Analysis and Prediction for Stability of Country

Fei Wang[1, a], Qinghe Wang[2, b], Wenjuan Cai[3, c], Wen Fu[2, d], Meng Wang[2, e], Qingchang Wang[3, f]

[1]Information Science and Technology College Dalian Maritime University Dalian, China

[2]College of Marine Electrical Engineering Dalian Maritime University Dalian, China

[3]School of Maritime Economics and Management Dalian Maritime University Dalian, China

[a]yarloy@dlmu.edu.cn, [b]aitwqh@dlmu.edu.cn, [c]kjxhcwj@dlmu.edu.cn, [d]18742524075@163.com, [e]wangmen @dlmu.edu.cn, [f]wangqingcgang666@163.com

Keywords: Country's stability, Analytic Hierarchy Process, Grey Model, Time Series Analysis Method, System Dynamics Model

Abstract: Climate change has become a serious problem and has even been proved to have influenced a country's stability. In this paper, country's stability evaluation and prediction system is presented. A comprehensive index named Stability Index to measure a country's stability is produced with the help of Analytic Hierarchy Process. To explain climate change's impact on Stability Index, 4 different forecast models is selected from Grey Relational Model and Time Series Analysis Method to predict other indicators respectively under the assumption of certain indicators from environmental aspects unchanged. The Cubic Exponential Smoothing Method from Time Series Analysis Method is adopt to predict American Stability Index in the future and several intervention plans and establish System Dynamics Model through the relations between the indicators is proposed. Results showed that country's Stability Index can be predicted and intervened, the state can increase Stability Index by investing money through the intervention plans proposed in this paper.

1. Introduction

Climate change, referring to the change of average climate state with time, has become a global concern in recent years [1]. Extreme weather caused by climate change such as acid rain, droughts and hurricanes have interrupted people' life to a large extent. It's estimated that 50 million people are killed in 2010 worldwide because of climate change, accounting for 0.74% of the world's population [2].

Worse still, research shows that climate change can also directly or indirectly influence a country's social and governmental structure [3], or to say, its stability, making it fragile. Situations may become more terrible for those countries whose state is already unstable.

Therefore, it is particularly important to develop a model to measure the level of a country's stability and its correlation with climate change.

Cheng Mo and Wu Yutong studied the vulnerability of agriculture and adaptation strategies under global climate change [4], Liu Xiaoping and others studied the study of the dimensional stability of the country [5]. The common characteristics of the above researches are to explain the impact of climate on national stability from a single perspective, and does not propose intervention policies. Zheng Zhangqin [6] proposed a measure of national stability and intervention policy, but the analysis was not specific enough and no specific intervention plan was given.

For the sake of holistic and objective considerations, this paper analyzes the impact of climate on national stability from multiple angles. In this paper, country's stability evaluation and prediction system is presented. We use the idea of PCA to determine the representative of the 10 indicators that contain almost all information and have the least overlapping. Through the AHP model, we get the weight of each indicator. What's more, we improve our model by normalizing the data and set a standard score system for evaluation after wide research. Then proposes national stability prediction and intervention policies, and specifically gives intervention plans, specifies the cost and return of the intervention plans. It has reference significance to help improve the stability of the country.

Due to the different characteristics of each indicator, we have adopted the corresponding prediction methods based on the Grey Model and the Time Series Analysis Method. Considering that the indicators has correlation in real life but not mutual independent, we create the System Dynamics model (SDM) to make a relevance between the indicators. All of the above make our assessment and prediction of SI more accurate and can propose better intervention plans.

2. AHP MODEL USED TO DETERMINE SI

We develop Stability Index (SI) to represent the stability of a country. After investigation of a great amount of literature, we use the idea of PCA to determine 10 representative indicators that influence SI. We divide the factors into 3 aspects: Economic factors, social factors and environmental factors.

So, there will be three layers of indicators. Indicator I is the comprehensive index of a country's stability, SI. Indicator 2 includes factors that influence SI on a large scale which are Economic Index, Social Index and Environmental Index. Indicator 3 comprises of more detailed factors which we select after deep research. We then build a hierarchy for these indicators as shown in Table 1.

