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Research on Applying a CRITIC-Based ARIMA Model to Predict the Number of Nuclear Weapons

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Abstract. Nuclear weapons are among the most destructive weapons and can swiftly devastate cities and even entire countries. Accordingly, analyzing the scale of nuclear arsenals is closely related to international security. Using nuclear-weapon data from multiple countries, This research formulates an Auto-regressive Integrated Moving Average (ARIMA) model and combines it with the CRITIC method to forecast how many countries may possess nuclear armaments in future times. To estimate the future number of nuclear-armed countries more accurately, a comprehensive evaluation model is constructed by considering factors such as each country's industrial and economic level and its willingness to develop nuclear weapons, and scores of each country are calculated. The high scorer believes that the country will have nuclear weapons in the future. In addition, the local outlier factor algorithm (LOF) is used to screen the data of past nuclear weapons inventory changes. After screening, the cleaned data are fed into the ARIMA model to obtain forecasts of the future number of nuclear weapons.

Keywords: Nuclear weapon, Critic, Arima, Lof

1. Introduction

Nuclear weapon is a highly destructive weapon, and its development history can be traced back to World War II. The development and harm of nuclear weapons is an extremely complex issue, involving many fields such as politics, military, science and technology. Since World War II, nuclear weapons have become a symbol of competition for global hegemony and status among nations, but they also bring great uncertainty and risk [1,2].

Analyzing which countries have nuclear weapons in the future is of great significance for the forward-looking deployment of future international security strategies, and it also has an indicative effect on the development of international relations between countries in the future. ARIMA-based forecasting [3-5] uses historical observations to project future values of a variable, and it can also be used to infer how a variable may change when the value of another variable changes. Because the country 's future possession of nuclear weapons is affected by many factors, the ARIMA model cannot predict multi-factor events. The idea of weight is introduced here. The common weight calculation methods are coefficient of variation method [6], entropy weight method [7], and CRITIC. To address the limitation that the coefficient of variation method and the entropy weight method derive weights mainly from the degree of data variation while potentially neglecting the

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intrinsic importance of the indicators, this study adopts CRITIC [8-10] to calculate the weights of three influencing factors: whether the country is willing to develop nuclear weapons, whether it is at present working on nuclear weapons, and how many countries already own nuclear arsenals. Based on these weights, a CRITIC-weighted ARIMA model is implemented to estimate the future number of nuclear-armed states. Meanwhile, considering factors such as each country's industrial and economic level and its willingness to develop nuclear weapons, A comprehensive evaluation model [11,12] is constructed to quantify the likelihood that each country will acquire nuclear weapons, exclude countries that already have nuclear weapons, and—based on the predicted total—identify the top candidates most likely to possess nuclear weapons in the future.

The holding of nuclear arsenals could bring potential hazards to the planetary environment and human survival. Moreover, the size of each country's nuclear stockpile can reflect its stance toward nuclear-weapons research, which may in turn influence its international standing, security situation, economic development, and other aspects [13,14]. Therefore, predicting nuclear-weapon quantities is important for human security and for assessing national strategic security. In the past, it was affected by historical factors such as arms competition, which led to some data anomalies. Here, abnormal observations are filtered using the LOF algorithm [15,16]. Following the screening procedure, the purified data are introduced into the ARIMA model to estimate the future count of nuclear weapons. Finally, the average share of nuclear weapons held by each country over the past two decades is computed, and this proportion is used to estimate each country's future holdings.

2. Proposal and establishment of ARIMA model based on CRITIC method

Since a country's future nuclear-weapon status is related to whether it is willing to develop nuclear weapons, whether it is currently developing nuclear weapons, and how many countries already possess nuclear weapons. First, it is examined whether these three factors affect a country's future acquisition of nuclear weapons and the strength of their influence.

The CRITIC weighting technique is adopted to assess the influence of the three elements on subsequent outcomes. The resulting weights are incorporated into a time series forecasting model to build an improved forecasting framework for predicting nuclear-weapon development over the next 100 years.

2.1. CRITIC

The shortcomings of the standard deviation method are very obvious. The larger the data in the index, the greater the proportion ; the disadvantage of the entropy weight method is that when the indicators are not independent of each other, it cannot consider the correlation between the indicators.

Compared with the above two methods, the CRITIC method comprehensively considers the variability and correlation of the indicators, and makes a relatively scientific evaluation through the objective attributes of the data itself.

2.1.1. Matrixization of data

Let's assume that you have n sample groups to evaluate, evaluation indices p, and a matrix of output indices is generated.

