VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

Zezhao Liu, Rui Ma, Huijia Wang

THRESHOLD TESTING BASED ON PUBLIC SAFETY RISK: AN EXPERIMENTAL SIMULATION BY SUPPORT VECTOR MACHINE METHOD AT THE REGIONAL LEVEL, CHINA

Abstract

Ever since the concept of public safety has expanded in contemporary society, it has tried to mitigate the risks that lead to uncertainties both from the state to individual level. On the system perspective, vulnerability-capacity theory is a framework for disaster management. Despite theoretical advances, the quantitative threshold value between vulnerability and managing capacity in the public safety has not yet been measured. In this paper, we use the method of Support Vector Machine (SVM) as a simulation tool to reveal the threshold effect by the indicator-based provincial data at different geographical scales in China. The study established a hierarchical index system and verified the threshold effect in the quantitative level. Results find out that when the regional public safety index exceeds a particular threshold value, the number of safety incidents will arise at a high level along with the increasing of the risk index. Therefore, to achieve a sound safety environment in China, the vulnerability-capacity element ought to be highly addressed for the local government and maintain its mutual relation at an appropriate level.

Keywords: threshold, public safety, vulnerability-capacity, Support Vector Machine (SVM)

VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

KÖZBIZTONSÁGI KOCKÁZATON ALAPULÓ KÜSZÖBVIZSGÁLAT: KÍSÉRLETI SZIMULÁCIÓ SZUPPORT VEKTORGÉPI MÓDSZERREL REGIONÁLIS SZINTEN KÍNÁBAN

Absztrakt

Amióta a közbiztonság fogalma a modern társadalomban terjedésnek indult, az emberiség igyekezett mérsékelni a különböző kockázatokat, az államtól a lakosság szintjéig. A rendszer szempontjából a sebezhetőség-kapacitás elmélet a katasztrófavédelem egyik eleme. Már történtek elméleti előre lepések, azonban a sérülékenység és a közbiztonság irányítóképessége közötti mennyiségi küszöbértéket még nem mérték meg. A cikkben a szerzők szupport vektorgépi módszerrel (SVM) felfedik a küszöbhatást az indikátoralapú tartományi adatok segítségével Kína egyes területein. A cikk eredménye, hogy ha a regionális közbiztonsági index túllép egy adott küszöbértéket, akkor a kockázati index növekedésével párhuzamosan a biztonsági események száma is magasra emelkedik. A biztonság megteremtése érdekében ezért Kínában kiemelten kezelik a sebezhetőség-kapacitást a helyi önkormányzatok tekintetében és emellett fenntartják a kölcsönös együttműködést is.

Kulcsszavak: küszöbérték, közbiztonság, sebezhetőség-kapacitás, szupport vektorgépi módszer (SVM)

VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

1. INTRODUCTION

Public safety, as the prerequisite for social order and sustainable development, is a concern for political authorities. The pervasive threat of various disasters has attracted widespread attention of governments at all levels to handle emergency. In the past decade, research in the field of emergency management and public safety have cast the focus on the *system* perspective, which helps to reveal the evolution of emergencies (ie. flood, industrial accident, explosion) and provide practical enlightenment for public sectors. Inter-American Development Bank (IDB) ever put forward the "vulnerability-capacity" framework for safety assessment, and further designed Disaster Risk Management Indicators (DRMI,2005) as a tool to analyze the level of public safety situation. Theoretically *vulnerability* and *capacity* for regional public safety is perceived to possess the inverse effect in evolution (IDB, 2011; Zhu, 2011). Briefly, when the capacity is weak, safety situation could reflect more probability of deterioration and even leads to crisis.

Since 2000s, China has enhanced the capacity to handle various disasters. In recent years, China has strengthened the capacity in providing so called "public goods of safety"(CPC, 2017), while the mitigation of regional vulnerability is a core goal for the government. What is the relationship between emergency-coping *capacity* and *vulnerability*, and whether the threshold value within exists in the reality? This will be a critical question for the public safety both theoretically and practically. In addition, the relevant public policy can be made to ensure the cognition of local servants and the general public in the emergency management activities. In light of this, this paper conducts an exploratory research by collecting provincial data in China, and expects to uncover the internal mechanism and likely threshold effect under the "vulnerability-capability" framework of emergency management.

