety and property safety.
      2. The factors affecting WUI fires are complex and there is an urgent need to review the state of research on WUI fires in order to provide scientific guidance for research and mitigation of WUI fires (Zong & Tian, 2022). The analysis of risk factors based on the IWUIC Code and safety guidance will facilitate future research on how to reduce the damage caused by WUI Fire.
   2. Step 2: (85%)
      1. Previous studies of the application of AHP in fire safety
         1. Park et al developed conceptual model for building fire safety performance analysis (Park, Meacham, & Dembsey, Conceptual Model Development for Holistic Building Fire Safety Performance Analysis, 2015). They build two conceptual models including a generic fire response model and an integrated characteristic interaction one using content analysis and AHP. Their work helps the decision making process in fire safety design solutions.
         2. To the best of our knowledge, Shields and Silcock were the first group of researchers to adapt the hierarchical approach to fire safety (Shields & Silcock, 1986). They investigated the mutual dependence of the various components and factors with the AHP and Delphi Technique. They quantify the parameters and interpret the requirements. Their work showed the possibility of applying AHP in fire safety.
         3. After Shields’ seminal work, a similar idea called Fire Risk Rating Schedules (FRRS) was raised by Watts in the modeling and scoring fire hazard (Waatts, 1992). This model is a heuristic model and a rapid and simple estimation of relative relationships between risks might be developed. He also gave some examples and develop a more rational and consistent approach in risk rating schedules.
         4. After Park’s work, there are also lots of derivative works on the application of AHP in fire safety
         5. Application of AHP on the upgrading of the fire safety level of hotels had been excavated (Chen, Chuang, Lin, & Chien, 2011). They built a simple fire safety evaluation for existing hotels with an empirical evaluation. They systems help the owner improving fire safety managements measures on existing buildings.
         6. Apart from the standard AHP, other variants, for example the buzzy-based AHP, is also used in fire safety assessment (Öksüz & Tanyer, 2022). They built a fire vulnerability evaluation model with the influence of architects on fire protection and building design characteristics with a fuzzy decision-making methodology. Their results ensures the effectiveness of the model in detecting and visualizing the vulnerability source.
         7. Similar to our study in the present paper, the framework for fire safety management had be build by (Jaafar, et al., 2021). Based on their interviews and observations in five selected public hospitals, they developed the framework of fire safety management plan (FSMP), and they reported the three main parameters promoting the fire safety program.
         8. The study of WUI fires, and how to potentially reduce the damage caused by them, is lagging far behind in the field of fire safety science (Manzello & et al, 2018).
         9. As mentioned in previous research, there are also various vulnerabilities within the WUI community that often exist and can cause significant challenges during the development of WUI Fire (Kuligowski, 2020). However, few relationships between risk factors were mentioned.
         10. Although many research articles have been published in the research filed of WUI fire safety management, the number of review articles on tis risk reduction is still limited (Ager, Palaiologou, & Evers, 2019).
         11. Decomposing a complex problem into several sub-problems (Manzello & et al, 2018) facilitates the identification of the relationships between the influencing factors.
2. Move 2:
   1. Step 1:
      1. WUI fires aren't just found in the continental United States. It is a problem that China will increasingly have to face as a result of climate warming and rapid urbanization. Regarding WUI fire research, researchers in the United States are the most active groups in WUI fire management, with 507 papers published in the past 30 years, sharing for 70.7% of the total number of papers. However, due to geographical differences, the best way to big a big picture of wildfires is to learn from their histories, as there will be some recurrence in the same place in similar time of a year due to the weather condition, the terrain and etc. Besides, the historical data also help us determine the WUI fire dangerous area and identify the protection area of interest. However, the previous studies in China mainly focused on the evaluation of fire events, and few studies analyzed the fire theory. Therefore, the shortcoming of previous studies on WUI wildfire was exposed: it was only applicable to the specific area studied. This paper will draw lessons from previous studies on wildfire, focus on the theoretical aspects, and find the related risk factors and their connections from the International Fire Code and Safety Guidance through AHP (Analytic hierarchy Process).
3. Move 3:
   1. Step 1:
      1. Purpose: Focus on the theoretical aspects, for wildfire protection, we will build a conceptual framework based on International Fire Codes, Safety Guidance and Safety Guidelines for quantitative analysis, and to find the relative relationship between risk factors and their potential contribution and interaction ways by utilizing AHP or other quantitative tools.
      2. Q  
         How to develop a conceptual framework to quantitatively assess WUI fire risk base on code requirements and safety guidelines
   2. Step 2:
      1. How to build the ICIM model and their quantitative relationship based on the IWUIC code, safety guidelines using the AHP.
      2. To be more specifically, we WUI2 and WUI 4 are going to use the content analysis and grounded theory to derived the contribution map and their interrelationships between factors from code and safety guide.
      3. Then, comparison will be made between the map made by WUI 2 and WUI4
      4. Based on the statistic derived from WUI 1 and WUI3, our framework will be used in practice to verify some simple decision making processes.
   3. Step 4:
      1. Value: Because most of the previous studies are based on local wildfire conditions, However, the development of a conceptual framework for quantitative WUI fire safety assessment can be improved and developed by subsequent researchers on this basis. This study is mainly based on the objective laws of WUI wildfire occurrence, which has a certain guiding role for specific locations. As the climate warms and urbanization increases, the probability of wildfires is increasing every year. Although only studying the local situation has obvious effect for the local area, it consumes serious manpower and financial resources and is not universal. Therefore, this paper starts from the theory is inspired by WUI Fire Code, and finds out related risk factors and connections through the AHP research method. By normalizing the special events as much as possible, it is hoped that the subsequent wildfire research period will be shortened, and the cost of manpower and money will be reduced.

