The Assessment of Modern Community Security Risks in Megacities Based on the Dempster–Shafer Theory

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Abstract: Through the study of community security risks in a megacity by employing the Dempster–Shafer theory, this paper developed an indicator system for the assessment of urban community security based on a combined array of both static and dynamic factors including natural disasters, man-made hazards, community administration and security support. A proper model was thereafter designed. Precluding content inadequacy, insufficient indicators and model inaccuracy and other problems occurred in preceding assessments predicted upon a combination of both static and dynamic factors, these efforts have enabled more effective urban community security assessment through a case study.

1. Introduction

The current urban administration is gradually transiting from community building and single-functional administration to community sharing and co-governance [1]. With comprehensive urban community administration going under way, however, risk factors exert an increasingly greater influence on the effectiveness of community governance [2]. Therefore, it is necessary to develop an assessment system for security risks in an urban community, especially in a megacity’s community.

2. Literature Review

Existing literatures on the assessment of urban community security risks can be roughly divided into two categories: The first category focuses on the formulation of the indicator system for community security assessment. For example, Du C [3] designed indicators for assessment through questionnaires, and divided them into internal and external ones. Mi H [4] assessed the risks of disasters to urban areas based on the AHP. Indicators for risk assessment were prioritized according to damages caused by disasters and the vulnerability and fragility of disaster stricken victims. The second category relates to the formulation of an assessment model for the overall risk of community security, and the analysis of current risks to urban community security based on this model. For example, Jia N [5] proposed a triangle model for community risk prevention, analyzed the triangle model from three aspects and provided a case study.

These aforementioned studies mainly focus on one-dimensional analysis, tracking and prevention of community risks without an in-depth analysis of complex issues such as the diversity and even repetitiveness of security risk sources in a megacity’s communities. By referencing existing assessment models and quantitative methods we summarized, we comprehensively analyzed the content composition of community security risk assessment according to different levels of community security risks in megacities, and proposed a method for the assessment of risks faced by a security system based on
the AHP and the Dempster–Shafer theory to minimize the subjectivity and one-sidedness of traditional assessment based on the opinions of experts.

3. Determining the Indicators for Community Security Risk Assessment in Megacities

3.1 Research Objects
As far as community security is concerned, it usually includes: safety in production and everyday life, safety in recreational activities, medical safety, water safety, food safety, traffic safety, environmental safety and school safety. Given there is a need for the timely evaluation of these security risks, we should start with the analysis of the community’s security level and the degree of exposure to risks for its members and property and promptly make suggested improvements to effectively preclude losses and negative influences. In addition, urban community public security and multiple related terms, such as community public order, safe community and disaster reduction community, have certain similarity in meanings and overlapped functional areas [6]. Based on the above analysis, it is believed that the security risks faced by megacity communities mainly derive from natural disasters, accidents, public health incidents, and social security incidents, posing threats to production safety, fire safety, traffic safety, social security, and public security.

3.2 The Indicator System for the Assessment of Community Security Risks in Megacities
Since urban community public security involves many community infrastructures and soft infrastructures, objective factors, and residents’ feelings, based on previous studies [7,8,9] in social public security and safe communities as well as our previous findings, we classified a number of indicators that are objectively inter-related and reflect the characteristics of community public security, and formulated four first-level indicators (natural disasters, man-made hazards, community administration and security support) with 16 second-level indicators. Details are shown in Table 1.

| First-level indicator | Second-level Indicator          |
|-----------------------|--------------------------------|
| Natural Disasters     | Storm and Blizzards Earthquakes and Volcanoes Floods and Mudslides |
|                       | Crimes Food and Drug Safety Community-wide Diseases Terrorist Attacks Fire Accidents Children and Elders’ Safety |
| Man-made Hazards      | Security Personnel Management Security Equipment Management Relationships between Residents and the Police Resident Turnover Rate Supporting Facilities Management Relations among Community Residents Development of Community Emergency Plans |
| Community Administration and Security Support | |

3.2.1 Natural Disasters
Factors taken into account here are main natural disasters occurring in urban communities, including severe weather disasters represented by storms and snowstorms, severe geological disasters represented by earthquakes and volcanoes, and derivative disasters caused by natural disasters, such as floods and mudslides.
3.2.2 Man-made Hazards
Man-made hazards mainly refer to community security risks caused by people in the city. Community crimes include crimes such as robbery and theft in the community; food and drug safety refers to threats to community security caused by food, water pollution and drug abuse; community diseases are community-wide health and safety issues caused by infectious diseases. Terrorist attacks are also seen as an independent indicator for security as they periodically take place in the last decade; fire accidents refer to fire conflagration caused by the use of electricity, gas, and arson, or the resulted casualties and property losses; children and elders’ safety refers to accidents happening to children and the elderly people in the community.