2. "VULNERABILITY-CAPABILITY" FRAMEWORK

For decades, high-frequency occurrence of emergency is a global status. In theory, all potential threats that could harm the order of fundamental functions of the society are considered in risk reduction and also formed corresponding analytical tools. The Coordination Continuity of Operations (COOP), produced by the USA Federal Emergency Management Agency, has covered typical indicators for social vulnerability and capacity of sustainability in overcoming practical emergencies (FEMA, 2004), which introduced a quantitative method by a straightforward analysis of the public safety maintenance. Under the UN Development Program for Natural Disaster Reduction, the"vulnerability-capability"framework has become one of the notable paths for disaster management (Wisne,2004; Birkmann, 2014). Meanwhile, the Disaster Risk Management Indicators (DRMI) developed by the National University of Colombia extended the definition of vulnerability and the assessment was put into application for handling emergency. Smit ＆ Wandel (2006) optimized a model and summarized two factors as natural and social aspects for evaluating risk elements. In China, researchers absorb the basic spirits of the framework above and build up analytical tools for Chinese emergency practices. Zhu (2011) put forward a framework, in which vulnerability & capacity was conceived to have an opposite effect in public safety, i.e., when the capacity system of public emergency handling is weak, social vulnerability and regional safety situation would be deteriorated; If the safety risk (referred by the safety index) overtakes a bounded value, the society is more likely to result in public crisis. Liu T.M (2012) suggests four aspects of vulnerability & capacity assessment as in natural force, man-made technology, social texture, and management, among which management elements include legal system and preparedness of emergency.

Concerning the vulnerability & capacity framework, threshold is one pivotal target in recognizing the inter-relationship in the emergency management. Threshold (also "critical value") is more applied in the field of disaster management, but the threshold in the public safety context is little concerned. As the reflection to non-linearity of a system, threshold is usually regarded as the specific point of transition from one system boundary to another (Alwang *et al*., 2011; Zhao, 2014). Many researchers have identified the importance of the threshold status on the qualitative evolution of a specific system (Wood, 2003; Ahamad, 2016), however, the value in public safety and emergency field is little addressed due to the texture of social context (Zhao, 2014). Focusing threshold effects in the academia of safety science, some studies used methods of simulation or system engineering (Güneralp,2010; Song, 2015), and quantitative index is always applied to act the operable analytical tool. For the macro level of regional public safety, Lagi (2011) used empirical data to analyze relations between prices and social unrest and found that when the FAO price index reached the threshold of 210, there was a great possibility of fatal social unrest. Still, it lacks empirical research as well as comparative analysis based on accessible index in the field of regional public safety.

3. METHODOLOGY

3.1. Index Design and Evaluation

(i) Index System

The regional public safety system is a complicated system subjected to multiple factors and the level of safety risk ("risk index" herein) is under the combined action of "vulnerability" and "coping capacity". Given the vulnerability and the coping capacity are reflected in different aspects and have varying impact on the system from time to time, the vulnerability, and the public safety, in fact, do not determine the regional safety level simply by positive and negative balancing. In other words, when the regional public safety index goes beyond a threshold, it will entangle the public safety system in mutations (see Fig 1), which is reflected as the public exposure or outbreak of disaster.

