Risk Decision Analysis Method for Emergency Response Based on Co-occurrence Network and Prospect Theory

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Abstract. From the point of co-occurrence analysis, the article uses theme search to identify a collection of emergencies, which selected from about 70 years of research literature in China Journal full-text database and Web of Science database between 1959 and 2012. Through analysing the frequency of emergencies, the article builds a co-occurrence matrix, creates an emergency network according to co-occurrence rate between emergencies, and identifies a number of hidden disaster chains within the emergency network model. Secondly, losses occur due to the intervention of decision markers, and the feeling of psychological and the weight of possible scenarios are described using the theory of prospect. According to the values, weights and alternative costs, the overall prospect value of each alternative is calculated to determine the rank of schemes. Finally, the analogy simulation is given to illustrate the feasibility and validity of the emergency network and the proposed method.

1. Introduction

Such as Indian Ocean Tsunami, earthquake in Japan and extreme weather, have taken place frequently all over the world. Furthermore, the secondary and derivative disaster results in more losses than the natural disasters themselves does. Due to the complexity, uncertainty, serious social panic and danger of the emergencies, the governments and organizations have difficulty coping with them.

On the research of emergency evolution, spread and management, Stallings and Quarantelli [1] studied the influences of pre-disaster, in-disaster and post-disaster based on the time series of disaster evolution. Turner [2,3] thought the evolution process of disasters generally has the above cycle, and different stages have different measures in disaster mitigation, and attributed the cause of disasters to the theoretical start point of the events instead of giving deep analysis of the early-stage events. Ibrahim and Razi model [4] is the fruit of research report into 7 disasters in Malaysia between 1968 and 2002. Callon [5,6] studied the theoretical basis and research examples of co-occurrence analysis method by analysing the role literatures. Clemens [7] applied co-occurrence analysis method to transportation, which broke the limitation of traditional use of co-word theory in analysing disciplinary thematic structure and development. Ulrich Schmidt, Chris and Robert [8] proposed that when decision weight is specified as order dependency, reference point can be uncertain, and proposed the third generation prospect theory, in which the reference point can be changed instead of being fixed.

According to the above literature, this paper takes emergencies as its search topic and retrieving object and constructs the emergency network through co-occurrence matrix in the two databases: SCIE and CNKI. In addition, it gives quantitative description of comprehensive psychological perception of policy makers in different environments based on prospect theory and makes selection of emergency plans based on comprehensive prospect values.
2. Co-occurrence Network

When the features of emergencies are analysed, it is very important to use relevant theory to build the evolution model of communication network and analyse this model, in order to study the development of emergencies and the inner mechanism of spread.

2.1. Co-occurrence Matrix

In this paper, all the data, obtained from 200,000 articles between 1945 and 2012, comes from Science Citation Index Expanded (SCIE) and Chinese Journal Full-text Database (CNKI). Through full-text retrieval, this paper uses topic search, including title, abstract and keywords. 200,000 pieces of data is processed, and 168,689 pieces of data obtain to build the original database of the text. As the selection of keywords, this paper, comparing Chinese with English, selects 57 related keywords (Table 1).

Table 1. The Co-occurrence Matrix (partial) of Emergency.