Table 1. Weights of indicators to Stability Index

Indicators	a_1	a_2	a_3	b_1	b_2	b_3	b_4	c_1	c_2	c_3
Weight	0.1667	0.0556	0.1120	0.0121	0.0389	0.0210	0.0390	0.0908	0.2998	0.1650

2.1 Comparison Matrix

We structure comparison matrix to calculate the weight of indicator 2 as following

- Multiply all elements in the judgement matrix: $T_i = \prod_{j=1}^{n} b_{ij} (i = 1, 2, ..., n)$,where b_{ij} is the element in the matrix, b_1 is Primary school enrollment rate, b_2 is Public health expenditure, b_3 is Labor force participation rate(age above 15), b_4 is the total unemployment rate.
- Calculate $\sqrt[n]{T_i} \cdot \vec{w}_i = \overline{\sqrt[n]{T_i}} = \sqrt[n]{\prod_{j=1}^{n} b_{ij}} \, (i = 1, 2, ... n)$
- Normalize $w_i = \dfrac{\overrightarrow{w_i}}{\sum_{i=1}^{n} \overrightarrow{w_i}}$,where $\vec{w}_i$ is the weight of rank of corresponding factors.
- Calculate eigenvalue: $\lambda_{max} = \dfrac{1}{n} \Sigma_{j=1}^{n} \dfrac{(Aw)_i}{w_i}$
- Calculate consistency index: $CI = \dfrac{\lambda_{max} - n}{n-1}$
- Search the mean random consistency index : $RI = \dfrac{\lambda_{max} - n}{n-1}$
- Calculate consistency ratio: $CR = \dfrac{\sum_{i=1}^{n} a_i CI_i}{\sum_{i=1}^{m} a_i RI_i}$
- Where CR<0.10, the result is consistent, where a_1 is GDP per capita, a_2 is GNI per capita, a_3 is GNI annual growth rate.

Then we obtain the weights of Economic Index α .Social Index β and Environmental Index γ as shown in Table 2.

Table 2. Comparison Matrix of Hierarchy 1-2

SI	α	β	γ	Weight
α	1	3	3/5	0.3333
β	1/3	1	1/5	0.1111
γ	5/3	5	1	0.5556

Through calculating the weights of three factors in hierarchy 2, we get λ_{max} =2.971 and CR= 0.0023.

By calculating the weights of the factors affiliated to the corresponding level II in all levels 3, we obtain all their λ_{max} and CR which Consistency Test is right.

Finally, the integrated weight vector of criterion with respect to SI is shown in Table 3.

Table 3. Average Relative Error of Indicators

Indicators	a_1	a_2	a_3	b_1	b_2	b_3	b_4	c_1	c_2	c_3
Average relative Error (%)	2.56	2.92	62.4	1.00	4.84	0.39	14.4	0.15	0.60	4.38

In order to eliminate the impact of units and base [4], we nondimensionalize and normalize our data in different ways for different indicators.

We define $F_j = \sum_{i=1}^{3} x_i w_{ij}, j = \alpha, \beta, \gamma$ where w_{ij} is the weight of indicator i subject to indicator j, as the coefficient of index j from hierarchy 2.

We also define $SI = \sum_{j=1}^{3} F_j W_j$,where W_j is the weight of indicator j from hierarchy 2. We can finally get the score of SI.

We calculate the Stability Index of 12 representative countries, based on the FSI grade criteria of these countries [7], and eventually determine our Stability Index Grading Criteria, as is shown in Table 4.

Table 4. Stability Index Grading Criteria

	Fragile	Vulnerable	Stable
Stability Index	(0,0.35)	(0.35,0.65)	(0.65,1)

Using AHP and quantifiable measurement we finally obtain the measurement of SI. The higher the SI, the more stable the country is. And in the following sections we will apply our model in specific countries to measure their stability.

3. CLIMATE CHANGE'S IMPACT ON SI

3.1 Stability Index Prediction

To determine how climate change may have decreased stability of Chad, we make two assumptions that since 1997, climate change has not been that acute, c_1 and c_2 will not decline as the actual situation.

