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# COVID-19 PROJECTIONS ON JAVA AND BALI ISLANDS INVOLVING VACCINATION AND TESTING INTERVENTIONS USING VARI-X MODEL

**Riza Andrian Ibrahim [1], Budi Nurani Ruchjana[2*]**

[1]*Doctoral of Mathematics Study Program, Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran*
[2]*Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran Raya Bandung-Sumedang Street KM. 21, Jatinangor District, Sumedang Regency, West Java, 45363, Indonesia*

*Corresponding author's e-mail: * **budi.nurani@unpad.ac.id***

## ABSTRACT

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*The Indonesian government implemented the policy of increasing vaccination and testing of Covid-19 for travel from or to the Java and Bali Islands to reduce the Covid-19 projected spread in there. As participation in these efforts, this study aims to project the Covid-19 spread measured by the active case rates by involving the intervention of vaccination and testing of Covid-19 in the two islands. Projections are performed using a vector of autoregression integrated with the exogenous variables (VARI-X) model. This model is used because it can simultaneously project the Covid-19 spread in the two islands by involving interventions of vaccination and testing of Covid-19 as exogenous variables. The most suitable model obtained is VARI-X (4, 2, 0). The mean-absolute-percentage error (MAPE) of the model for the Java and Bali Islands is 5.3027% and 3.0301%, respectively. Based on the MAPE value, the model is very accurate for projecting the future Covid-19 spread on the two islands. This accuracy can be seen practically from the Covid-19 spread projection results in the next four days, which are very close to the actual data. This research is expected to help the Indonesian government project the spread of Covid-19 on the Java and Bali Islands.*



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# 1. INTRODUCTION

As measured by the daily active case rate, the spread of Covid-19 in Indonesia, especially on the Java and Bali Islands, experienced a rapid increase from June to July 2021. The highest records of the active case rates of Covid-19 on the Java and Bali Islands happened from June to July 2021. On 9 July 2021, the highest recorded active case rates of Covid-19 on the Java and Bali Islands were 46.13% and 3.64%, respectively. This unpleasant record continues to be broken daily, and until 30 September 2021, the highest recorded active case rates of Covid-19 on the Java and Bali Islands were 65.49% and 13.80%, respectively.

The cause of this rapid increase in daily Covid-19 active case rates is the presence of a more contagious Covid-19 variant, the Delta variant [1]. This variant came when people's mobility conditions in Java and Bali increased after almost a year of being hit by Covid-19. Public places like restaurants and tourist attractions were opened, and travel between regions was allowed. This condition was exacerbated by people getting tired, stressed, and bored to maintain discipline in complying with the Covid-19 health protocol [2], [3]. In addition, the vaccination coverage carried out is also still minimal. Based on these situations, the Indonesian government must issue a new policy to reduce the projected Covid-19 active case rates on Java and Bali Islands.

One of the policies carried out by the Indonesian government to reduce the active case rates of Covid-19 in the Java and Bali Islands was to accelerate vaccination in the community [4]. This policy aims to strengthen the community's immune system so that the possibility that people will be infected with Covid-19 is slight. In addition, the possibility that people exposed to Covid-19 will recover is also great [5]. Acceleration of vaccination was carried out from June to July 2021. This program is aimed at the general public, especially adolescents aged 12 to 17 years, vulnerable groups such as residents of correctional institutions, and persons with disabilities. With this policy, the projected active case rates of Covid-19 are expected to decrease.

Another policy carried out by the Indonesian government through the Minister of Home Affairs is the policy of Implementation of Emergency Community Activity Restrictions (PPKM) for the islands of Java and Bali. This policy started on 3 July 2021. The policy is broadly aimed at limiting community activities. One of these restrictions is travel restrictions from or outside the Java and Bali Islands [6]. Only people who can show the results of the Covid-19 test are allowed to travel. There are two types of Covid-19 test results shown. The first type is the antigen test result one day earlier. This test can be used for travel from or to the Java and Bali Islands via land and sea transportation. Then the second type of Covid-19 test is the polymerase chain reaction (PCR) test two days earlier. This test is used for air transportation travel from or to the Java and Bali Islands. With this policy, people who come or go to the Java and Bali Islands have a tiny chance of spreading Covid-19 [7]. It is certainly expected to reduce the projected active case rates of Covid-19 in the two islands in the future.