| Storm | Drought | Snow | Mudslide | Collapse | Earthquake | Epidemic | Fire | Explosions | Communication | Power Accident | Traffic |
|-------|---------|------|----------|----------|-------------|----------|------|------------|----------------|----------------|---------|
| 9884  | 401     | 31   | 411      | 141      | 313         | 7        | 44   | 12         | 20             | 246            | 574     |
| 401   | 63096   | 37   | 140      | 371      | 286         | 65       | 270  | 12         | 6              | 275            | 544     |
| 31    | 37      | 1075 | 19       | 15       | 127         | 1        | 15   | 1          | 10             | 31             | 40      |
| 411   | 140     | 19   | 5622     | 642      | 729         | 1        | 23   | 15         | 9              | 44             | 114     |
| 141   | 371     | 15   | 642      | 163662   | 3424        | 49       | 348  | 1238       | 19             | 1902           | 757     |
| 313   | 286     | 127  | 729      | 3424     | 129349      | 84       | 1156 | 1215       | 168            | 1930           | 1442    |
| 7     | 65      | 1    | 49       | 84       | 76209       | 14       | 10   | 427        | 230            |                |         |
| 44    | 270     | 15   | 23       | 348      | 1156        | 14       | 100489| 4268       | 135            | 2579           | 899     |
| 12    | 12      | 1    | 15       | 1238     | 1215        | 10       | 4268 | 50234      | 89             | 1340           | 627     |
| 20    | 6       | 10   | 9        | 19       | 168         | 1        | 135  | 89         | 1691           | 897            | 1725    |
| 246   | 275     | 31   | 44       | 1902     | 1930        | 427      | 2579 | 1340       | 897            | 435163         | 10055   |
| 574   | 544     | 40   | 114      | 757      | 1442        | 230      | 899  | 627        | 1725           | 10055          | 153755  |

As seen, the data shows the existing research literature in a sort of emergency, and the data on other location shows the number of the articles when the two emergencies are in the same literature. Taking when-chuan earthquake as an example, the rainstorm blocked rescue workers’ entrance, landslides and collapse caused barrier lakes, mountain collapse led to traffic disruption and 30-hour communication interruption. This verifies the feasibility of co-occurrence theory in building emergency network.

2.2. Formatting author names

In co-occurrence network of emergency, co-occurrence matrix can reflect the co-occurrence frequency of every two subject terms. Because the frequency of one search term is much greater than the co-occurrence frequency of two terms. In order to eliminate the negative effect of this kind of deviation on data process and emergency decision-making, it normalizes Jaccard index.

\[ J_{ij} = \frac{J_{ij} - J_{\text{min}}}{J_{\text{max}} - J_{\text{min}}} \] (1)

The top 20 is shown in Table 2. The co-occurrence rate of railway accidents and communication incidents is 1, indicating that there is a strong correlation between them. Policy makers should focus on the role communication system plays in emergency. From the analysis of co-occurrence matrix, these unexpected events show in the form of network, in which every event works as a node. The emergency association network shows in figure 1 using the Pajek. If the contribution rate of two events is greater than 0, these two nodes will be connected. The degree of network nodes is the number of edges connected by nodes, which can reflect the important role.
Table 2. The Co-occurrence rate (partial) of Emergency.

| List | Emergency i     | Emergency j     | Co-occurrence Rate | List | Emergency i      | Emergency j     | Co-occurrence Rate |
|------|-----------------|-----------------|--------------------|------|------------------|------------------|--------------------|
| 1    | Railway Accident| Communication   | 1                  | 11   | Hurricane         | Typhoon          | 0.2846             |
| 2    | Tropical Cyclone| Typhoon         | 0.8773             | 12   | Earthquake       | Tsunami          | 0.2646             |
| 3    | Tropical Cyclone| Hurricane       | 0.8178             | 13   | Fire             | Explosions       | 0.2630             |
| 4    | Coast           | Mudslide        | 0.6551             | 14   | Storm            | Flash Flood      | 0.2457             |
| 5    | Food Accident   | Medical Accident| 0.5412             | 15   | Drought          | Soil Accident    | 0.2281             |
| 6    | Storm           | Typhoon         | 0.4733             | 16   | Earthquake       | Building Accident| 0.2137             |
| 7    | Epidemic        | Medical Accident| 0.4482             | 17   | Tornado          | Hailstone        | 0.2002             |
| 8    | Storm           | Flood           | 0.4387             | 18   | Landslip         | Building Accident| 0.1997             |
| 9    | Traffic         | Subway Accident | 0.4265             | 19   | Coast            | Earthquake       | 0.1840             |
| 10   | Flash Flood     | Mudslide        | 0.3136             | 20   | Storm            | Coast            | 0.1772             |

The greater the degree of node is the more important relationship between the emergency represented by this node and other emergencies. All these are natural disasters, indicating that the emergencies represented by these nodes have a close relation with other emergencies.
3. Comprehensive Prospect of Emergencies
Due to uncertain changes of emergency and risk decision methods, there may be an unreasonable result of decision-making analysis, lacking the consideration of decision-makers’ behaviour characteristics (reference dependence, loss aversion, diminishing sensitivity and probability judgment distortion etc.). So this takes the risk decision method of prospect theory.