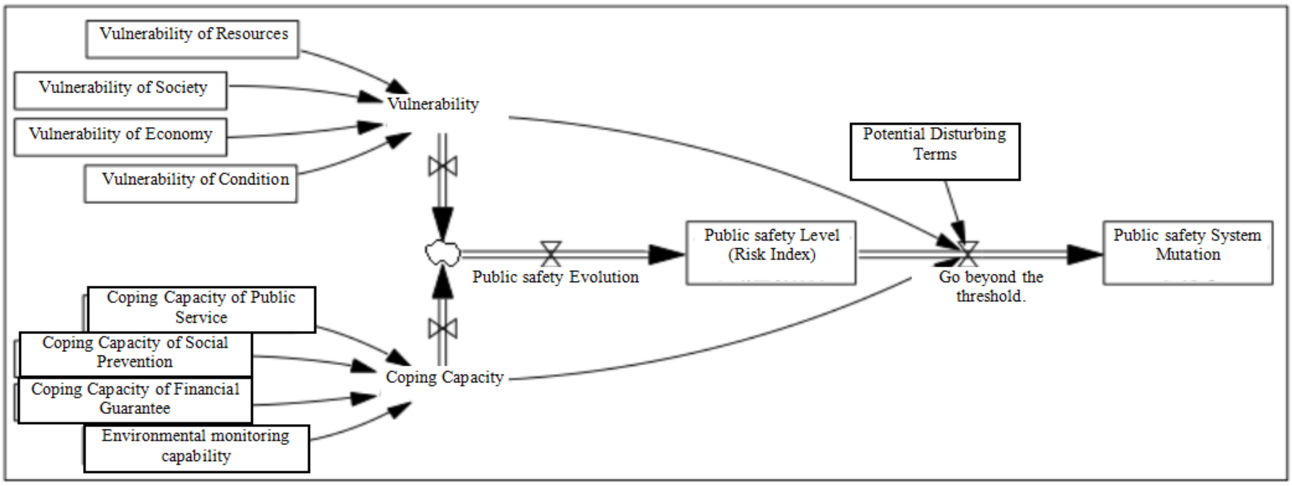


Fig. 1- Threshold Analysis Framework of the Regional Public safety System

As defined by the United Nations International Strategy for Disaster Reduction, the vulnerability is impacted by multiple factors. Burton *et al* (1993) divided the regional vulnerability into economic, social, and natural aspect, and believed in the significance of social factor in vulnerability assessment; Shi (2002) expanded the division of economic, social, humanistic, and political factor into V-typed integrated system. In terms of emergency coping capacity, scholars commonly divide indexes by the implement subject of the capacity and are prone to ignoring the self-regulation ability of the society.

Based on the components of regional public safety system, the vulnerability factors in this paper are classified into four aspects including resources, environment, economy and society in line with the principles of comprehensiveness, measurability, effectiveness and reliability, i.e. four subsystems of regional public safety system. With reference to the objective attributes of evaluation index, the coping capacity is thus divided into public service, environmental regulation, the financial guarantee, and social prevention. A hierarchical index system for regional public safety evaluation is established (Table 1) and data on the sampled regions are acquired from *China Statistical Yearbook*, provincial statistical yearbooks, statistical bulletins, security production incident statistics and related reports.

(ii) Fuzzy Comprehensive Evaluation

The fuzzy comprehensive evaluation method is one of the most extensively used methods in the practice of multi-index comprehensive evaluation and is applicable to either subjective evaluation or evaluation based on objective data. In this paper, the public safety situation of S Province is applied as the object set and the evaluation index factor set is set.

The evaluation is set as: $U=\{u_1,u_2,\cdots,u_m\}$. $V=\{v_1,v_2,\cdots,v_p\}$

The fuzzy weight vector of the factor set U is set as:

$$\underset{\sim}{A}=\frac{a_1}{u_1}+\frac{a_2}{u_2}+\cdots+\frac{a_m}{u_m} \qquad \text{o}\leq,\alpha\text{-}i.\leq 1. \qquad (1)$$

Table 1 Evaluation system of regional public safety in the vulnerability-capacity framework

Level I index	Level II index	Measure index
Vulnerability （V）	Vulnerability of Resources （VR）	Arable land per capita, per capita water resource, etc.
	Vulnerability of Condition （VC）	Yield of industrial solid waste, industrial wastewater discharged, etc.
	Vulnerability of Economy （VE）	Proportion of labor remuneration in regional GDP, per capita GDP, etc.
	Vulnerability of Society （VS）	Registered urban unemployment rate, urban-rural consumption ratio, etc.
Coping Capacity （C）	Coping Capacity of Public Service (CPS)	Number of hospital beds per 1,000 people, transport line density, etc.
	Coping Capacity of Environmental Regulation （CER）	Treatment rate of industrial solid waste, compliance rate of industrial wastewater discharged, etc.
	Coping Capacity of Financial Guarantee （CF）	Proportion of public safety budget, per capita public safety budget, etc.
	Coping Capacity of Social Prevention （CSP）	Participation rate of town basic endowment insurance, proportion of illiterate population, etc.

Where a_i is the membership degree of u_i to A.