The projected active case rates of Covid-19 are closely related to the time series forecasting problem. Therefore, several studies regarding the projected Covid-19 transmission on the Java or Bali islands using a time series approach are briefly described in this paragraph. In addition, the novelty of this study is also described in this paragraph. Wirawan and Januraga [8] projected the maximum number of confirmed cumulative cases and bed capacities in the intensive care unit (ICU) Covid-19 on Bali Island. They were considering the intervention of any policy in the projection process. They used the susceptible, exposed, infected, and recovered (SEIR) model. Then, Jaya and Folmer [9] mapped spatiotemporal patterns and projected the status of Covid-19 transmission from districts in East Java province. They used a spatiotemporal Bayesian model. Pasaribu et al. [10] projected daily Covid-19 positive cases in six provinces on Java Island. They used a generalized space-time autoregressive (GSTAR) model with a distance weight matrix determined based on the train route between the six provinces. Subiyanto et al. [11] projected the cumulative number of Covid-19 cases in West Java province during the Large-Scale Social Restrictions period. They apply the susceptible, infected, and recovered (SIR) model to project it. Based on the previous study descriptions, there has yet to be researched on the projected Covid-19 active case rates on the Java and Bali Islands involving the intervention of vaccination and testing of Covid-19. Therefore, this is a gap that is a novelty of this study.

Based on this preliminary description, this study aims to project the daily active case rates of Covid-19 in the Java and Bali Islands with the interventions of vaccination and testing of Covid-19. The model used to perform the projection is a vector of autoregression integrated with the exogenous variables (VARI-X) model. The model is used because it can simultaneously project the active case rates of Covid-19 in the two islands involving the interventions of vaccination and testing of its as exogenous variables. The Covid-19 vaccination is represented by the cumulative first-dose vaccination rates. It is conducted because the Indonesian government targeted it at this time. Then, the Covid-19 testing is represented by the daily ratio between the cumulative test done and the number of citizens of the Republic of Indonesia. For the Indonesian government, this research can assist in projecting active case rates of Covid-19 in the Java and Bali Islands.

## 2. RESEARCH METHODS

### 2.1 Materials

This study material is divided into two, the material of data and the material of tools. The material of data is the observation data used, while the material of tools is the devices used in processing the material of data. The material data used in this study are as follows:

1. The daily Covid-19 active case rate data on Java and Bali Islands.
2. The cumulative first-dose Covid-19 vaccination rate data in Indonesia
3. The cumulative Covid-19 test rate data in Indonesia.

All data considered is from 26 July 2021 to 26 September 2021. The three data were obtained on the website https://covid.go.id and accessed on 1 October 2021. Meanwhile, the tool material used is software R version 4.1.2 and Microsoft Excel 2016. The R software is used in determining the order and parameter of the VARI-X model, while the Microsoft Excel software is used to predict and determine the mean-absolute-percentage error size of the model.

### 2.2 Mathematical Notations and Assumptions

The basic mathematical notations used are as follows:

1. $y_{1,t}$ represents the active case rates of Covid-19 on Java Island on day $t$.
2. $y_{2,t}$ represents the active case rates of Covid-19 on Bali Island on day $t$.
3. $x_{1,t}$ is the Covid-19 vaccination rate of Indonesian citizens on day $t$.
4. $x_{2,t}$ is the Covid-19 testing rate from Indonesian citizens on day $t$.
5. $\Delta^d$ represents the differentiation operator $d$ times.
6. $e_{k,t}$ represents white noise.
7. $r$ denotes autoregression order.
8. $s$ represents exogenous order.

