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Double Intervention Analysis on The Arima Model of Covid-19 Cases in Bali

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Abstract. The time series process is not only influenced by previous observations, but some phenomena result in drastic changes to observations in the time series process so that there is a change in the average or only a temporary change in observations. For example, there is a policy from the government towards handling a case. This is referred to as an intervention. Therefore, it is necessary to do time series modeling with intervention factors. One form of intervention in the current pandemic era is a policy issued by the government. In this study, the time series model used is ARIMA. This study aimed to analyze the effect of an intervention on the ARIMA model on Covid-19 cases in Bali. This study uses data on the number of new Covid-19 cases in Bali from 24 April 2020 to 31 May 2021. There are two interventions used in this study, namely restrictions on activities for the Panca Yadnya ceremony and crowds in Bali and restrictions on traveling outside the area and/or going home and/or leaving for employees of the State Civil Apparatus during the Covid-19 pandemic. The results of this study show that two policies issued by the Bali provincial government can handle the addition of new cases of Covid-19. It can be seen from the decline in the number of new Covid-19 cases in Bali until the end of May 2021.

Key words and Phrases: Intervention, step function, pulse function, MSE, restriction

1. INTRODUCTION

Time series analysis is a method for modeling a time series process, namely a stochastic process, a series of random variables with a time index [1]. Equations are generated as a result of time series analysis that reflect the progression of data across time. Therefore, the fundamental goal of time series analysis is to forecast

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how a process will evolve throughout subsequent periods [2]. Time series analysis can be used to simulate a variety of topics that are encountered in everyday life [3]. Some examples include anticipating the movement of stock prices and the number of tourists who will visit in the next months. Therefore, time series analysis is a particularly applicable science in the sense that it helps solve a great deal of everyday issues ([4], [5]).

The time series analysis only applies excellent form patterns to some observations [6]. An illustration of this would be a decision made by the government regarding how to handle a particular instance, which leads to an abrupt rise in the average. The spread of the Covid-19 virus is tied to one of the measures that the government has in place [7]. The government has created a policy in response to the Covid-19 outbreak that emphasizes reducing the risk of transmission within the population [8]. In general, the government's strategy for avoiding the spread of infectious diseases is broken up into three distinct categories: in and around the place of residence, when traveling, and when engaging in activities that take place outside the home. Researchers such as [9], [10], [11], and [12] have successfully applied time series analysis to the COVID-19 data. Aside from that, there are also a large number of studies that integrate time series analysis with intervention analysis. One such study was undertaken by [13], [14], and [15], who investigated the effects of the COVID-19 pandemic using intervention analysis.

The data on the spread of Covid-19 in several areas, including in Bali, has increased again with a slowing recovery rate [16]. The emergence of clusters of Covid-19 cases stems from community interactions, so Parisadha Hindu Dharma Bali Province and the Traditional Village Council The Province of Bali issued circulars Number 081/PHDI-Bali/IX/2020 and Number: 007/SE/MDA-Bali Province/IX/2020 concerning Restrictions on the Activities of Panca Yadnya Ceremonies and Crowds in Bali in the Gering Agung situation. The ceremony is attempted to be carried out with provisions, a maximum of 1 (one) day unless other provisions require more than 1 (one) day while still implementing strict health protocols. In addition, the Bali provincial government has also issued a circular regarding Restrictions on Activities for Traveling Outside the Region and/or Homecoming and/or Leave for State Civil Apparatus Employees during the Corona Virus Disease 2019 (Covid-19) Pandemic. This is done in the context of preventing and overcoming the Corona Virus Disease 2019 (Covid-19), which has the potential to increase due to people traveling during Christmas Day 2021 and New Year 2022. The two policies issued by the Bali provincial government can be said to be a form of intervention to suppress the addition of positive cases of Covid-19 in Bali.