3.2.3 Community Administration and Security Support
Community administration and security support are factors summarized from the information on security managers, equipment and residents in the community. Security personnel, security equipment and supporting facility management refers to the management and maintenance of existing manpower, and physical and technical defences; the relationships between residents and the police reflects the degree of residents’ trust in the police; resident turnover rate and relations among residents represent the degree of satisfaction of community residents with community security; and the community emergency plan represents the capabilities of the community to tackle emergencies.

4. The Assessment Model Based on the Dempster–Shafer Theory

4.1. The Dempster–Shafer Theory
The concept of evidential reasoning was first proposed by Dempster in 1967 and was further expanded and improved by Shafer to make it systematized and complete to become a theory usually known as the Dempster–Shafer theory, which can be used for uncertain, vague and inaccurate information. Due to the uncertainty of community security risk assessment, the Dempster–Shafer theory is applicable in our study[10].

(1) Frame of Discernment: $\Theta$ is a complete set of disjoint events, which can be expressed as: $\Theta = \{\Theta_1, \Theta_2, \Theta_3, \cdots, \Theta_N\}$

(2) Dempster’s Rule of Combination
Dempster’s rule of combination refers to the orthogonal sum of two or more mass assignments, which represents the interaction between evidence.

Dempster’s rule of combination for multiple mass functions: Assuming that there are n mass functions ($m_1$, $m_2$, ..., $m_n$) under the frame of discernment $\Theta$, and the focal elements are $A_i$ ($i=1, 2, ..., n$), the rule of combination is as follows:

$$m(A) = \left\{ \begin{array}{ll} \sum_{\cap A_i = A} \Pi_{1 \leq i \leq n} m_i(A_i) & A \neq \emptyset \\ 0 & A = \emptyset \end{array} \right. \quad (1)$$

Where,

$$K = \sum_{\cap A_i = \emptyset} \Pi_{1 \leq i \leq n} m_i(A_i) \quad (2)$$

Where, $1/(1 - K)$ is called the regularization factor. When $K$ is 0, the evidence sets are completely the same; when $K$ is 1, evidence sets completely contradict one another, and the rule of combination is thus not applicable.

4.2 The Model for the Assessment of Urban Community Security Risks
The assessment begins by determining the degree of belief for indicators at the lowest level concerning the assessment target with the help of experts, followed by the calculation of each indicator’s basic probability assignment. Then the rule of combination is repeatedly applied to each hierarchy’s data before yielding the quantitative value of urban community security risks. Details are as follows:
4.2.1 Defining the set of assessment levels.
According to the standard for the assessment of community security risks and with reference to commonly used classification methods, we divide the security level into five categories, namely $V = \{ (V_1), (V_2), (V_3), (V_4), (V_5) \}$ = {dangerous, relatively dangerous, general, relatively safe, safe}, and denote $(V_i) = \{ p(V_1), p(V_2), p(V_3), p(V_4), p(V_5) \}$ as the assessment value of the comment set obtained from fuzzy quantitative analysis. Since most of indicators for the assessment of community safety are qualitative indicators and cannot be directly quantified, they need to be transformed into quantitative indicators. The classification of scoring levels can facilitate the quantification of qualitative indicators, and each level corresponds to an interval of values, as shown in Table 2.

Table 2. Assessment Levels.

| Interval       | Level         | Level         | Level         | Level         |
|----------------|---------------|---------------|---------------|---------------|
| $0 \leq \tau \leq 2$ | Dangerous     | Relatively Dangerous | General       | Relatively Safe | Safe |
| $2 < \tau \leq 4$      |               |               |               |               |
| $4 < \tau \leq 6$      |               |               |               |               |
| $6 < \tau \leq 8$      |               |               |               |               |
| $8 < \tau \leq 10$     |               |               |               |               |

4.2.2 Issuing questionnaires to experts to gather their opinions.
We invited expert to qualitatively comment on the indicators at the lowest level in the indicator system, and transform their opinions into quantitative values.