3.1. Formatting the title Comprehensive Value of Emergency
Due to the psychological characteristics of decision-makers’ reference dependence, that is, decision-makers regard results as gains or losses of reference point, decision-makers make estimation interval of emergency as $\left[ x_j^L, x_j^U \right]$, while the gain or loss value between result and reference value $x_j$ is

$$ [e_j^L, e_j^U, e_j^0] = [x_j^L, x_j^U, x_j^0]$$

$x_j^L > 0$ is that $S_j$ is greater than the reference value, because makers take more positive measures and make thorough preparations for secondary and derivative disasters. The psychological perception is gain. $x_j^U < 0$ is that $S_j$ is smaller, because makers underestimate the impact of the natural disasters and the destruction of the secondary, derivative disasters. The psychological perception is loss.

Disaster level $x_j$ is a random variable of $[x_j^L, x_j^U]$. The evolution function, which including the evolution time $t$, the influence coefficient $r$ and the damage caused by $S_j$ in $x_j$, is

$$ f(x_j, r, t) = 10^{x_j} r e^{\frac{t}{2}} \left( \frac{L_j}{2} \right)^{x_j-1} / \Gamma(2x_j) \tag{2} $$

Based on it, $S_j$ is calculated like this.

$$ \hat{v}_j = \int_0^{x_j^L} v^-(x_j) f(x_j, r, t) dx_j dt + \int_0^{x_j^U} v^+(x_j) f(x_j, r, t) dx_j dt + \int_{x_j^L}^{x_j^U} v^+(x_j) f(x_j, r, t) dx_j dt \tag{3} $$

If $x_j \leq 0$, $v^-(x_j) = -\lambda (-x_j) ^{\beta}$ means the negative estimated the value (loss) of disaster level. If $x_j \geq 0$, $v^+(x_j) = \lambda (x_j) ^{\alpha}$ means the positive estimated the value (gain) of disaster level. $\alpha$ and $\beta$ indicate the extent of concave and convex of value function, and reflect psychological characteristics that decision-makers’ sensitivity to disaster level evaluation is diminishing. $\lambda > 1$ means the loss is more sensitive than gain in level evaluation. In general, $\alpha = 0.89, \beta = 0.92, \lambda = 2.25$.

**Conclusion 1** If policy-makers overestimate or underestimate the disaster level of emergency, the comprehensive value of emergency is reduced, and its speed is faster over time.

3.2. Comprehensive Prospect Value of Emergency
According to the prospect theory, as for the psychological characteristics of probability judgment distortion of policy-makers, $v_1, v_2, \cdots, v_n$ is in descending order,

$$ v_{(1)} \geq v_{(2)} \geq \cdots \geq v_{(k)} \geq 0 \geq v_{(k+1)} \geq \cdots \geq v_{(n)} $$

In which, $v_{(k)}$ indicates the comprehensive value when $v = k$ in $v_1, v_2, \cdots, v_n$. If $k < h$, $v_{(k)} \geq 0$. If $k \geq h + 1$, $v_{(k)} \leq 0$. $\hat{p}_{ij}$ signifies the probability of the representation of $S_i$ and $S_k$, and $\hat{p}_{ij} = 1 - J_{ij}$. So the weight of the policy-makers’ sensing scenarios $S_i$ and $S_k$ can be expressed as,
\[ \pi_{ik} = \begin{cases} 
    w^{+} \left( \sum_{j=1}^{k} p_{y}(J_{y}) \right) - w^{-} \left( \sum_{j=1}^{k-1} p_{y}(J_{y}) \right) & k = 1, 2, \cdots, h \\
    w^{-} \left( \sum_{j=k+1}^{n} p_{y}(J_{y}) \right) - w^{-} \left( \sum_{j=k+1}^{n} p_{y}(J_{y}) \right) & k = h + 1, h + 2, \cdots, n 
\end{cases} \quad i = 1, 2, \cdots, m \quad (4) \]