Meanwhile, the assumptions used in this study are as follows:

1. $\Delta^d y_{k,t}$ and $\Delta^d x_{m,t}$ with $k = 1,2$ and $m = 1,2$ are stationary in mean and variance. In other words, the expectation and variance of $\Delta^d y_{k,t}$ are the same for all $t$, and the expectation and variance of $\Delta^d x_{m,t}$ are also the same.
2. $e_{k,t}$ is a sequence of independent and identically normally distributed random variables with zero vector mean and variance of the covariance matrix.
3. $x_{m,t}$ and $e_{k,t}$ are assumed to be independent.

### 2.3 Vector of Autoregression Integrated with Exogenous Variables (VARI-X) Model

The vector of autoregression integrated with exogenous variables (VARI-X) model is a multivariate time series model used to causally project several objects in the future based on the values of these objects in the past with the addition of intervention from exogenous variables that influence them. In this study, the VARI-X model is used to project the active case rates of Covid-19 on Java and Bali Islands with interventions of vaccination and testing of its. In general, the VARI-X form in this research case is as follows [12], [13]:

$$\Delta^d y_{k,t} = \sum_{i=1}^{r} \sum_{l=1}^{2} \phi_{kl,i} \Delta^d y_{l,t-i} + \sum_{j=0}^{s} \sum_{n=1}^{2} \psi_{kn,j+1} \Delta^d x_{n,t-j} + e_{k,t}, \quad (1)$$

where $\phi_{kl,i}$ and $\psi_{kn,j+1}$ represent autoregression and exogenous coefficients, respectively. The model in Equation (1) is often referred to as the VARI-X $(r, d, s)$ model. Equation (1) can also be converted into matrix and vector multiplication as follows [12], [14]:

$$\Delta^d \mathbf{y}_t = \sum_{i=1}^{r} \mathbf{\Phi}_i \Delta^d \mathbf{y}_{t-i} + \sum_{j=0}^{s} \mathbf{\Psi}_{j+1} \Delta^d \mathbf{x}_{t-j} + \mathbf{e}_t, \tag{2}$$

where

$$\Delta^d \mathbf{y}_t = \begin{bmatrix} \Delta^d y_{1,t} \\ \Delta^d y_{2,t} \end{bmatrix}, \Delta^d \mathbf{x}_t = \begin{bmatrix} \Delta^d x_{1,t} \\ \Delta^d x_{2,t} \end{bmatrix}, \mathbf{\Phi}_i = \begin{bmatrix} \phi_{11,i} & \phi_{12,i} \\ \phi_{21,i} & \phi_{22,i} \end{bmatrix}, \mathbf{\Psi}_j = \begin{bmatrix} \psi_{11,j} & \psi_{12,j} \\ \psi_{21,j} & \psi_{22,j} \end{bmatrix}, \text{ and } \mathbf{e}_t = \begin{bmatrix} e_{1,t} \\ e_{2,t} \end{bmatrix}.$$

There are several criteria to determine autoregressive order $r$ and exogenous order $s$. These criteria include the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC). The BIC and AIC of the VARI-X $(r, d, s)$ model can be determined respectively by the following equation [12]:

$$BIC = \ln(|\mathbf{\Sigma}|) + 2\frac{K}{T}\ln T, \tag{3}$$

and

$$AIC = \ln(|\mathbf{\Sigma}|) + 2\frac{K}{T}, \tag{4}$$

where $K$ represents the number of parameters to be estimated, $T$ represents the number of observation data, and $\mathbf{\Sigma}$ represents the covariance matrix of $\mathbf{e}_t$.

### 2.4 Parameter Estimation of the VARI-X Model with the Least Square (LS) Method

Estimating the VARI-X model parameters in Equation (1) can be done via the least squared method. Suppose that the autoregression order $r$ is greater than the exogenous order $s$. Equation (1) can be written as follows:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{e}, \tag{5}$$