The weighting factor of the index denotes the relative importance of the index. In this paper, the mean square error method is used to determine the weight coefficient of each index, which uses each evaluation index as a random variable and the normalized value of which is the value of this random variable. After normalizing the sample data [0, 1], the following steps are employed to calculate:

The mean of the jth index: $E(I_j)$

$$E(I_j) = \frac{1}{n}\sum_{i=1}^{n} y_{ij} \quad (2)$$

The mean square error of the j[th] index: $\sigma(I_j)$

$$\sigma(I_j) = \left[\sum_{i=1}^{n}\left(y_{ij} - E(I_j)\right)^2\right]^{\frac{1}{2}} \quad (3)$$

The weight coefficient of the j[th] index: ω_j

$$\omega_j = \sigma(I_j) / \sum_{j=1}^{m}\sigma(I_j) \quad (4)$$

After the weight of each index is determined, use r_{ij} to indicate the membership degree of u_i to the evaluated v_k and establish the fuzzy comprehensive evaluation matrix between the factor domain and the evaluation domain:

$$\underset{\sim}{R} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mp} \end{bmatrix} \quad (5)$$

Then, the fuzzy evaluation result can be acquired:

$$\underset{\sim}{B} = \underset{\sim}{A} \cdot \underset{\sim}{R} \quad (6)$$

Correlation analysis was carried out based on the data on disaster casualties caused by incidents of each sampled province in China and the calculation results of the regional public safety index. According to the test results (Table 2), there is a significant positive correlation between the regional public safety index of each province and the death tolls, injuries and casualties caused by incidents, indicating that the index system and fuzzy comprehensive evaluation results have higher credibility. Thus, the risk index can be employed to represent the level of regional public safety risk.

Table 2- Pearson Correlation Analysis for the Regional Public safety Index and Casualty

Provincial Region	Pearson correlation coefficient		
	Death tolls	Injuries	Casualties
Hebei	0.887^{***}	0.745^{**}	0.768^{***}
Shaanxi	0.800^{***}	0.983^{***}	0.989^{***}
Jilin	0.952^{***}	0.603^{*}	0.717^{**}
Hunan	0.923^{***}	0.909^{***}	0.933^{**}
Sichuan	0.976^{***}	0.913^{***}	0.938^{***}
Yunnan	0.964^{***}	0.787^{***}	0.934^{***}
Shaanxi	0.948^{***}	0.837^{***}	0.898^{***}
Gansu	0.959^{***}	0.947^{***}	0.958^{***}

Notes: $^{***}P<0.01$, $^{**}P<0.05$, $^{*}P<0.1$。

3.2. Threshold Identification and Analysis

According to the "capacity-vulnerability" framework, the threshold effect inregional safety risk can be described with the number of public safety incidents as an index: The increase in the number of incidents has a significant difference below and above the risk threshold. After going beyond the threshold, the increasing risk level comes with sharply increasing number of incidents. However, this upward trend remains relatively flat before going beyond the threshold. On such a basis, this paper makes regression fitting on the level of regional public safety risk and the number of incidents by the support vector machine (SVM) technology and the trend performance is verified by the slope change of the regression curve.

VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

According to the basic principle of SVM, the objective function of the optimization problem can be expressed as:

$$\omega\left(\alpha,\alpha^*\right)=-\frac{1}{2}\sum_{i,j=1}^{l}\left(\alpha_i,\alpha_i^*\right)\left(\alpha_j,\alpha_j^*\right)k\left(x_i,x_j\right)+\sum_{i=1}^{l}y_i\left(\alpha_j-\alpha_j^*\right)-\varepsilon\sum_{i=1}^{l}\left(\alpha_i+\alpha_i^*\right) \quad (7)$$

$$s.t. \quad 0\leqslant\alpha_i,\ \alpha_i^*\leqslant C,\ \ i=1,2,\ldots,l \quad (8)$$

$$\sum_{i=1}^{l}\left(\alpha_i-\alpha_i^*\right)=0,\ \ i=1,2,\ldots,l \quad (9)$$

The least square method or the sequence minimal optimization algorithm is employed to get the regression fitting function (the fitting function relationship between regional public safety index and the number of safety incidents) and the fitting result is tested by the statistical index MSE.

$$f\left(x\right)=\sum_{i,j=1}^{l}\left(\alpha_i,\alpha_i^*\right)k\left(x_i,x_j\right)+b \quad (10)$$

$$MES=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i-\hat{y}_i\right)^2} \quad (11)$$