And then because Grey Model (GM) can make predictions about systems with uncertainties [7] and Time Series Analysis Method can predict by generating series according to existing historical data, we use these two methods respectively for different indicators to see how SI change. Ultimately, we can obtain the climate change's impact on a country's stability.

3.2 Maintaining the Integrity of the Specifications

Our prediction methods for different indicators are shown in Table 5.

Table 5. Prediction Methods for Indicators

Indicators	Prediction method
b_1	GM (2, 1)
b_2	Second Exponential Smoothing Method
c_2	Cubic Exponential Smoothing Method
$a_1, a_2, a_3, b_3, b_4, c_1, c_3$	GM (1, N)

- Assuming c_1 is unchanged, we get that the SI of Chad in 2013 is 0.3337, increasing by 26.98% comparing with the original 0.2628.
- Assuming c_1 and c_2 are unchanged, we get that the SI of Chad in 2013 is 0.3441, increasing by 30.94% comparing with the original 0.2628.

Using our model, we have proved that Chad's instability is partly on account of the declining of public green area and renewable freshwater resources, which are the consequences of climate change. So we can conclude that if Chad could increase vegetation coverage and the utilization of fresh water resources, it may be more stable.

4. Predication of SI

4.1 Model Application and Analysis

We have collected annual data of ten indicators of the United States since 1997 and applied them to our model and obtained SI of the United States from 1997 to 2014 shown in Table 6 and Table 7.

Table 6. Sensitivity of Indicators

Indicator	a_1	a_2	a_3	b_1	b_2	b_3	b_4	c_1	c_2	c_3
Sensitivity	0.109	0.109	0.117	0.070	0.130	0.124	0.076	0.177	0.183	0.177

Table 7. SI of The United States SI (2006-2014)

Age	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Excluding the effect of the economic crisis and exceptional cases, we can see that the SI of the United States from 1997 to 2014 have been declining year by year.

According to our analysis of the data from the World Bank, from 1997 to 2014, the per capita GDP and GNI are continuously growing, GNI growth tends to be stable, primary school enrollment rate is stable and saturated, public health expenditure slowly rises, labor participation rate slowly decreases, unemployment rate due to the economic crisis have a mutation in 2009, and then leveled off, annual rainfall basically remains unchanged, the public green area per capita also gradually increase.

However, the per capita renewable freshwater resources are decreasing rapidly year by year, the labor force participation rate is too low and the population is aging seriously.

Through the analysis of our model, we know that the lack of renewable freshwater resources per capita and the low labor force participation rate lead to the decrease of the American SI year by year.

4.2 Stability Index Prediction

4.2.1 Assumption

- Assume that our prediction is accurate.

• Assume that the cyclical effects of the economic crisis are minute.

4.2.2 Prediction of Stability Index

At first, we used the GM [8] to predict, but found the GM could not display the direction of development in the long term, so we choose the Time Series Analysis Method [9], which makes the forecast data conforms to the tendency of development and the historical development law.

To be precise, we adopted Cubic Exponential Smoothing Method. By selecting the weights accurately, the forecast results for all data in 120 years from 1997 are more accurate in complying with the trend of things and the law of historical development.

Per capita GDP, per capita GNI will gradually increase and show the tendency of saturation, GNI annual growth rate will be more and more tend to be 0, primary school enrollment rate has been saturated, public health expenditure proportion tends to saturation, labor participation rate basically stable, the total unemployment rate increase slowly, forest area of slow growth will slow down after the saturation, renewable freshwater resources per capita exponentially trend down, and annual rainfall in a stable value fluctuate.

For GNI annual growth rate, the total unemployment rate and average annual rainfall, which fluctuate wildly, we adopt the second exponential smoothing method and compare with the cubic exponential smoothing forecast, and choose the results obeys the law of actual development trend more. Average relative error of indicators is shown below:

Table 8. Average relative error I of ndicators

Indicators	a_1	a_2	a_3	b_1	b_2	b_3	b_4	c_1	c_2	c_3
Average relative error	2.56%	2.92%	62.4%	1.00%	4.84%	0.39%	14.37%	0.15%	0.60%	4.38%

4.2.3 Model Evaluation and Results

We use the predicted 10 indicators to evaluate our model.