where

$$\mathbf{y} = \begin{bmatrix} \Delta^d y_{1,r+1} \\ \Delta^d y_{2,r+1} \\ \vdots \\ \Delta^d y_{1,T} \\ \Delta^d y_{2,T} \end{bmatrix}, \mathbf{\theta} = \begin{bmatrix} \phi_{11,1} \\ \phi_{12,1} \\ \phi_{21,1} \\ \phi_{22,1} \\ \vdots \\ \phi_{11,r} \\ \phi_{12,r} \\ \phi_{21,r} \\ \phi_{22,r} \\ \theta_{11,1} \\ \theta_{12,1} \\ \theta_{21,1} \\ \theta_{22,1} \\ \vdots \\ \theta_{11,s} \\ \theta_{12,s} \\ \theta_{21,s} \\ \theta_{22,s} \end{bmatrix}, \mathbf{e} = \begin{bmatrix} e_{1,r+1} \\ e_{2,r+1} \\ \vdots \\ e_{1,T} \\ e_{2,T} \end{bmatrix}, \text{ and } \mathbf{X}' = \begin{bmatrix} \Delta^d y_{1,r} & 0 & \cdots & \Delta^d y_{1,1} & 0 \\ \Delta^d y_{2,r} & 0 & \cdots & \Delta^d y_{2,1} & 0 \\ 0 & \Delta^d y_{1,r} & \cdots & 0 & \Delta^d y_{1,1} \\ 0 & \Delta^d y_{2,r} & \cdots & 0 & \Delta^d y_{2,1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \Delta^d y_{1,T-1} & 0 & \cdots & \Delta^d y_{1,T-r} & 0 \\ \Delta^d y_{2,T-1} & 0 & \cdots & \Delta^d y_{2,T-r} & 0 \\ 0 & \Delta^d y_{1,T-1} & \cdots & 0 & \Delta^d y_{1,T-r} \\ 0 & \Delta^d y_{2,T-1} & \cdots & 0 & \Delta^d y_{2,T-r} \\ \Delta^d x_{1,r+1} & 0 & \cdots & \Delta^d x_{1,r+1-s} & 0 \\ \Delta^d x_{2,r+1} & 0 & \cdots & \Delta^d x_{2,r+1-s} & 0 \\ 0 & \Delta^d x_{1,r+1} & \cdots & 0 & \Delta^d x_{1,r+1-s} \\ 0 & \Delta^d x_{2,r+1} & \cdots & 0 & \Delta^d x_{2,r+1-s} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \Delta^d x_{1,T} & 0 & \cdots & \Delta^d x_{1,T-s} & 0 \\ \Delta^d x_{2,T} & 0 & \cdots & \Delta^d x_{2,T-s} & 0 \\ 0 & \Delta^d x_{1,T} & \cdots & 0 & \Delta^d x_{1,T-s} \\ 0 & \Delta^d x_{2,T} & \cdots & 0 & \Delta^d x_{2,T-s} \end{bmatrix}.$$

By manipulating Equation (5), the estimated vector $\mathbf{b}$ can be expressed as follows:

$$\hat{\mathbf{b}} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{y}. \tag{6}$$

## 3. RESULTS AND DISCUSSION

### 3.1 Descriptive Statistics of Data

Descriptive statistics of each data are presented in **Table 1**. The calculation of descriptive statistics for each data is carried out using Microsoft Excel software.

**Table 1. Descriptive statistics of the data**

| Variables | Mean (%) | Standard Deviation (%) | Minimum (%) | Maximum (%) |
|---|---|---|---|---|
| $y_{1,t}$ | 23.0276 | 18.6687 | 2.3968 | 61.9918 |
| $y_{2,t}$ | 7.8737 | 4.1617 | 1.514 | 13.803 |
| $x_{1,t}$ | 22.7264 | 4.494 | 16.458 | 31.7168 |
| $x_{2,t}$ | 7.7044 | 0.8495 | 6.2189 | 9.2913 |

**Table 1** shows that the average daily active case rates of Covid-19 in Java and Bali Island are 23,0276% and 7,8737%, respectively. The two average values are high, so the Indonesian government must be vigilant. Then, the daily active Covid-19 case rate deviation from the average is 18.6687% and 4.1617%, respectively. The deviation is large enough that the maximum and minimum values of the Covid-19 active case rate on the two islands also have an enormous difference. Then, the average cumulative vaccination and testing rates of Covid-19 are 22,7264% and 7,7044%, respectively. These two mean values should be increased because they are still small. Finally, the standard deviation of the two is slight enough that the difference between the minimum and maximum levels is not too significant.

