The Novel Risk Analysis of Emergency Food Supply under Post-earthquake Conditions

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ABSTRACT

The quick and effective supply of food into an earthquake-affected area is paramount. However, after an earthquake, the road blockages and the communication disruptions significantly impair the timeliness of the food supply. Therefore, we established a risk evaluation index system of emergency food supply on the basis of the fuzzy theory. The thresholds and the key risk factors were determined to signal real-time warnings for the risk indicators of the emergency food supply.

CCS CONCEPTS

• **Computer systems organization**; • **Real-time systems**; • **Real-time operating systems**;

KEYWORDS

Earthquake, Food supply, Fuzzy theory, Risk analysis, Monitoring, Early warning

ACM Reference Format:

Xuefang Sun, Yan Liu, and Hong Zhang*. 2021. The Novel Risk Analysis of Emergency Food Supply under Post-earthquake Conditions. In *The 5th International Conference on Computer Science and Application Engineering (CSAE 2021), October 19–21, 2021, Sanya, China.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3487075.3487095

1 INTRODUCTION

Natural disasters occur frequently in China. Therefore, ensuring that the adequate emergency food supply arrives quickly and accurately in the areas affected by the natural disasters is very important. In the study of Wenchuan earthquake in China and Iwate Miyagi inland earthquake in Japan, it is found that when natural disasters occur, food supply cannot be guaranteed. However, after the occurrences of the natural disasters and the secondary disasters, the interruptions of roadways, the paralyses of information networks, the influx of governmental and social rescue groups, and the flow of disaster victims create high uncertainties in the allocation and the transportation of the emergency food. Therefore, we established a risk evaluation model on the basis of the fuzzy theory to analyze the impact of earthquake on emergency food supply, comprehensively analyze the risk types of emergency food allocation, transportation and other links, identify and summarize the risk factors of each link, screen and classify the identified risk factors of each link by using cluster analysis method, and build a comprehensive risk index model of multi factor coupling emergency food supply system under different natural disaster conditions.

CSAE 2021, October 19–21, 2021, Sanya, China

ACM ISBN 978-1-4503-8985-3/21/10…$15.00
https://doi.org/10.1145/3487075.3487095

2 THE CHARACTERISTICS OF EARTHQUAKES AND THE SECONDARY DISASTERS

The earthquake is a natural phenomenon in which the rapid release of energy from the earth crust generates vibrations and seismic waves. The compressions and the collisions of tectonic plates, which produce dislocations and ruptures on the edges and within the plates, are main reasons of the earthquake [1]. The earthquake occurs instantaneously; the formation of the hypocenter is very brief: the formation of the hypocenter of the earthquake of 7 or 8 magnitude occurs within tens to a hundred and tens of seconds, and the propagation of an earthquake may span several kilometers per second [2]. In addition, the occurrence of an earthquake is unpredictable due to the invisibility of the earthquake source, the complexity of the earthquake physics, and the low probability of the earthquake occurrence. Therefore, predicting an earthquake is difficult and the timespan for pre-disaster prevention and control is short. Nonetheless, the number of casualties due to an earthquake is significant [3-6]. In China, during the time period between 1949 and 1991, the death tolls due to earthquakes constituted more than 50% of the death tolls due to various natural disasters.

The earthquake secondary disasters are the series of disasters that occur after an earthquake [4] and include landslide, mudslide, tsunami, flood, plague, fire, explosion, gas leakage, and radioactive material contamination. The fire disaster is the most common and the most deleterious earthquake secondary disaster, followed by the mudslide disaster. There are various causes of the fire disaster, such as the damages to stoves, electrical facilities, chemical containers, and chimneys. Upon an earthquake, timely fire-fighting measures and rescues are challenging, which allows the rapid spread of the fire. On the other hand, the mudslide disaster is caused by the increases in surface deformations and cracks due to an earthquake that reduce the mechanical strengths of soil and rock, increase the groundwater level, and change the runoff conditions. These changes modify the inertial force of the sloping body and trigger sliding motion and debris flow. In addition, the collapses and the landslides and the damages to water sources generate a large amount of loose solid materials that increase the debris flow.

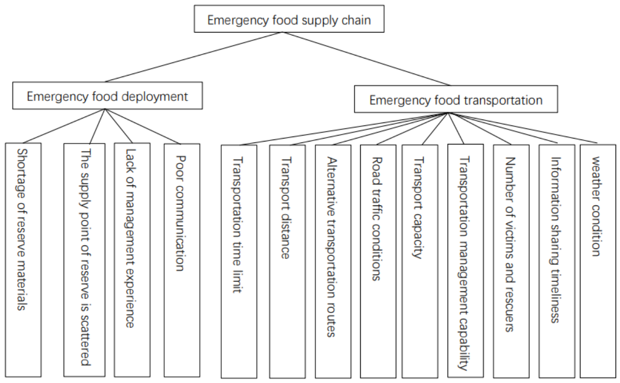

Figure 1: Index System of Emergency Food Supply Chain under Earthquake Conditions.