We have identified a tipping point: the stability index is 0.65 as a clear indicator. If a country's SI changes from above 0.65 to below 0.65 over time, it means the country becomes vulnerable.

We put the predicted indicators into the model and got the final annual stability evaluation results from 1997 to 2117. Through calculation we found that SI of the United States in 2070 is 0.6503 and the SI of the United States in 2071 is 0.6493. Assuming our prediction is correct, that the United States will be transformed from a stable state to a vulnerable state by 2071.The figure of the Prediction of SI of the United States is shown below.

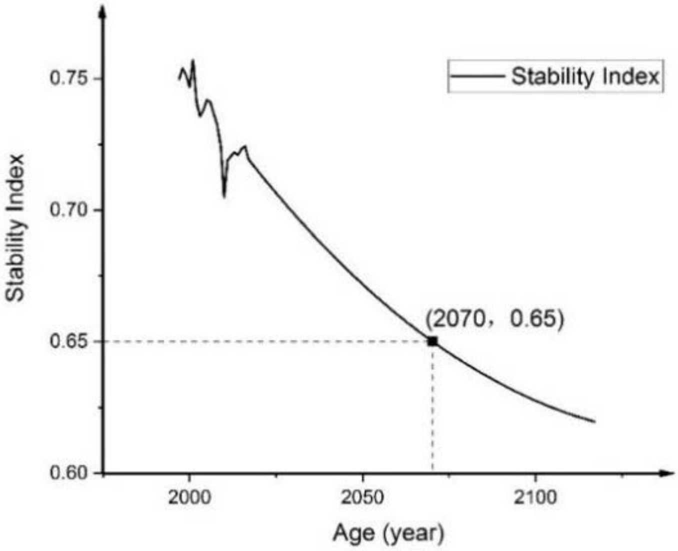


Figure 1. Prediction of SI of the United States

5. Intervention Plans and the Cost

5.1 Plan Making

According to the requirement to reduce the risk of climate change and prevent a country from becoming a fragile state. We decide to offer some plans.

With our analysis on the trends of the three indicators, we develop several initiatives which have different effects for different countries as intervention plans [10] [11].

- Prevent excessive urbanization.
- Increase the vegetation coverage.
- Improve the control of water resources.
- Enhance infrastructure construction.
- Increase public health investment.
- Promote economic development.

Based on the System Dynamics Model and the Grey Model, we use the relevant data in America to verify our intervention plan and calculate the estimated cost.

5.2 Verification by GM and SDM

5.2.1 Model Overview

Since Grey Forecast Model (GM) is appropriate for forecasting development trend with less data, we adopt it to predicting Fj (j=1, 2, 3) in the coming 20 years.

System Dynamics model (SDM) is developed for predicting consequences of interactions among subsystems and analyzing the implications of different policies and programs. In our case, SI consists of three subsystems: Economic system (F1), Social system (F2), and Environmental system (F3). These subsystems affect each other. The interactions in dynamic system is complicated because they not only simultaneously involve various factors, but also dynamically change over time [12]. Therefore, SDM is an appropriate option in our model. Meanwhile, it is handy to analyze how to reduce the risk of climate change.

We design the dynamic system for our indicators and show the relationship between them in Figure 2. To quantitatively analyze the interaction between indicators, we invoke the definition of structure equation modeling and use Three-Stage Least Squares (3SLS) to estimate the parameters in dynamic system equations[13] [14] [15].