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$$X = \begin{pmatrix} x_{11} \cdots x_{1p} \\ \vdots \\ x_{n1} \cdots x_{np} \end{pmatrix} \tag{1}$$

where x_{ij} represents the numerical value of the j-th evaluation criterion corresponding to the i-th sample.

2.1.2. Dimensionless treatment

Dimensionless data processing basically solves the problem of data comparability, which is also the most important goal of standardized data processing. In this case, the exponential weights are calculated using the CRITIC method, and the data is usually forward or reversed.

Forward or reverse transformation: for beneficial indicators, higher values indicate better performance:

$$x_{ij}^{'} = \frac{x_j - x_{\min}}{x_{\max} - x_{\min}} \tag{2}$$

For cost-type (contrarian) indicators, lower values indicate better performance:

$$T_{ij}^{'} = \frac{T_{\max} - T_j}{T_{\max} - T_{\min}} \tag{3}$$

2.1.3. Indicator variability

Determine the mean value and the dispersion degree of the j-th evaluation criterion

$$\begin{cases} \overline{x}_j = \frac{1}{n} \sum_{i=1}^{n} x_{ij} \\ S_j = \sqrt{\frac{\sum_{i=1}^{n} \left(x_{ij} - \overline{x}_j\right)^2}{n-1}} \end{cases} \tag{4}$$

S_j represents the standard deviation associated with the j-th indicator.

2.1.4. Conflicting indicators

It can be depicted by means of the correlation coefficient:

$$R_j = \sum_{i=1}^{p} \left(1 - r_{ij}\right) \tag{5}$$

r_{ij} represents the correlation coefficient measuring the relationship between evaluation indicators i and j., capturing the relationship between the two datasets.

2.1.5. Calculate the amount of information

The larger the C_j , the greater the impact of the corresponding index on the event.

$$C_j = S_j \sum_{i=1}^{p} \left(1 - r_{ij}\right) = S_j \times R_j \tag{6}$$

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2.1.6. Compute objective weights

The weight W_j of the jth index calculated by CRITIC weighting method is :

$$W_j = \frac{C_j}{\sum_{j=1}^{p} C_j} \tag{7}$$

Table 1 reports the CRITIC-derived weights:

Table 1. CRITIC weight calculation results

	Indicator variability	Indicator conflict	Amount of information	weight
Consider development in the future	2.897	2.421	7.014	40.54%
Is developing	1.911	1.772	3.387	19.58%
Already owned	2.993	2.305	6.899	39.88%

Chart 1 indicates that the weights for "consider development in the future" and "already owned" are both close to 40%; together they account for more than 80%, suggesting that these two factors dominate the subsequent results.

2.2. ARIMA model

2.2.1. AR model (autoregressive)

Once data of the variable itself is used to predict it. The mathematical model is described as follows:

$$y_t = \mu + \sum_{i=1}^{p} T_i y_{t-1} + \epsilon_t \tag{8}$$

y_t is the current value, μ is the constant term, p is the order, r is the autocorrelation coefficient, ϵ_t is the error.

2.2.2. MA model (moving average)

In the MA model, the accumulation of incorrect terms and the mathematical model is as follows:

$$y_t = \mu + \epsilon_t + \sum_{i=1}^{q} \theta_i \epsilon_{t-i} \tag{9}$$

y_t is the current value, μ is the constant term, ϵ_t is the error, q is the autoregressive order.

2.2.3. ARIMA model

The ARIMA(p,d,q) model integrates an autoregressive term with a moving-average term; its mathematical form is:

$$y_t = \mu + \sum_{i=1}^{p} r_i y_{t-1} + \epsilon_t + \sum_{i=1}^{q} \theta_i \epsilon_{t-i} \tag{10}$$

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2.3. Establish a CRITIC-based ARIMA model prediction model

Use CRITIC to calculate the weights of the three elements on the impact of future events. They are weighted 0.4054, 0.1958 and 0.3988 respectively.

$$D_{i+1} = [(w_1 - \bar{w})a_{1i} + (w_2 - \bar{w})a_{2i} + \cdots + (w_j - \bar{w})a_{ji}] + d_i \tag{11}$$

Because this article considers only three sets of factors for the impact of future quantities, the formula can be

$$D_{i+1} = [(w_1 - \overline{w})a_{1i} + (w_2 - \overline{w})a_{2i} + (w_3 - \overline{w})a_{3i}] + d_i \tag{12}$$

$$a_{3i} = d_i \tag{13}$$

D_{i+1} denotes the number of nuclear-weapon states in year i+1 forecast by the CRITIC-based ARIMA model; d_i denotes the number of nuclear-weapon States in year i predicted by the ARIMA model; a_{ji} denotes the value for year i predicted by the jth factor based on the ARIMA model.