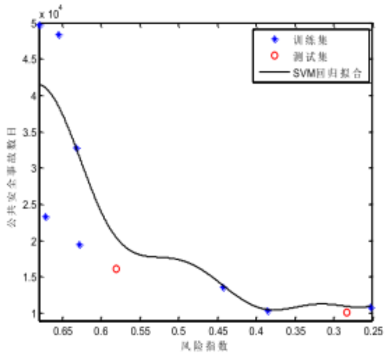
The key to the simulation of the SVM rests in determining the kernel function k (x_i, x_j). Given the kernel precision and generalization performance, the Gaussian radial basis function kernel is employed as the SVM kernel function herein.

$$k\left(x_i,x_j\right)=\exp\left(-\frac{\left\|x_i-x_j\right\|^2}{2\sigma^2}\right) \quad (12)$$

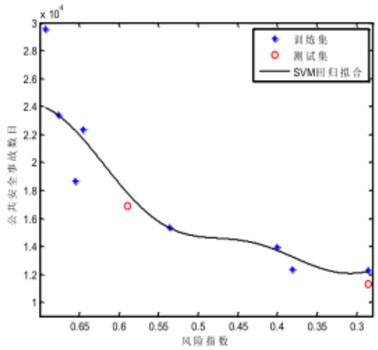
Data in two years are extracted from each region as test sets and other data are used as training sets. According to the optimization algorithm and genetic algorithm, the parameters of RBF kernel are determined and the fitting relationship between the regional public safety index (horizontal axis) and the number of public safety incidents (vertical axis) is acquired by making use of Matlab7.0 and

Libsvm toolbox (Fig. 2).

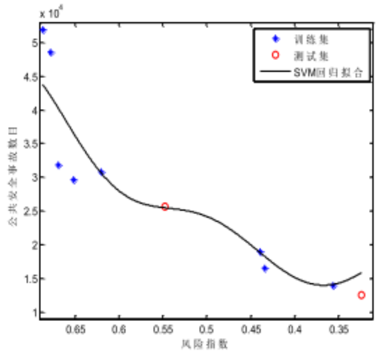
Fig. 2 Regression Fitting Results of Regional Public Safety Index and Incidents in Sampled Provinces