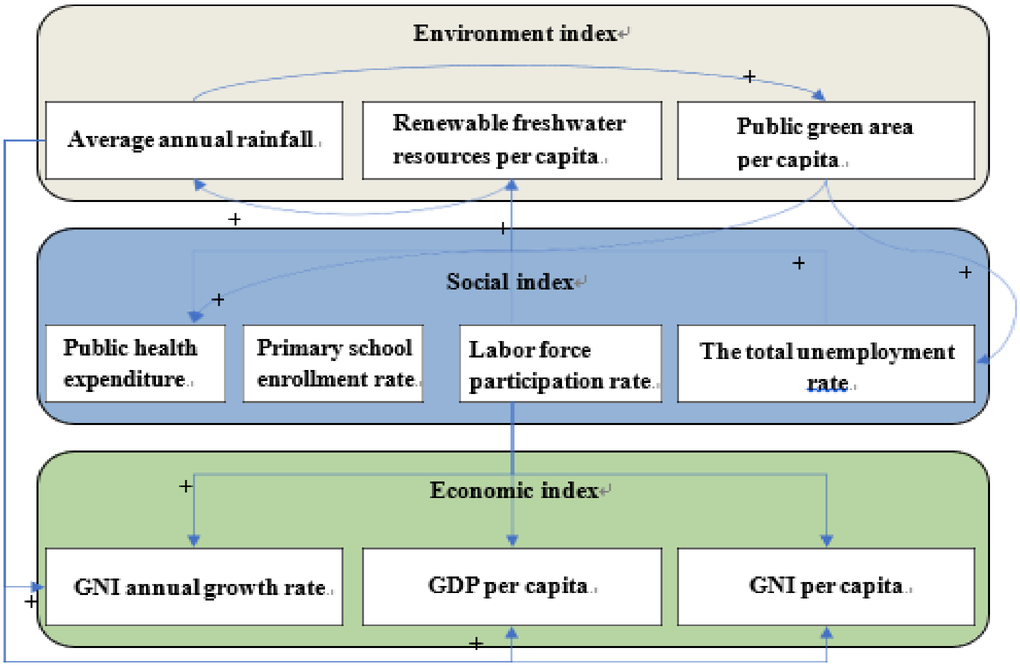


Figure 2. The flow chart of System Dynamics Mode

The parameter estimation result and the meanings of each acronym are demonstrated in Table 9 and Table 10.

Table 9. Estimated Equations of Each Subsystem

Social index	Economic index	Environmental index
$popn1\ (1\ acc)\ popn$ $gdpan\quad gdpap\ gdpn1$ $gdpn\ gdpn1\ gdpan$ $agdpn\ gdpn + popn$ $wpn\ a\ \ln(agdpn\ )\ b$	$fipn\ a(agdpn)\ b$ $acain\ a(gdpn\ )\ b$ $dbpn\ dbn\ gdp$ $ncb\ n\ a\ \ln(sein\ )\ b$	$ra\ a\ \ln(tri)b$ $aar\ n\ ran\ /\ popn$ $fpc\ undn1\ undangp\ gp\ n\ gp\ n1\ gpan$ $cgn\ a\ lnpwin\ b$

Table 10. The Meaning of Each Acronym

Indicator	*Formula Definition*
pop	*Total Population of the Country*
gdpa	*Natural population growth rate*
gdp	*GDP*
agdp	*Index value of GDP per capita*
wp	*Social labor productivity*
fip	*Local fiscal revenue per capita*
acai	*Total investment in fixed assets*
ncb	*Number of climate bills*
ra	*Per capita road area*
aar	*Average annual rainfall*
fpc	*Freshwater per capita*
gp	*Public green area per capita*

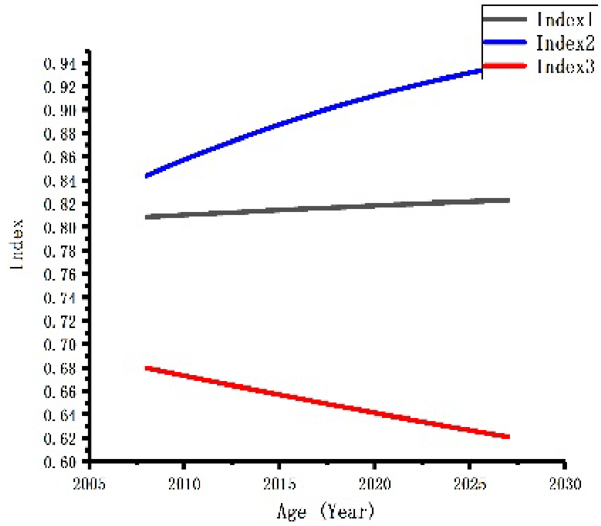
5.2.2 Non-intervention Prediction

We use Grey Forecast Model (GM) to predict the trends without intervention in 20 years by using historical data. The steps of procedure is shown as below.