# Methods

1. Move 1: Overview
   * + - 1. Grounded Theory

What is grounded theory

A qualitative research method that aims to understand the significance of subjects' behavioral patterns, occurrences, and interactions.

To develop concepts, researchers gather data using any method and then analyze the information.

Through a comparison of these concepts, the plan theories, continue until they reach sample saturation, in which no new information upsets the theory they have formulated.

The grounded theory, on the other hand, does not presuppose that an event, thing, or concept has just one meaning. In grounded theory, all data are interpreted as facts or materials that fall into the categories that your research team develops.

How to conduct grounded theory research

Concepts or specific technical terms should be derived from interviews, observations, and reflection or any other peer-reviewed materials, either by directly quotation or self-interpretation.

Data, or its relating information like its frequency or other statistics, should be classified or recorded into categories with a similar topic or subject to certain rules.

Comparison of the categories derived from different researchers should be compared to reduce the subjectivity, and help building well-established categories.

The overall outcome of grounded theory might be either a construction of a new research hypothesis or some conceptual map or framework.

Common features of grounded theory

Coding

Codes are the cornerstone of grounded theory. These are phrases used to describe the importance of a phenomenon. They are recorded via observations, interviews, and other kinds of information. The codes can be discovered by looking for common themes in a particular event or in a larger population. Following the creation of the codes, the researcher must choose the concepts that shall symbolize each code.

Theoretical Memoing

Internal data organization, idea development, and research validity testing are taking place at this time. The researcher must be well-versed in their theoretical position before performing this. Effective ways of theorizing include looking at a convincing theory or analysis that already exists and attempting to identify their relationships.

Compile Findings

After a theory has been derived from the data, the last stage is to write up the results. The results of the investigation can also be used to create a working hypothesis.

* + - 1. Move 3
         1. To build the qualitative integrated characteristic interaction mode (ICIM) from the IWUIC and Safety Guidance to determine the WUI fire contributed risk factors and their links, and then use AHP to quantify them.
      2. Move 4:
         1. Step 1: Indicating source of data

2021 version of International Wildland-Urban Interface Code International Code Council

Wildland-Urban Interface fire safety guides from International Association of Fire Chiefs, U.S. Fire Administration and Ready, Set, Go!

* + - * 1. Step 2:

One code and nine Safety Guidance

* + - * 1. Step 4:

Read the International Wildland-Urban Interface Code and guidance word by word and [extract](javascript:;) contributed factors of WUI fire and build their relationships through the ground theory.

* + - * 1. Step 5:

The International Wildland-Urban Interface Code uses prescriptive and performance-related elements to set minimum standards for land use and the built environment in designated wildland-urban interface zones. It is based on information gathered from experiments, fire events, technical reports, and international mitigation tactics. (INTERNATIONAL CODE COUNCIL. & International Code Council, 2020)

* + - 1. Move 5 Procedures
         1. Development of Integrated Characteristic Interaction Model (ICIM)

To build our ICIM ([Fig. 1](#_Figure_1.Draft_of)), we need to read the IWUIC code 2021 edition and some safety guides words by words and highlight the requirements. The model is built by the factors called performance attribute which could be an influence of WUI fire such as mean of egress, fire spread, driveway access and so on. Our purpose of doing this project is to consider the life safety and property protection of WUI fire. Therefore, our top-level factor are life safety and property protection.