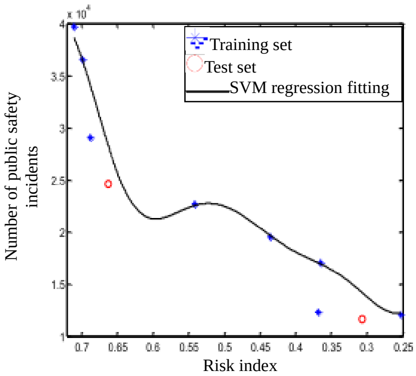
Hebei Province



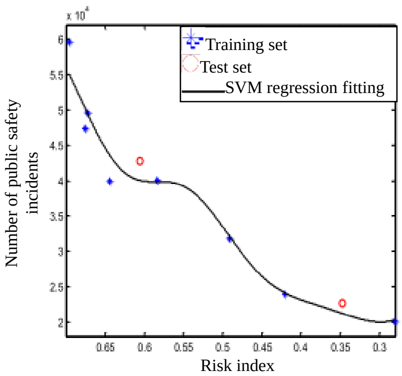
Shanxi Province



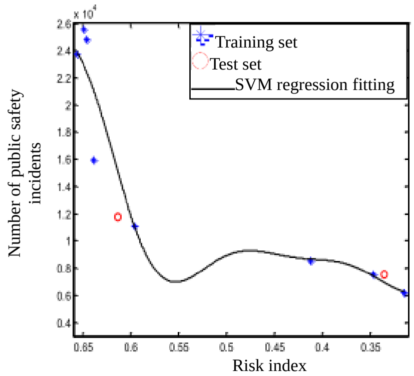
Jilin Province



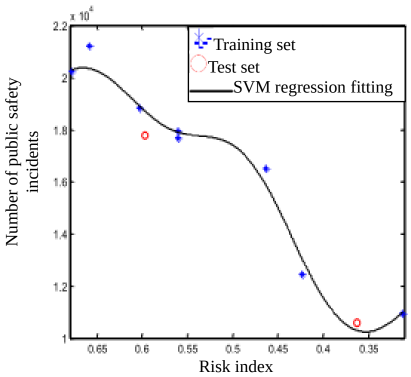
Hunan Province



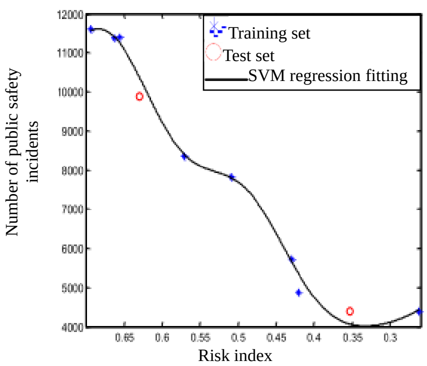
Sichuan Province



Yunnan Province



Shaanxi Province



Gansu Province

According to the fitting results, the public safety risk index and the number of incidents in each province share a characteristic that when the index is in a certain area, the actual number of incidents decreases rapidly along with the decrease of risk index; after a certain critical point, the downward trend changes significantly from violent fluctuations to steady. This change law can be confirmed by observing the slope of the regression curve of safety risk index and the number of incidents, that is, the slope of the curve suddenly changes from a large negative value to a small value. Based on this, the position where the slope of fitted curve changes significantly is inferred and the corresponding risk index is the threshold of regional public safety risk. The threshold effect is characterized by the following. When the level of regional safety risk is below the threshold, the number of incidents increases slowly as the risk level increases; when the risk level goes above the threshold, this upward trend will suddenly speed up, imposing tremendous risk response pressure to the region.

The conclusions are supported by the results of regression test. According to Table 3, although three regions have relatively large fitting errors in their the training sets, the risk index corresponding to the coordinate points with poor fitting exceeds the threshold of regional public safety index (Fig.2). In this region, a slight change in the risk index is accompanied with a sharp fluctuation in the number of incidents, making it hard to fully demonstrate the effect of regression fitting. By comparison of the fitting error of the test set (Table 4), the regression fitting effect of each region is relatively ideal, thus verifying the overall effectiveness of the regression fitting.

Table 3- Results of SVM Regression Fitting Training Set

Province	Hebei	Shanxi	Jilin	Hunan	Sichuan	Yunnan	Shaanxi	Gansu
MSE	0.1998	0.0768	0.0803	0.0320	0.0135	0.0517	0.0076	0.0026
R-squared	0.6646	0.8412	0.8382	0.9488	0.9677	0.9182	0.9856	0.9969

Table 4- Results of SVM Regression Fitting Test Set

Province	Hebei	Shanxi	Jilin	Hunan	Sichuan	Yunnan	Shaanxi	Gansu
MSE	0.0246	0.0134	0.0160	0.0513	0.0123	0.0638	0.0177	0.0141

According to Fig 2, three provinces have public safety risk index with thresholds and two have slope of the curve from a larger negative value to a smaller one. Specifically, when regional public safety index exceeds the threshold and approaches a certain level, the number of incidents will rise at a high level along with the increasing of the risk index. However, when the index continues to rise to a higher level, the upward trend in the number of incidents accelerates abruptly, which means that exceeding of the level of regional public safety risk to the higher threshold puts much more pressure on the management of regional risks. However, after the public safety index of Hebei Province drops below the threshold, the number of incidents does not fully show slow declining; on the contrary, the decline in the number of public safety incidents again shows remarkable acceleration, indicating that the regional public safety index may have a threshold at a lower level.

4. CONCLUSION

Based on the perspective of "vulnerability-capacity", this paper makes an empirical test on the threshold effect of eight sampled provinces in China. The results show that regional public safety system has nonlinear complex characteristics and that the threshold does exists at the overall level. Before reaching a specific threshold, the regional public safety system remains relatively stable and the degree of risk is low. However, once a certain threshold is exceeded, the system will undergo violent mutations, the regional security situation will rapidly deteriorate, and the risk will also rise significantly. At the same time, the level of regional safety risk has multiple thresholds, that is, the threshold effect may be characterized by multi-stage characteristics. In the past decade, China's local governments have greatly raised their capacity against public crisis. However, though regional public safety risks have mitigated, public crisis caused by vulnerability still remains serious. Particularly, in the wake of globalization, contradictions is intensified and the threshold of public safety risk level may drop down. Therefore, to strengthen the response to vulnerability and build effective systems to reduce the level of regional safety risk will be the task of China's government in risk governance. It should be especially noted that the regional safety system is a complex system composed of multiple elements. Thus, it is not enough to rely solely on the enhanced economic strength to reduce the level of public safety risks. Only through a deeper exploration of the institutional work, can fundamental conditions be created for improving the public safety.