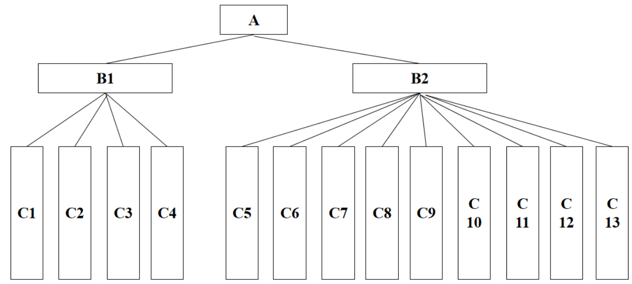

Figure 2: Index System of Emergency Food Supply Risk Assessment.

3 THE RISK EVALUATION MODEL ON THE BASIS OF FUZZY THEORY

3.1 The Supply-chain Evaluation Index System under Post-earthquake Conditions

Failure mode and effects analysis is an important element of the risk evaluation of emergency food supply. Among various possible risk factors, the possible failures of emergency food supply due to the risk factors were analyzed to assess the potential developments of the potential failures into failure events. The failure events occurred in the sequence of risk factor–potential failure–failure–chain failure.

On the basis of the failure modes and the risk factors of the allocation and the transportation of emergency food under post-earthquake conditions, we established a risk indicator system of the emergency food supply (Figure 1).

The key risk factors of the allocation of emergency food were insufficient food reserves, scattered storage points, inadequate management experience, and poor communication. On the other hand, the key risk factors of the transportation of emergency food were the transportation timeliness, transportation distance, alternative transportation routes, traffic conditions, transportation capacity, transportation management capability, the number of people who were affected and to be rescued, the timeliness of information sharing, and weather conditions.

3.2 The Fuzzy Comprehensive Evaluation of Emergency Food Supply

Because the risk evaluation index system of emergency food supply is a complete system with a certain level of hierarchy, a multi-level fuzzy comprehensive evaluation was used to analyze the system [7-8]. Three levels of fuzzy comprehensive evaluation were used. The first-level fuzzy comprehensive evaluation was performed on the three-level risk indicators to obtain the comprehensive evaluation results of the corresponding secondary indicators. The second-level fuzzy comprehensive evaluation was performed on the secondary indicators to obtain comprehensive evaluation results that were analyzed by the third-level fuzzy comprehensive evaluation to obtain the risk levels of the risk indices of the emergency food supply.

3.3 The Risk Level Assessments of the Risk Factor Sets

On the basis of the established risk evaluation index system of emergency food supply (Figure 2), the following risk evaluation index sets were obtained:

A = {B1, B2},
B1 = {C1, C2, C3, C4} ,
B2 = {C5, C6, C7, C8, C9, C10, C11, C12, C13} .

3.4 Judgment Matrices

The judgment matrices for all risk levels were constructed on the basis of the analytic hierarchy process (AHP) method. Firstly, the hierarchical structure and the specific risk indicators were determined. Then, judgment matrices were constructed on the basis of the reference documents and expert opinions, and the importance coefficients were calculated according to the characteristics of the risk indicators of the emergency food supply shown in Table 1

3.5 Supply-chain Risk Indicator System

On the basis of the judgment matrices of the risk evaluation index system of emergency food supply and the calculated importance coefficients, the key risk factors of the allocation of emergency food under post-earthquake conditions were insufficient food reserves, scattered storage points, and insufficient management experience [9-10]. On the other hand, the key risk factors of the transportation of emergency food were the transportation timeliness, traffic conditions, transportation management capability, the number of people who were affected and to be rescued, the timeliness of information sharing, and weather conditions (Figure 3).