VARI-X modeling requires that every variable involved has strong correlation rates. Therefore, correlation rates analysis is carried out, and the results are presented in **Table 2**. **Table 2** shows that each pair of data has a strong correlation rate. Covid-19 active case rates between Java and Bali appear to have a strong positive relationship, where the correlation rate between the two is 0.8790. It means that Covid-19 active case rates on both islands tend to rise or fall together. It is also the case between Indonesia's cumulative first dose Covid-19 vaccination rates and Indonesia's cumulative Covid-19 testing rates. Then, the correlation rate between endogenous and exogenous variables appears to have a strong negative relationship. It is viewed from the significant correlation rate, which is large and negative. It indicates that the endogenous and exogenous variables tend to occur in opposite directions. Correlation rates between these data are very representative of the actual conditions. Furthermore, the strong correlation rates between data make it possible to model the data using the VARI-X model.

**Table 2. The correlation rate between the data**

| Pair of Data | Correlation Rate |
|---|---|
| $y_{1,t}$ and $y_{2,t}$ | 0.8790 |
| $y_{1,t}$ and $x_{1,t}$ | -0.9097 |
| $y_{1,t}$ and $x_{2,t}$ | -0.9502 |
| $y_{2,t}$ and $x_{1,t}$ | -0.9645 |
| $y_{2,t}$ and $x_{2,t}$ | -0.9450 |
| $x_{1,t}$ and $x_{2,t}$ | 0.9920 |

### 3.2 Stationarity Testing of the Data

Stationarity testing of each data is checked visually first through the visualization of each data. The visualization of each data is presented in **Figure 1**.