When $w_1 - \bar{w} > 0$, it indicates that the expected value of the group of elements has a greater impact on the future quantity than the average expected value, so it is necessary to add the less expected part, and $w_1 - \bar{w} < 0$ indicates that the expected value of the group of elements is less than the average expected value, so it is necessary to subtract the lower expected part.

Table 2 presents the parameter estimation results of the ARIMA model used to forecast the future development of the number of nuclear-weapon states:

Table 2. Consider development in the future

item	symbol	coefficient	Standard error	95% CI
Constant terms	c	0.012	0.107	-0.198 ~ 0.222

AIC: 239.314

BIC: 244.176

Obviously, when the order of the ARIMA model is higher, its ability to describe the object sample is stronger. However, when the order is higher, the parameters are more, which is easy to cause the phenomenon of over-fitting. Therefore, it is necessary to find a measurement tool to determine the optimal order. Commonly used information criteria consist of the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). On the whole, a lower AIC implies a more appropriate model fitting.

Table 2 summarizes the analysis of the number of states that plan to develop nuclear weapons in the future. The optimal specification is ARMA(0,1,0), and the model can be written as: y(t)=0.012.

Figure 1 shows the ARIMA-based projection of the future number of nuclear-weapon States.

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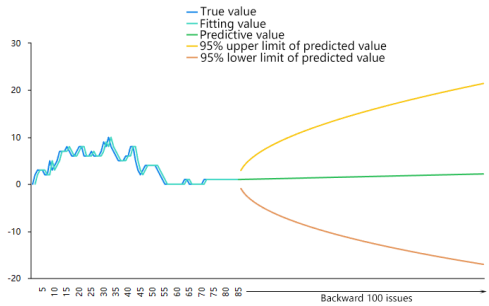

Figure 1. Projections for the number of countries considering development in the future

Parameter estimation for the ARIMA model applied to the number of developing nuclear-weapon states is reported in Table 3.

Table 3. Analysis results for the number of developing nuclear-weapon States

item	symbol	coefficient	Standard error	95% CI
Constant terms	c	0.209	0.134	-0.054 ~ 0.472
AR	α1	1.083	0.123	0.841 ~ 1.324
	α2	-0.170	0.115	-0.395 ~ 0.055

AIC: 196.110

BIC: 205.881

As shown in Table 3, AR(2) is selected as the optimal model for the number of developing nuclear-weapon states, with the model expression: y(t)=0.209+1.083*y(t-1)-0.170*y(t-2).

Figure 2 displays the ARIMA-based forecast of the number of developing nuclear-weapon States.

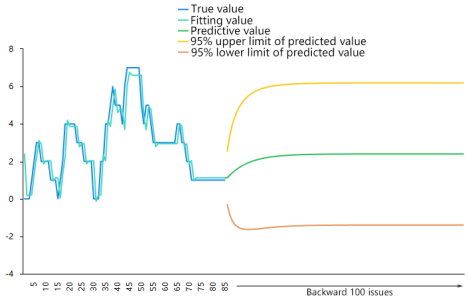

Figure 2. Quantitative modelling and projections of nuclear-weapon states are being developed

Table 4 lists the ARIMA parameter estimates used to model the total number of nations with nuclear weapons:

Table 4. ARIMA-based forecast results for countries possessing nuclear weapons

item	symbol	coefficient	Standard error	95% CI
Constant terms	c	0.107	0.063	-0.016 ~ 0.231

AIC: 79.175

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BIC: 84.036

Table 4 summarizes the forecasting results for the total number of nations with nuclear weapons. The optimal model is ARMA(0,1,0), and the model formula is: y(t)=0.107.

Figure 3 presents the ARIMA-based projection of the total number of nations with nuclear weapons.

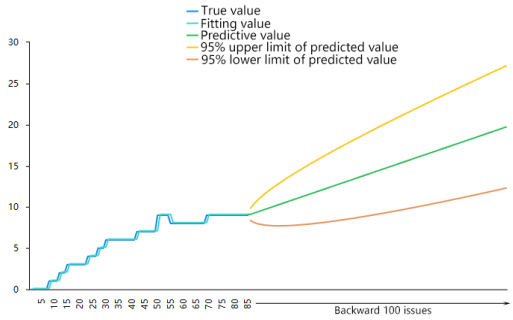

Figure 3. ARIMA-model projections for countries possessing nuclear weapons

The projected number of nuclear-weapon states under the CRITIC-adjusted ARIMA framework is shown in Figure 4.