From the perspective of system analysis, this paper sorts out the factors affecting regional public safety risk, establishes an index system and measures the risk index of China's sampled provinces. The SVM tool is employed for regression fitting of the regional public safety index and and changes of the curved slope reveal the presence of threshold effect. For a complex system, there are potential disturbing terms in the social system. Consequently, regional public safety risk cannot be precisely evaluated and threshold cannot be completely disclosed. At present, research on this issue is limited and the disturbance still needs to be considered in the future. Explorations under a multi-disciplinary platform are also desperately needed to serve the the practice of regional safety governance.

ACKNOWLEDGMENT

This research is supported by Jiangsu Postdoctoral Science Fund, China (2021K147B)

REFERENCES

Alwang J., Siegel PB., Jorgensen SL. *Vulnerability: A view from different disciplines*. Social protection discussion paper series 0115. Washington, DC: 2011.

Bank, I. A. D. (2011). *Indicators for disaster risk and risk management: programme for Latin-America and the Caribbean*: Belize. IDB Publications.

Birkmann & Jirn. (2014). Assessment of vulnerability to natural hazards introduction vulnerability: a key determinant of risk and its importance for risk management and sustainability. *Assessment of Vulnerability to Natural Hazards*, 9-13.

B Güneralp, G Gertner, G Mendoza. (2013). Spatial simulation and fuzzy threshold analyses for allocating restoration areas. *Transactions in GIS*, 7(3), 325-343.

Burton，I． et al．(1993) ． *The Environment as Hazard*． New York: Guilford．

Chapter, & Annex. (2009). *Climate change: impacts, adaptation and vulnerability.* Cambridge. 56 (5), 81-111.

Dan Wood, B. , & Doan, A. . (2003). The politics of problem definition: applying and testing threshold models. *American Journal of Political Science, 47*(4), 640-653.

Federal Emergency Management Agency (FEMA). 2004: FEMA/DHS Office of National Security Coordination Continuity of Operations (COOP) *Assessment Questionnaire/Worksheet*. Washington DC: FEMA, 1- 14.

National University of Colombia-Manizales, Inter-American Development Bank. *System of Indicators for Disaster Risk Management*: Program for Latin America and the Caribbean Main Technical Report [EB/OL]. http://idea.unalmzl.edu.co, 2005-08-01.

Liu (2012). Study on the re-assessment of vulnerability of emergencies——perspective of vulnerability. *China Science & Technology of Safety Production*.6 (5). **(In Chinese)**

Smit B． & Wandel J. (2006) ． Adaptation，adaptive capacity and vulnerability． *Global Environmental Change*，16 : 282–292.

Song, G. , Wang, Y. , Zhao, K. , & Zhou, C. . (2015). Pattern simulation and the determination of security threshold of cultivated land use system security in northeast china. *Geographical Research*, 34(3), 555-566.

Turner, B L. , Kasperson, R E. , Matson, PA. , et al. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of Natural Academy Science*, USA, 100(14), 8074-8079.

Xinhua News Agency. Xi Jinping delivered a report at the 19th National Congress of the Communist Party of China (CPC), Beijing: Oct. 18, 2017.

http://www.xinhuanet.com//english/special/2017-11/03/c_136725942.htm

Wisner，B. *et al*. (2004) ． *At Risk*． London: Routledge．

Zhao.AX. (2014) Definition, significance and application of disaster loss threshold. *Journal of Natural Disasters*, 23(6),13-18.(In Chinese)

Zhu Z.W., Cai Li.. (2011) The Framework of social safety assessment on the "vulnerability-ability" perspective. *China's Public Administration*, (8), 101-106. **(In Chinese)**

Zezhao Liu

Jiangsu Normal University, School of Government, Nanjing University, Nanjing, China

E-mail: zzliu@jsnu.edu.cn

ORCID:

Rui Ma

School of Public Administration and Sociology, Jiangsu Normal University; Xuzhou, China

E-mail: zzliu@jsnu.edu.cn

ORCID: 0000-0002-6629-0579

Huijia Wang

People’s Procuratorate in Tongshan District

E-mail: zzliu@jsnu.edu.cn

ORCID: 0000-0002-6629-0579