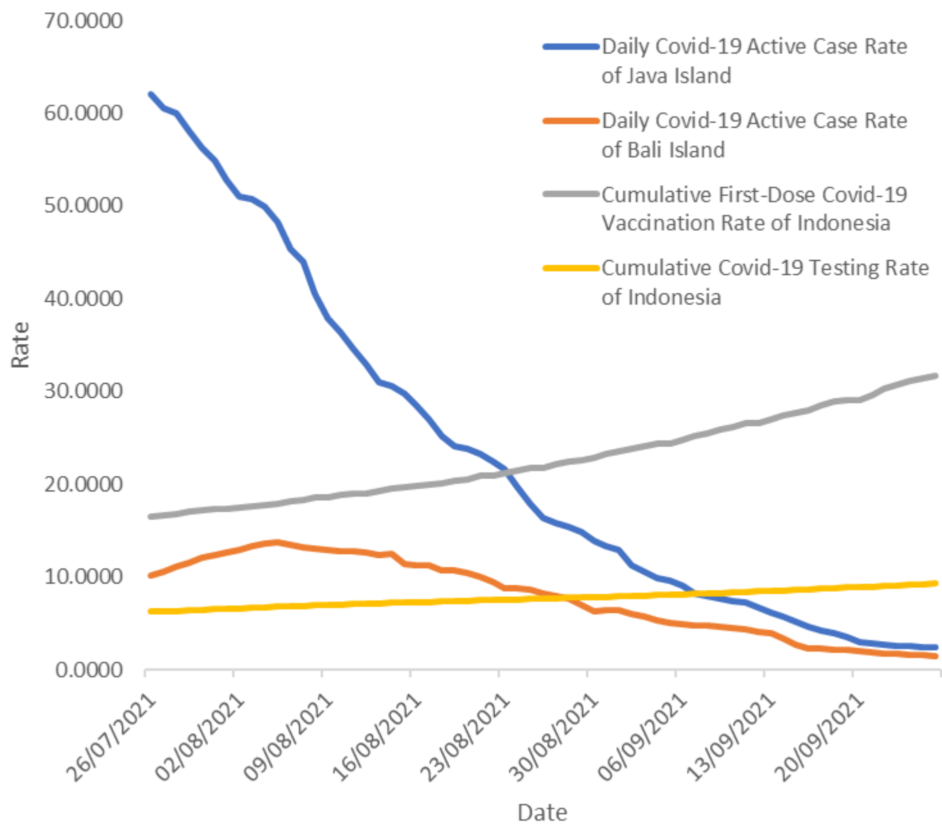


**Figure 1. Visualization of the Data**

**Figure 1** shows that the visualization of each endogenous variable has a decreasing trend, while the visualization of the exogenous variable has an increasing trend. It shows that visually, each data is not stationary in mean and variance. A formal mean-stationary test with the Augmented Dickey-Fuller (ADF) with a significance level of 0.01 is conducted. This testing process is carried out using the R software version 4.1.2. In the first test, all data are not stationary in mean because the test statistic value of each data is greater than the critical value (-4.1314). The test statistic values of $y_{1,t}$, $y_{2,t}$, $x_{1,t}$, and $x_{2,t}$ are -0.6155, -3.2340, 0.5110, 0.0936, respectively. Therefore, all data are differentiated. In short, after data differentiation is performed twice, all data are stationary, where the test statistic values of $\Delta^2 y_{1,t}$, $\Delta^2 y_{2,t}$, $\Delta^2 x_{1,t}$, and $\Delta^2 x_{2,t}$ are -5.4367, -6.6258, -6.0206, -5.9842, respectively. Next, the formal variance-stationarity test with Box-Cox parameter test is conducted. In short, $\Delta^2 y_{1,t}$, $\Delta^2 y_{2,t}$, $\Delta^2 x_{1,t}$, and $\Delta^2 x_{2,t}$ are also stationary in variance because all Box-Cox parameter of them is greater than 1.

### 3.3 Order Identification of VARI-X Model

The order of the VARI-X model is selected using the AIC and BIC criteria in **Equation (3)** and **Equation (4)**, respectively. The maximum order of autoregressive and exogenous considered are five. The order selection is carried out using the R software version 4.1.2. Top five VARI-X models with the smallest AIC and BIC values are presented in **Table 3**.

**Table 3. The Top Five Suitable VARI-X Models based on AIC and BIC Criteria**

| Based on AIC Criteria | | | Based on BIC Criteria | | |
|---|---|---|---|---|---|
| **Rank** | **VARI-X Model** | **AIC Value** | **Rank** | **VARI-X Model** | **BIC Value** |
| 1 | VARI-X (4, 2, 0) | -3.6646 | 1 | VARI-X (1, 2, 0) | -3.0667 |
| 2 | VARI-X (4, 2, 1) | -3.5653 | 2 | VARI-X (2, 2, 0) | -3.0501 |
| 3 | VARI-X (5, 2, 0) | -3.5596 | 3 | VARI-X (3, 2, 0) | -2.8915 |
| 4 | VARI-X (2, 2, 0) | -3.5431 | 4 | VARI-X (4, 2, 0) | -2.8761 |
| 5 | VARI-X (3, 2, 0) | -3.5310 | 5 | VARI-X (1, 2, 1) | -2.8414 |

**Table 3** shows that the VARI-X (4, 2, 0) model appears to be in the top five best models based on AIC and BIC criteria. On the AIC criteria, the VARI-X (4, 2, 0) model is in the first rank, while on the BIC criteria, the VARI-X (4, 2, 0) model is in the fourth rank. The VARI-X (2, 2, 0) and VARI-X (3, 2, 0) models are also

in the top five best models based on the AIC and BIC criteria. However, it ranks these two criteria lower than the VARI-X model (4, 2, 0). Therefore, the VARI-X (4, 2, 0) model is chosen as the best model.