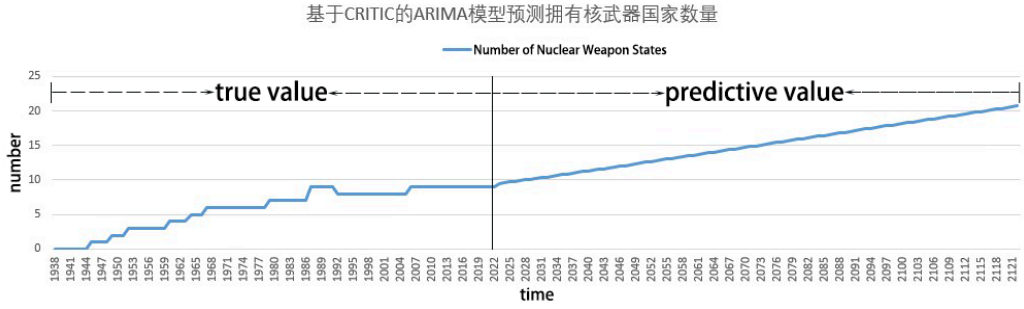

Figure 4. Projected number of countries with nuclear weapons

By combining the three factors with their respective weights, the model indicates that 21 countries may possess nuclear weapons 100 years from now, including the nine current nuclear-weapon states: the United States, Russia, France, China, the United Kingdom, India, Pakistan, North Korea, and Israel. The remaining countries appear in the top 12 and are therefore regarded as likely to become nuclear-armed.

Based on the collected information on the industrial and economic levels of a number of countries, this paper infers that the following twelve countries may possess nuclear weapons in the future: Japan, Germany, South Korea, Canada, Australia, Italy, Switzerland, Norway, Saudi Arabia, Ireland, Brazil, Spain.

3. Using the ARIMA model to forecast the number of nuclear weapons over the next 100 years

To forecast nuclear-weapon trends over the next 100 years. First, the evolution of nuclear arsenals in recent decades is reviewed, and the main patterns are summarized. Subsequently, a differenced autoregressive moving-average model is constructed to forecast both the overall quantity of nuclear armaments and the nuclear stockpile of each nation over the next century.

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3.1. Local outlier factor

The future is peaceful, and the past is influenced by historical factors, arms race and other reasons that lead to some data anomalies. Here, the local anomaly factor method is introduced to remove the abnormal data. The LOF algorithm (Local Outlier Factor) is a commonly used anomaly detection algorithm that can be used to identify outliers in a dataset. The core idea is to compare each observation with its neighbors and evaluate how anomalous it is by computing the local density around it.

It should be noted that the LOF algorithm is very CRITICal to the choice of parameter k, small k values will lead to overly sensitive results, and larger k values may mask minor anomalies. In general, Approaches including cross-validation can be employed to determine the optimal k value.

The local outlier factor method was applied to the data from 1961 to 1991, and many anomalies can be attributed to historical factors; during the period of the United States and the Soviet Union, nuclear-weapon numbers fluctuated sharply, and 1945-1960 corresponds to the early stage of nuclear-weapons development. Because these data are not representative, In this paper, the fluctuations in nuclear weapons numbers over the past two decades are adopted as the foundation for subsequent predictions.

3.2. Forecasting the number of nuclear weapons by country over the next 100 years

The ARIMA model is built, and the results are reported in Table 5.

Table 5. Parameter estimates for future nuclear-weapon projections

item	symbol	coefficient	Standard error	95% CI
Constant terms	c	-0.329	127.294	-249.821 ~ 249.163

AIC: 1284.436

BIC: 1289.097

The results of nuclear weapon storage prediction analysis are shown in Table 5. The optimal model is ARMA (0,2,0), and the model formula is:y(t)=-0.329. Figure 5 illustrates the ARIMA-based projection of nuclear-weapon stockpiles over the next 100 years.