When the top-level factors are identified, we need to consider the subfactors. For example, “Driveways shall provide a minimum unobstructed width of 12 feet (3658 mm) and a minimum unobstructed height of 13 feet 6 inches (4115 mm).” (IWUIC, 2021). The relationship between factors is the performance of factor A is influenced by factor B. Therefore, the factors can be determined as “driveway” and “the length and height of obstruction”, because when the length and height of obstruction are not eligible, the performance of driveway could be limited.

For this teamwork project, we should not only read and analysis by individual, we should hold a meeting to discuss the relationship because individual analysis is difficult to avoid subjectivity. When our team has determined the final factors by discussion and asked for the advisor. Then, the factor is considered effective. When encountered some incomprehensible terminologies, we should google them and read some other resources to explain them.

Figure 1. Integrated Characteristic Interaction Model (ICIM), this is a semi-finished product. We need to revise it over and over again.

* 1. Development of Quantification Method: Analytic Hierarchy Process (AHP)

An AHP method is used to reveal the relative importance of performance attributes with the ICIM in Figure 1. The AHP is a method for organizing and analyzing the complex decision, using math and psychology, which was developed by Thomas (Thomas, 1990).

Here we would introduce the methods listed in [Subramanian et al, “A review of applications of Analytic Hierarchy Process in operations management” Int. J. Production Economics, 138 (2012) 215-241]. They use a four-step AHP procedure.

Step 1 Reconstruct the decision matrix into a hierarchical model

It involves breaking down the decision problem into components based on their shared traits and creating a hierarchical model with several levels. Goal, criteria, and alternatives make up the three levels of a straightforward AHP model (Fig. 2), while more complicated models with more levels could be formulated.

Step 2 The judgmental matrix should be derived from the pair-wise comparisons with factors.

The risk factors of a certain layer are compared with the entry or factors in the upper level. 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 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.

Each entry  of the judgmental matrix is governed by the three rules



Let  be the entry of i row and j column in the judgmental matrix, then each  should satisfy the above rules. Which is that, each element should larger than 0, the elements on the diagonal line should be 1, and the symmetrical elements should have a production of 1.

However, if the number of risk factor in a layer is large, AHP might require much more extra judgements. As the number of comparison increase with the square number of n.

Step 3 Determination of local weight and the consistency test.

Local weights should be calculated by the eigenvector method (EVM)

Here is a simple example of randomly picked number to show how the EVM and AHP works in order that the reader can have a better understanding of our methodology.

Assuming that we have got a judgmental matrix from Step 2, which is 

We should first calculate the weight for each row of elements

Calculate the product of the elements in each row  where i=1,2,3, … n

Here n mean the number of the factors that use in this judgmental matrix. In the given example, the n would be 6, just as the number of rows and columns.

Calculate the n power root of  we have 

Normalizing the vectors





So  is the required eigenvector

In the given case, the judgmental matrix should be 

Now let’s do the consistency test

Define the coefficient of consistency as where 

In this case, the maximum eigenvalue is 

Substitute in the consistency test, we have 

So CR<0.1, the judgmental matrix is consistent

Pair-wise comparison, which is usually made by experts, reflects the relatively importance of factors, 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 pasted.

However, it is worth noting that the criteria CR<0.1 is given by Saaty (Thomas, 1990) as a rule of thumb. Scientists are not sure whether the consistency test is useful or whether the given CR criteria is valid.

Step 4 Rearrange of local weight and calculation of final weight, with normalization.

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.

1. Limitations
   1. Grounded theory
      1. With grounded theory, consensus might not always be able to achieved. As there is always conflicting interpretation and understanding between scholars, and none of them can persuade others.
      2. Grounded theory is so theorical that one argues whether it has some real applications. And grounded theory can not tell a hypothesis is true or false.
      3. Grounded theory along does not raise any new idea and solution. It has to be combined with other tools and methods to be practical in engineering or real questions.
   2. AHP
      1. Where the number of the elements in AHP is large, the workload might be soaring, since to get the n rank, people have to compare  times
      2. All the weight must be a positive value, while in some engineering practices, there are indeed some behaviors that would harm the final goal
      3. Lack of application and theory on the circumstances where there are quantitative and qualitative factors at the same time.
      4. AHP can only select the “best” approval from the given approvals, it cannot produce any new ideas
      5. AHP did not take the relationships for elements at different levels.

# Results

Text

# Discussion

Text

# References

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# **Table 1 –** Title

# Figure 1.Draft of the ICIM model

图示

描述已自动生成