### 3.4 VARI-X (4, 2, 0) Parameter Estimation

The VARI-X parameters (4, 2, 0) are estimated using the LS method as described in Section 2.4. The parameter estimation is carried out using **Equation (6)** and is compute using Microsoft Excel software. In short, the VARI-X (4, 2, 0) model with the parameters in the form of matrix and vector multiplication is expressed as follows:

$$\begin{bmatrix}\Delta^2 y_{1,t}\\ \Delta^2 y_{2,t}\end{bmatrix} = \begin{bmatrix}-0.4178 & -0.0915\\ -0.0470 & -0.4033\end{bmatrix}\begin{bmatrix}\Delta^2 y_{1,t-1}\\ \Delta^2 y_{2,t-1}\end{bmatrix} + \begin{bmatrix}-0.3299 & 0.2390\\ 0.0389 & -0.4589\end{bmatrix}\begin{bmatrix}\Delta^2 y_{1,t-2}\\ \Delta^2 y_{2,t-2}\end{bmatrix} + \begin{bmatrix}-0.2252 & 0.5272\\ -0.1127 & -0.0503\end{bmatrix}\begin{bmatrix}\Delta^2 y_{1,t-3}\\ \Delta^2 y_{2,t-3}\end{bmatrix} + \begin{bmatrix}-0.1936 & 0.5951\\ 0.0708 & -0.3272\end{bmatrix}\begin{bmatrix}\Delta^2 y_{1,t-4}\\ \Delta^2 y_{2,t-4}\end{bmatrix} + \begin{bmatrix}-0.2912 & 5.3178\\ 0.1035 & 4.3991\end{bmatrix}\begin{bmatrix}\Delta^2 x_{1,t}\\ \Delta^2 x_{2,t}\end{bmatrix} + \begin{bmatrix}e_{1,t}\\ e_{2,t}\end{bmatrix}. \quad (7)$$

If **Equation (7)** is converted into the original data form, then **Equation (7)** becomes the following equation:

$$\begin{bmatrix}y_{1,t}\\ y_{2,t}\end{bmatrix} = \begin{bmatrix}1.5822 & -0.0915\\ -0.0470 & 1.5967\end{bmatrix}\begin{bmatrix}y_{1,t-1}\\ y_{2,t-1}\end{bmatrix} + \begin{bmatrix}-0.4943 & 0.4220\\ 0.1329 & -0.6523\end{bmatrix}\begin{bmatrix}y_{1,t-2}\\ y_{2,t-2}\end{bmatrix} + \begin{bmatrix}-0.0168 & -0.0423\\ -0.2375 & 0.4642\end{bmatrix}\begin{bmatrix}y_{1,t-3}\\ y_{2,t-3}\end{bmatrix} + \begin{bmatrix}-0.0731 & -0.2203\\ 0.3351 & -0.6855\end{bmatrix}\begin{bmatrix}y_{1,t-4}\\ y_{2,t-4}\end{bmatrix} + \begin{bmatrix}0.1620 & -0.6630\\ -0.2543 & 0.6041\end{bmatrix}\begin{bmatrix}y_{1,t-5}\\ y_{2,t-5}\end{bmatrix} + \begin{bmatrix}-0.1936 & 0.5951\\ 0.0708 & -0.3272\end{bmatrix}\begin{bmatrix}y_{1,t-6}\\ y_{2,t-6}\end{bmatrix} + \begin{bmatrix}-0.2912 & 5.3178\\ 0.1035 & 4.3991\end{bmatrix}\begin{bmatrix}x_{1,t}\\ x_{2,t}\end{bmatrix} + \begin{bmatrix}0.5824 & -10.6356\\ -0.2070 & -8.7982\end{bmatrix}\begin{bmatrix}x_{1,t-1}\\ x_{2,t-1}\end{bmatrix} + \begin{bmatrix}-0.2912 & 5.3178\\ 0.1035 & 4.3991\end{bmatrix}\begin{bmatrix}x_{1,t-2}\\ x_{2,t-2}\end{bmatrix} + \begin{bmatrix}e_{1,t}\\ e_{2,t}\end{bmatrix}. \quad (8)$$

**Equation (8)** shows that the daily Covid-19 active case rates on Java and Bali's islands today are influenced by the daily Covid-19 active case rates on Java and Bali's islands for the previous six days. Then, the daily Covid-19 active case rates on Java and Bali Islands today are influenced by the cumulative first dose of Covid-19 vaccination rates and the cumulative Covid-19 testing rates for the previous two days.