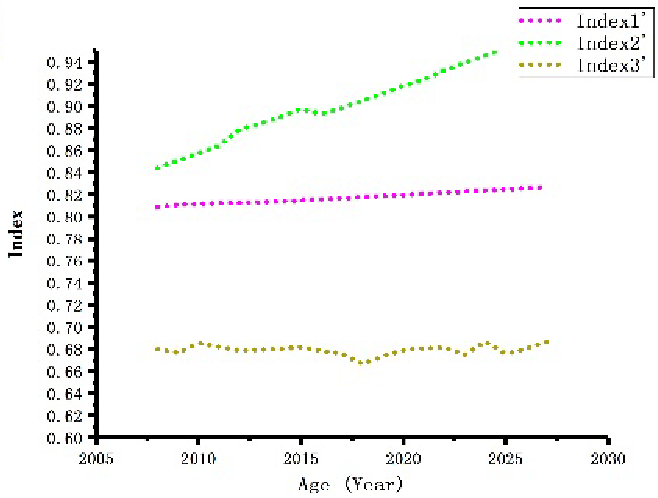
Figure 3 (a) describes the trends of 1 F1, F2 and F3 respectively in America through our calculating consequences. Obviously, we can see that the Economic index and Social index will grow in the next 20 years, especially Social index more rapidly, while the Environmental index is going to fall. Hence, our plan should focus more on the environment in America.

5.2.3 Prediction with the Schemed Plan

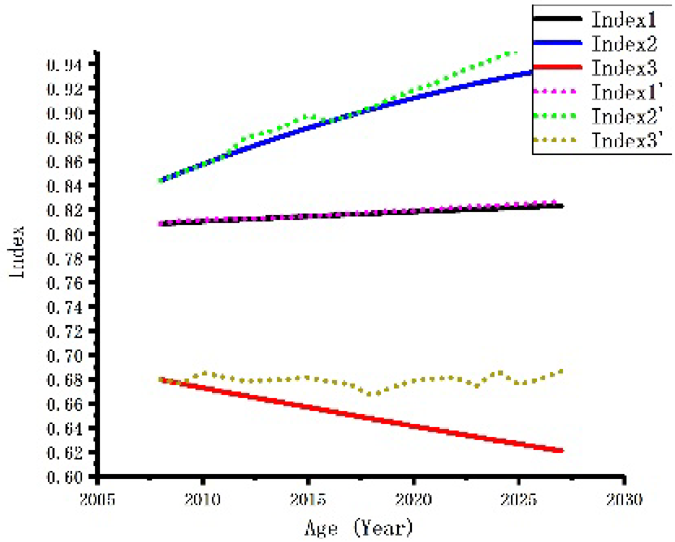
After implementing our schemed plan into the model, our simulation in SDM obtains the values of indicator 2 for each year in the next 20 years. The predicted trend of each indicator is shown in Figure 3 (b).



(a)



(b)



(c)

Figure 3. Trends of Prediction in American

From the comparing figure above, we conclude that our plan has a positive effect on each indicator.

We consider that the characteristics of geography, renewable land and land law in different states are different, so we attempt to perfect our plan in terms of these three aspects. Eventually, we propose two improved pertinent plans as below.

- Increase investment in environmental protection to combat the effects of climate change.
- Increase forest cover.

And based on the System Dynamics Model, we obtain the cost of intervention for this country by calculating Table IX. It accounts for 1.372% of GDP according to the average of several years.

5.2.4 The Cost of Intervention

Due to the different situations in different countries, different intervention plans are needed. So their cost is different, and we calculate 10 countries which have obviously different disparities, their cost accounts for the country's GDP between 0.76% and 2.42%.

6. Sensitivity Analysis

Because the model constructed with AHP has certain subjectivity, the measurement may be biased. So we use sensitivity analysis to evaluate our model by altering the value of indicators to see its influence of on the whole system.

We first select a set of fixed indicators to obtain a stability evaluation. Then, increase the value of each indicator score by 0.1, use fixed incidence matrix to get the corresponding changes of the other nine indicators, thus getting 10 new indicators. We use the following formula to calculate the ratio of SI change rate and the total change rate of the ten indicators.