4 THE RISK PREVENTION SYSTEM

4.1 The Framework of the Risk Evaluation of Emergency Food Supply

The risk evaluation of emergency food supply encompassed basic data layer, data analysis layer, and data application layer. The basic data layer analyzed the supplies and the demands in earthquake-affected area and collected basic information on the distributions

Table 1: Judgment Matrix of Risk Assessment Index System for Emergency Food Supply and Importance Coefficient Calculation

A~B	A	B1	B2								WA
	B1	1	5								0.167
	B2	0.2	1								0.833
B1~C	B1	C1	C2	C3	C4						WA
	C1	1	5	5	0.33						0.132
	C2	0.2	1	3	0.2						0.339
	C3	0.2	0.33	1	0.14						0.479
	C4	3	5	7	1						0.050
B2~C	B2	C5	C6	C7	C8	C9	C10	C11	C12	C13	WA
	C5	1	0.33	0.33	5	0.33	5	0.14	5	5	0.097
	C6	3	1	0.2	7	0.33	5	5	7	3	0.056
	C7	3	5	1	3	5	5	5	7	0.33	0.031
	C8	0.2	0.14	0.33	1	0.2	0.2	0.14	0.2	0.33	0.223
	C9	3	3	0.2	5	1	0.2	5	3	5	0.069
	C10	0.2	0.2	0.2	5	5	1	0.33	5	3	0.109
	C11	7	0.2	0.2	7	0.2	3	1	5	3	0.093
	C12	0.2	0.14	0.14	5	0.33	0.2	0.2	1	5	0.182
	C13	0.2	0.33	3	3	0.2	0.33	0.33	0.2	1	0.139

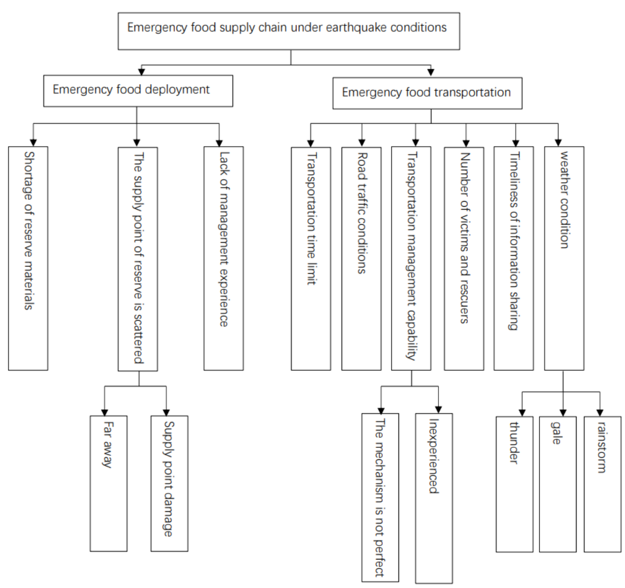

Figure 3: Supply Chain Risk Index System.

and the storage points of the emergency food (e.g., food type, food quantity, the distance from the affected area) and the transportation plans (e.g., transportation routes, transportation capacity, the transportation timeliness). On the other hand, the data analysis layer used the median method, mean principle, convolutional neural algorithm, and expert consultation in combination with the data obtained from the basic data layer to calculate early-warning thresholds, to classify the risk factors, and to establish a dynamic early-warning model. Subsequently, the results of the data analysis layer were processed in data application layer by remote dispatch and the emergency food supply plans were optimized on the basis of the early-warning model to ensure an efficient emergency food supply (Figure 4).

4.2 The Determination Methods of Early-warning Thresholds

The artificial neural network and the convolutional neural network models were selected to determine the early-warning thresholds. The calculations of early-warning thresholds by convolutional neural network model encompassed the input layer, the hidden layer, and the output layer. The input layer processed the three-dimensional input data, while the hidden layer included the convolutional layer, the pooling layer, and the fully-connected layer. The convolutional layer used matrix multiplication, and a fully-connected network was constructed between the convolutional layers. The parameters of the convolutional layer included the hyperparameters of convolutional neural network, namely the size of convolutional kernel, the step size, and the padding. The parameters determined the size of the output feature map of the convolutional layer. After the feature extraction by the convolutional layer, the output feature map was analyzed by the pooling layer for feature selection and information filtering. The pooling layer selected the pooling areas in the similar steps to the convolution kernel scanning of the feature map. On the other hand, the fully-connected layer transmitted signals to the other fully-connected layers. The spatial topology of the feature map diminished in the fully-connected layer and was transformed into a vector and subjected to the activation function. The upstream of the output layer was a fully-connected layer, which structure and working principle were similar to those of the output layers of traditional feedforward neural networks. The image semantic segmentation of the output layer directed the classification output of each pixel. The determinations of early-warning thresholds by convolutional neural network followed equations 1)