### 3.5 Checking Diagnostic of VARI-X (4, 2, 0) Model

Checking the independence of $e_{1,t}$ and $e_{2,t}$ for all $t$ in this study is conducted using the Ljung-Box (LB) test. By significance level and degrees of freedom 0.01 and 1, respectively, $e_{1,t}$ and $e_{2,t}$ is independent for all $t$. It is because the test statistic values of $e_{1,t}$ and $e_{2,t}$, 3.2712 and 1.3992, are smaller than the critical value, 6.6350. Next, checking that $e_{1,t}$ and $e_{2,t}$ is normally distributed with zero mean and constant variance in this study is conducted using the Kolmogorov-Smirnov (KS) test. By significance level of 0.01, the test statistic values of $e_{1,t}$ and $e_{2,t}$, 0.1071 and 0.1788, are smaller than the critical value, 0.2120. Therefore, $e_{1,t}$ and $e_{2,t}$ are normally distributed with zero mean and constant variance **[15]**.

Next is checking the assumption that $x_{m,t}$ and $e_{k,t}$ are independent. It is analysed by the correlation rates of them. In short, $x_{1,t}$ and $e_{1,t}$, $x_{1,t}$ and $e_{1,t}$, $x_{1,t}$ and $e_{1,t}$, $x_{1,t}$ and $e_{1,t}$ are independent because all the correlation rates of them close to zero, 0.0346. 0.0273, 0.0258, and 0.0359, respectively. Thus, all the VARI-X modeling assumptions on the problem of projecting the Covid-19 spread on Java and Bali Islands with interventions of vaccination and testing are met **[16]**.

Finally, the error size should also be checked. In this study, the error size is reviewed based on the mean absolute percentage error (MAPE). $y_{1,t}$ and $y_{2,t}$ have MAPE of 5.3027% and 3.0301%, respectively. The MAPE size of $y_{1,t}$ and $y_{2,t}$ is less than 10%. It indicates that the model is suitable for predicting the daily rate of active Covid-19 cases on Java and Bali's islands.

### 3.6 Forecasting

Forecasting the daily Covid-19 active case rates on Java and Bali Islands is practically carried out in four days. Forecasting is conducted using **Equation (8)**. Forecasting results with the original data are presented in Table 4. Table 4 shows that the forecast results are close to the actual data. It indicates that the VARI-X (4, 2, 0) model is very accurate to use.

**Table 4. Forecasting Results and Actual Data**

| Date | $y_{1,t}$ | Forecast | $y_{2,t}$ | Forecast |
|---|---|---|---|---|
| 27 September 2021 | 2.2557 | 2.3453 | 1.4380 | 1.4418 |
| 28 September 2021 | 2.2127 | 2.2252 | 1.2590 | 1.4431 |
| 29 September 2021 | 2.1375 | 2.1643 | 1.1600 | 1.1644 |
| 30 September 2021 | 2.0402 | 2.0140 | 1.0120 | 1.0533 |

## 4. CONCLUSIONS

The suitable VARI-X model to be used in projecting the daily Covid-19 active case rates on Java and Bali Islands involving vaccination and testing of Covid-19 is the VARI-X (4, 2, 0). This model meets the assumptions of VARI-X modeling and has a very small MAPE. The estimation results in the next four days obtained practically using Equation (8) also give a value almost close to the actual data. Furthermore, the VARI-X (4, 2, 0) model obtained shows that Covid-19 active case rates on Java and Bali Islands today are influenced by Covid-19 active case rates on Java and Bali Islands during the previous six days. Then, Covid-19 active case rates on Java and Bali Islands are also influenced by the cumulative first-dose Covid-19 vaccination rates and the cumulative Covid-19 testing rates for the previous two days. The VARI-X (4, 2, 0) model is expected to assist the Indonesian government in projecting Covid-19 transmission on Java and Bali Islands.


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