We define the Sensitivity as S, $S = \frac{\Delta SI / SI}{\sum_{i=1}^{10} \Delta I_i / I_i}$ Stability Index as SI and Ii (i=1, 2, 3,…,10) as the 10 indicators. The sensitivity of ten indexes to the system is as follows:

Table 11. Sensitivity of Indicators

Indicator	a_1	a_2	a_3	b_1	b_2	b_3	b_4	c_1	c_2	c_3
Sensitivity	0.109	0.109	0.117	0.070	0.130	0.124	0.076	0.177	0.183	0.177

The mean sensitivity was 0.127 and the variance was 0.056.

The change of single index has a moderate impact on the whole system, so we can conclude that the model we constructed has a high degree of credibility.

7. Conclusion

In this paper, country’s stability evaluation and prediction system is presented. We use the idea of PCA to determine the representative of the 10 indicators that contain almost all information and have the least overlapping [16].Through the AHP model, we get the weight of each indicator. What’s more, we improve our model by normalizing the data and set a standard score system for evaluation after wide research. Due to the different characteristics of each indicator, we have adopted the corresponding prediction methods based on the Grey Model and the Time Series Analysis Method. Considering that the indicators has correlation in real life but not mutual independent, we create the System Dynamics model (SDM) to make a relevance between the indicators. All of the above make our assessment and prediction of SI more accurate and can propose better intervention plans.

References

[1] Lixi W, Haiyan Y, Nali. Summary of Climate Change Research [J]. Agriculture and Forestry Science and Technology in Ningxia, 2006, (3): 27 - 31.

[2] Jade A C, Lin F G, Zhongwei Y. Review and Prospect of China Research on Extreme Climate Change Observations [J]. Climate and Environment Studies, 2010, 15 (4): 337 - 353.

[3] Long A. Evaluating the effect of international climate change assistance on government structure and policy in the Pacific: a case study from Kiribati [J], 2009.

[4] Cheng Mo, Wu Yutong. The effect of manual intervention on meteorological factors on the weather [J]. Jilin Agriculture, 2017 (23): 96.

[5] Liu Xiaoping, Yu Yue, Chen Yongbo. Climate change affects national vulnerability [J]. Digital communication world, 2018 (09): 220 - 221.

[6] Zheng Zhangqin. Analysis of National Vulnerability Measurement and Intervention Policy Impact [J]. Economic and trade practice, 2018 (17): 233.

[7] Nondimensionalization [J], 2010.

[8] Shi M, Jiang L, Fu Y. Study on Prediction Methods for the Fault State of Rotating Machinery Based on Dynamic Grey Model and Metabolism Grey Model [J]. Wireless Personal Communications, 2018.

[9] Higuchi T, Kitagawa G. Special Section on Nonparametric Approach to Time Series Analysis [J]. Annals of the Institute of Statistical Mathematics, 2002, 54 (1): 169 - 169.

[10] Jepma C J, Munasinghe M. Climate Change Policy [J]. Ethics Policy & Environment, 2000, 372 (3): 108 - 111.

[11] Shove E. Beyond the ABC: climate change policy and theories of social change [J]. Environment & Planning A, 2010, 42 (6): 1273 - 1285.

[12] Zhang Bo Y Z-H, Sun Qiang, Li Shun, Huang Ming-Xiang, Wang Li-Qiang. An Overview of System Dynamics and Its Related Software [J].

[13] He Nan Z S I O I T I B O T-S L S M J J O U T, 2014, 12 (05): 72-77 + 71.

[14] Zellner A, Theil H. Three-Stage Least Squares: Simultaneous Estimation of Simultaneous Equations [J]. Econometrica, 1962, 30 (1): 54 - 78.

[15] Zhang Weimin. Beijing city sustainable development comprehensive evaluation research [D]. Beijing University of Technology, 2002 [J].

[16] Xuehui R, Ying L, Jian W. Climate Comfortability of Human Settlements in Northern Coastal Cities in Recent 60 Years - A Case Study of Liaoning Province [J]. Journal of Natural Resources, 2013, 28 (5): 811 - 821.