\[ p_{y} = \frac{\hat{p}_{y}}{\sum_{i} p_{y}}, \quad w^{+} (\cdot) \text{ and } w^{-} (\cdot) \text{ are nonlinear weighting function of respectively gains and losses.} \]

\[ \chi = 0.61, \quad \delta = 0.69, \quad w^{+} (p) = \frac{p^{\chi}}{p^{\chi} + (1 - p)^{\chi}}, \quad w^{-} (p) = \frac{p^{\delta}}{p^{\delta} + (1 - p)^{\delta}}. \]

The expected prospect value of prospect value \( v_{(1)}, v_{(2)}, \cdots, v_{(a)} \) and scene weight \( \pi_{(1)}, \pi_{(2)}, \cdots, \pi_{(a)} \) is \( EV_{i} = \sum_{k=1}^{n} v_{k} \pi_{ik} \).

In order to eliminate the influence of different dimensions to calculation result, it normalizes the expected prospect value of program \( A_{i} \),

\[ \overline{EV}_{i} = \frac{EV_{i}}{\max \|EV_{i}\}} \quad i = 1, 2, \cdots, m \quad (5) \]

In which, \( \max \|EV_{i}\} = \max \|EV_{1}\|, EV_{2}, \cdots, EV_{n} \|, \quad 0 \leq \|EV_{i}\| \leq 1, \quad i = 1, 2, \cdots, m. \)

**Conclusion 2**

(1) If \( S_{j} \) causes one derivative or secondary event, the expected prospect value of the program \( A_{i} \) is proportional to the comprehensive value of \( S_{j} \) while it is inversely proportional to the relevant coefficient \( J \).

(2) If \( S_{j} \) causes multiple (equal or greater than 2) derivative or secondary events, \( A_{i} \) is inversely proportional to the cumulative sum of \( J \).

**4. Computation**

This paper takes earthquake as the research object. Earthquake-related natural disasters with high coefficient in the original emergency network graph is shown in figure 3.

**Figure 2 Co-occurrence Network of Earthquake**

The table 2 shows that the secondary disasters after earthquake include: Level 1 (landslides, disclosure, mud-rock flow and collapse), Level 2 (medical malpractice, dam break, railway, building and fire), Level 3 (food incidents, plant disease, special equipment accident, power accident and water resource), Level 4 (mine accident and road accident). In order to simplify calculation, when the co-
occurrence rate between each level disaster is converted to level 1, the earthquake-related rate of contribution is defined as the final contribution rate.

The following conclusions, (1) As $\hat{p}_{ij}$ are decreasing, the weight is increasing, indicating that program should pay more attention to it. So program design should lay stress on the secondary derivative disasters with high weight. (2) The comprehensive value of emergency is in line with the finally adopted program prospect expected value, that is, with the reduction of the comprehensive value, the prospect expected value is decreasing. But there is the kind of difference between them due to weight and influence coefficient. So it is very important to select weight and influence coefficient, which affects the final selection of emergency plans. (3) we can mention influence coefficient to get better expect prospect value of one secondary disaster, and more attention benefits the emergency disaster control, especially the secondary disaster control.