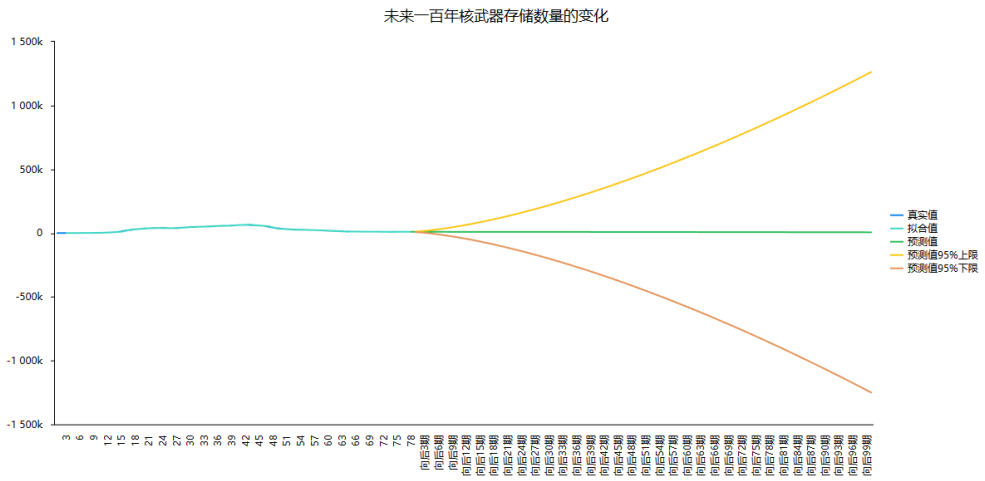

Figure 5. Projected trajectory of nuclear-weapon stockpiles over the next 100 years

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In the end, the model predicted that there would be about 5979 nuclear weapons in a hundred years. However, anomalies detected by the LOF algorithm in the decades preceding nuclear-weapon possession do not reflect the future evolution of nuclear-weapon numbers. Accordingly, this study uses changes in nuclear-weapon numbers over the past two decades as the baseline and extrapolates forward for the next 100 years from that basis.

$$\frac{1}{20}\sum_{1}^{20}\frac{x_i}{y_i} \tag{14}$$

x_i denotes a country's nuclear-weapon inventory in year i, and y_i denotes the worldwide aggregate number of nuclear armaments in year i.

Using the approach in Table 6, each country's share of nuclear weapons after 100 years is calculated, and the corresponding projected quantities are reported in Table 7.

Table 6. Proportion of nuclear weapons by country after 100 years

Country	Percentage
China	0.02237
France	0.02635
India	0.008101
Israel	0.006898
North Korea	0.00064
Pakistan	0.008872
Russia	0.45684
South Africa	0
United Kingdom	0.01896
United States	0.450966

Table 7. Projected nuclear-weapon stockpiles by country after 100 years

Country	China	France	India	Israel	North Korea	Pakistan	Russia	South Africa	United Kingdom	United States
quantity	134	158	48	41	4	53	2731	0	113	2696

Unit: pcs

Tables 6 and 7 suggest that, even if The worldwide total stockpile of nuclear weapons is projected to decline in the coming years, the United States and Russia are still likely to hold roughly 90% of the world's nuclear weapons for a long time, which is broadly consistent with their current share of the global total.

4. Conclusion

Based on the application of ARIMA model based on CRITIC in the prediction of nuclear weapons quantity, the following conclusions are drawn:

(1) Since a country's future possession of nuclear weapons is influenced by multiple determinants, a conventional ARIMA model is unable to directly capture such multi-factor dynamics. To address this limitation, the concept of weighting is incorporated, and The CRITIC technique is adopted to ascertain the weighting values of three key influencing factors: a country's

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willingness to develop nuclear weapons, its current development status, and the count of nucleararmed states in the world. Based on these weights, A hybrid ARIMA model incorporating the CRITIC technique is constructed to estimate the future quantity of nuclear-weapon states. The findings indicate that 21 countries may possess nuclear weapons in the future. Meanwhile, a comprehensive evaluation framework is developed to assess the probability of nuclear-weapon possession by taking into account each country's industrial and economic capacity as well as its willingness to pursue nuclear development. Existing nuclear-weapon states—namely the United States, Russia, France, China, the United Kingdom, India, Pakistan, North Korea, and Israel—are excluded from this assessment. According to the projection results, the leading candidate countries most likely to acquire nuclear weapons in the future include Japan, Germany, South Korea, Canada, Australia, Italy, Switzerland, Norway, Saudi Arabia, Ireland, Brazil, and Spain.

(2) Historically, phenomena such as arms races have led to irregular fluctuations in the dataset; therefore, The Local Outlier Factor (LOF) algorithm is applied to detect and eliminate abnormal observations. Since the period from 1961 to 1991 contains numerous abnormal data points, and 1945–1960 corresponds to the initial phase of nuclear-weapons development, these intervals are excluded from the reference framework. Consequently, this study adopts the changes in nuclear-weapon numbers over the most recent two decades as the baseline, and the filtered data are then input into the ARIMA model to project future stockpile levels. Furthermore, by calculating the average share of historical nuclear weapon inventories by country in the last two decades, these proportions are applied to estimate the future distribution of nuclear weapons among countries. Based on this estimation, the projected numbers of nuclear weapons for China, France, India, Israel, North Korea, Pakistan, Russia, South Africa, the United Kingdom, and the United States are 134, 157, 48, 41, 4, 53, 2731, 0, 113, and 2696, respectively.

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