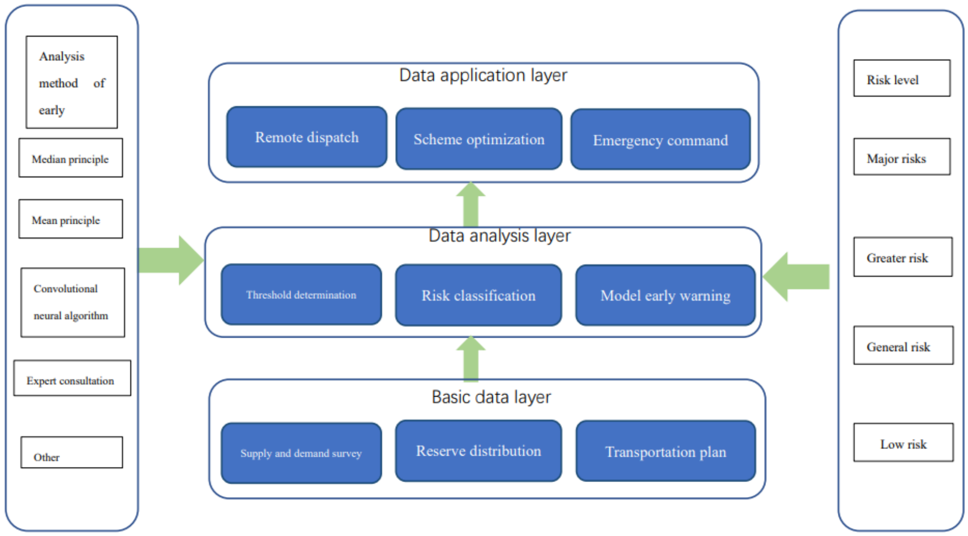

Figure 4: Whole Chain Risk Analysis System of Emergency Food Supply.

and (2)

$$u = \sum_{i=1}^{n} w_i x_i \ , \tag{1}$$

$$y = \varphi\left(u - \theta\right) \ , \tag{2}$$

where x_i represented the input signal of the artificial neural network model, w_i represented the connection weight of the output signal, n represented the information quantity of the input signal, θ represented the early-warning threshold, φ represented the excitation function, u represented the intermediate quantity, and y represented the output of the artificial neural network model. The results of the judgments of early-warning thresholds

The non-linear and adaptive information processing system was composed of a large number of interconnected processing units, which had the non-linear, non-limited, highly qualitative, and non-convex basic characteristics. On the basis of the response functions and the early-warning thresholds, the early-warning signals were judged.

On the basis of the risk acceptability (i.e., the risk level), the risks were classified into very high risks, high risks, moderate risks, or low risks. The transportation failure rate of emergency food that was higher than 80% was classified as a very high risk, the transportation failure rate of emergency food that was between 50% and 80% was classified as a high risk, the transportation failure rate of emergency food that was between 30% and 50% was classified as a moderate risk, and the transportation failure rate of emergency food that was lower than 30% was classified as a low risk.

(1) Established the determination criteria of early-warning thresholds

On the basis of the basic data, namely the supplies and the demands in the earthquake-affected area, the distributions and the storage points of emergency food (e.g., food type, food quantity, and the distance from the disaster area), and transportation plans (transportation routes, transportation capacity, and the transportation timeliness), the combination of convolutional nerves and the risk evaluation index system of emergency food supply was used to calculate the early-warning thresholds of emergency food supply. In addition, the risk levels were judged and a dynamic early-warning model was established.

(2) Optimized the transportation plans

Threshold analyses and key risk-factor analyses were performed on the basis of the post-earthquake surveys on the food supplies and demands, the distributions and the storage points of emergency food, and the transportation plans, weather conditions, traffic conditions, and the transportation timeliness. The real-time early-warnings of the risk indicators that affect emergency food supply assist the working groups to accomplish plan optimizations and timely on-site and remote coordination to realize the real-time managements and controls of the deployment, the transportation, and the arrival of the emergency food. The effective managements and controls include the analyses of the supply-demand relationships of emergency food in earthquake-affected areas, remote route planning, and the optimizations of food allocation plans at the storage points of the emergency food.

5 CONCLUSION

The risk evaluation model of emergency food supply on the basis of fuzzy theory identified the risk factors of the emergency food supply. The risk factors were analyzed by dynamic cluster analyses to establish a three-level risk indicator model. The key risk factors were identified by a risk evaluation system that involved basic data layer, data analysis layer, and data application layer. Combined with the risk evaluation index system of the emergency food supply, the calculations of the early-warning thresholds of the emergency food supply were performed, the risk levels were determined, and a dynamic early-warning model was established.

ACKNOWLEDGMENTS

This research project was made possible through the financial support from the project NO. 2018YFC1603706 by ‘13th five-year’ national key research and development plan.

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