| Secondary Events | Level | Contribution Evaluation rate | Comprehensive Prospect Value | Probability of Probability | Weight of | Project | Project | Project | Project | Project | Project |
|------------------|-------|------------------------------|------------------------------|-----------------------------|-----------|--------|--------|--------|--------|--------|--------|
| Mine Incident    | 4     | 0.3637 [7.68,7.78]          | 0.5964                      | 0.6363                      | 0.0601    | 0.1660 | 0.37   | 3.2806 | 0.57   | 5.0539 | 0.34   | 3.0146 |
| Coast            | 1     | 0.1758 [7.85,7.95]          | 0.4942                      | 0.8241                      | 0.0777    | 0.1097 | 0.18   | 0.8740 | 0.38   | 1.8451 | 0.15   | 0.7283 |
| Medical Accident | 2     | 0.6962 [7.82,7.92]          | 0.4512                      | 0.3037                      | 0.0286    | 0.0356 | 0.7    | 1.000  | 0.9    | 1.2857 | 0.59   | 0.8428 |
| Leakage          | 1     | 0.0544 [7.85,7.95]          | 0.3707                      | 0.9455                      | 0.0892    | 0.0981 | 0.05   | 0.1629 | 0.25   | 0.8145 | 0.04   | 0.1303 |
| Railway          | 2     | 0.2412 [7.82,7.92]          | 0.3008                      | 0.7587                      | 0.0716    | 0.0798 | 0.24   | 0.4911 | 0.44   | 0.9004 | 0.2    | 0.4092 |
| Road Traffic Accident | 4 | 0.3268 [7.68,7.78]0.5 | 0.2984                      | 0.6731                      | 0.0635    | 0.0655 | 0.33   | 0.5778 | 0.53   | 0.9279 | 0.22   | 0.3852 |
| Building         | 2     | 0.1551 [7.82,7.92]          | 0.2256                      | 0.8448                      | 0.0797    | 0.0791 | 0.16   | 0.2558 | 0.26   | 0.4157 | 0.1    | 0.1599 |
| Fire             | 2     | 0.0998 [7.82,7.92]          | 0.1504                      | 0.9001                      | 0.0849    | 0.0707 | 0.1    | 0.0953 | 0.3    | 0.2859 | 0.06   | 0.0571 |
| Water Resource   | 3     | 0.5480 [7.75,7.85]          | 0.1258                      | 0.4519                      | 0.0426    | 0.0291 | 0.55   | 0.1807 | 0.75   | 0.2464 | 0.45   | 0.1478 |

5. Summary
In this paper, the evolution and propagation network of emergencies is built by co-occurrence theory. And through analysing the emergency decision-making response, decision makers reply using loss aversion, diminishing sensitivity and probability judgment distorted mind behaviour characteristics, and control effect of secondary disasters. This is the practical significance for emergency management department of construction of emergency management.

References
[1] Stallings R, Quaratelli E. Emergent citizen groups and emergency management[J]. Public Administration Review,1985,1(45):93-100
[2] Turner B A. The organizational and inter-organizational development of disasters[J]. Administrative Science Quarterly,1976,21(3):378-397
[3] Turner B A. The sociology of safety[M]. London: McGraw Hill,1992
[4] Ibrahim S M, Fakhard Razi A, Mustapha S. Technological disaster’s criteria and models[J]. Disaster Prevention and management,2003,12(4):305-307
[5] Callon M, Law J, Rip A. Mapping the Dynamics of Science and Technology[M]. The Mac-Millian Press Ltd,1986
[6] Callon M, Courtial J P, Iallive F. Co-word Analysis as a tool for describing the network for interactions between basic and technological research: the case of polymer chemistry[J]. Scientometrics, 1991, 22(1):155-205
[7] Clemens W, Alexander K. Co-occurrence and knowledge mapping to identify hot topics and key players in the field of mobility and transport. http://www.semantic-web.adfile-upload/rootmpphp A4EeZH. pdf, 2006-3-13

[8] Schmidt U, C Starmer and R Sugden. Third-generation prospect theory[J]. Risk Uncertainty, 2008(36):203-223

[9] Chen M, Ma Q, Li M, etal. Cognitive and emotional conflicts of counter-conformity choice in purchasing books online: an event-related potentials study[J]. Biological Psychology, 2010, 85(3):437