4.2.3 Comprehensively processing the opinions of experts.
Considering the differences in the knowledge and experience of each expert and the influence of subjectivity, it is necessary to quantitatively modify their belief assignments. By denoting the weights of n experts as $\{ \omega_1, \omega_2, \cdots, \omega_n \}$ $\sum_{i=1}^{n} \omega_i = 1$, the indicator with the largest weight in each comment set as the key indicator (its index weight as $\omega_{max}$), and others indicator as general indicators, we obtain the basic belief assignment as follows:

$$m(A_{ij}) = \frac{\omega_{ij}}{\omega_{max}} \times \varepsilon \times m(A_{ij})$$ (3)

Where, $\varepsilon$ is a coefficient reflecting the experience and preferences of experts, which is generally set as $0.9 \leq \varepsilon \leq 1$. 0.9 is used in this paper.

4.2.4 Dempster’s rule of combination
Formula 1 is used to fuse all indicators at the lowest level, followed by the repeated calculation of the belief assignment of upper-level indicators until we calculate the belief assignment of the entire system.

4.2.5 Calculating the comprehensive risk value $\tau$ for community security.

$$\tau = \sum_{i=1}^{5} m p(V_i)$$ (4)

5. Model Application in a Megacity
Our case is a community in Nanjing which contains three closed residential quarters. Since this community has many rental apartments with a versatile range of residents, its current security risks are representative of those of modern urban communities. According to the indicator system, the assessment model and the calculation method mentioned above, we made the following analysis.

After calculating the weight vector of indicators of each level through the AHP and conducting consistency verification, we obtain the weight of each indicator as shown in Table 3.

Table 3. The Weights of Indicators for Community Security Risk Assessment.

| First-Level Indicator | Weight | Second-level Indicator | Weight |
|-----------------------|--------|------------------------|--------|
| $B_1$                 | 0.3796 | $B_{11}$               | 0.3572 |
Five experts with respective weights of \{0.18, 0.25, 0.22, 0.16, 0.19\} were organized to assess each indicator based on the indicator system for community security risk assessment above, and provide their opinions on all second-level indicators. An example is listed in Table 4 to show the opinions given by 5 experts on the indicator $B_{21}$.

We calculate the assignments of each expert for $B_{21}$ according to formula 3, and then obtain the belief assignments for $B_{21}$ based on Dempster's rule of combination (Formula 1), as shown in Table 5.

Similarly, we calculate the belief assignments for second-level indicators. Based on the data in Table 4 and the weights of the second-level indicators, we employ Formula 3 to normalize second-level indicators, and then Dempster's rule of combination (Formula 1) to obtain the belief assignments of the first-level indicator $B_1$, $B_2$, $B_3$.

Similarly, based on the belief assignments for and the weights of first-level indicators, we employ Formula 3 to normalize the first-level indicators, and then Dempster's rule of combination (Formula 1) to obtain the belief assignments of the entire system, as shown in Table 6.
Based on calculations, it can be seen that the belief assignment is 0 for \( V_1 \), 0 for \( V_2 \), 0.7428 for \( V_3 \), and 0.2571 for \( V_4 \) and 0.0002 for \( V_5 \). The security level of the entire system is calculated based on Formula 4:

\[
\tau = \sum_{i=1}^{5} mp(V_i) = 0 \times 2 + 0 \times 4 + 0.7428 \times 6 + 0.2571 \times 8 + 0.0002 \times 10 = 6.5148
\]

The indicator for community security risks \( \tau \) is 6.5148, which means the assessment outcome for security risks of this community is "relatively safe" according to Table 2.

6. Conclusions
During the assessment of community security risks in a megacity by employing the Dempster–Shafer theory, we summarized key factors influencing urban community security risks; improved the contents of community security risks assessment; developed an indicator system for the assessment of urban community security based on a combined array of both static and dynamic factors including natural disasters, man-made hazards, community administration and security support; and designed a proper model. Precluding content inadequacy, insufficient indicators and model inaccuracy and other problems occurred in preceding assessments predicted upon a combination of both static and dynamic factors, these efforts have enabled more effective urban community security assessment through a case study.

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