This study analyzes the time series model while considering intervention considerations. The autoregressive integrated moving average, sometimes known as the ARIMA model, is a popular choice for modeling time series. The number of new Covid-19 cases in Bali from 24 April 2020 to 31 May 2021 was used as the dependent variable in this study. Meanwhile, there are two intervention factors, namely: Restrictions on the Activities of Panca Yadnya Ceremonies and Crowds in Bali in the Gering Agung situation (stated as the first intervention) and Restrictions on

Activities for Traveling Outside the Region and/or Homecoming and/or Leave for State Civil Apparatus Employees during the Corona Virus Disease 2019 (Covid-19) Pandemic (stated as the second intervention). Because there are two intervention factors, this study analyzes the time series model with double intervention. The first part of this study describes the background. The second and third sections explain an overview of the ARIMA time series model and the ARIMA model with double intervention factors. The data analysis and conclusions can be seen in the fourth and fifth sections.

2. ARIMA TIME SERIES MODEL

Assuming that the sequence of random variables Z_t adheres to the ARIMA process, the definition of Z_t can be expressed as [17].

$$\phi_p(B)(1-B)^d Z_t = \theta_0 + \theta_q(B)a_t \tag{1}$$

where $\phi_p(B) = (1-\phi_1 B - \cdots - \phi_p B^p), \theta_q(B) = (1-\theta_1 B - \cdots - \theta_q B^q)$, B is backshift operator and a_t is *error* at time t. The model in Equation (1) is called the ARIMA model with the order (p, d, q) and is written as the ARIMA model (p, d, q) [18]. If $p = 0$, then ARIMA (p, d, q) model is also called IMA model with order (d, q). Likewise, if $q = 0$, then the ARIMA (p, d, q) model is called an ARI model with order (p, d). ARIMA model is a model used for data stationery with the following three main stages [19]:

(1) **Order identification**, can be accomplished by utilizing Auto-Correlation Function (ACF) plots and Partial Auto-Correlation Function (PACF) plots.
(2) **Parameter estimation**, minimum-squares and maximum-likelihood estimation.
(3) **Diagnostic test**, independent and normal residual tests.

After the three primary steps have been completed, the best model will have been obtained, and it will now serve as a point of reference for any subsequent forecasts, h [20].

3. ARIMA MODEL WITH INTERVENTION FACTOR

Step and pulse functions are the two varieties found in the time series model with intervention elements [21].

(1) **Step function**, which takes place at time T and always leaves the effect of the intervention after it, symbolizes the intervention at that moment. One definition of an intervention with a step function type is [22]:

$$S_t^{(T)} = \begin{cases} 0, & \text{for } t < T, \\ 1, & \text{for } t \geq T. \end{cases}$$

(2) **Pulse function**, refers to an intervention that will only have an effect within a specific period; alternatively, the effect will end at $t = T$ or some point after $t = T$. The following is a definition of the intervention type known as the pulse function [23]:

$$P_t^{(T)} = \begin{cases} 0, & \text{for } t \neq T, \\ 1, & \text{for } t = T. \end{cases}$$

Both a step function and a pulse function are viable options for accurately representing models incorporating intervention factors [24]. Because the findings of the step function type differentiation can be used to derive the pulse function type intervention, this is the case [25]:

$$S_t^{(T)} - S_{t-1}^{(T)} = (1-B)S_t^{(T)} = P_t^{(T)}.$$

Numerous other answers could be taken in response to either form of intervention. The following are some of the various intervention responses that frequently come up [26]:

(1) The constant impact of the intervention was felt b the period after the intervention.

$$\omega B^b S_t^{(T)}$$

or

$$\omega B^b P_t^{(T)}.$$

For the step function type, the intervention will constantly impact ω. As for the pulse function type, the intervention will only impact ω at the time of the T event.

(2) The perceived impact of the intervention b period after the intervention, but the resulting response is gradual. For the step function, write:

$$\frac{\omega B^b}{(1-\delta B)} S_t^{(T)}.$$

Furthermore, for the pulse function, written:

$$\frac{\omega B^b}{(1-\delta B)} P_t^{(T)}$$

with $0 \leq \delta \leq 1$.

In this instance, an intervention based on a step function has an impact that gradually increases or decreases until it reaches a constant state. Meanwhile, the intervention based on the pulse function has a gradual impact, but it will run out of steam at a certain point in the future.

The following is a textual representation of the generic ARIMA model of the time series, which incorporates the intervention components [27]:

$$Z_t = N_t + f_t$$

where

$$f_t = \frac{\omega_c(B)}{\delta_r(B)} B^b I_t^{(T)}$$

and N_t is the time series model before adding the intervention factor, $\omega_c(B) = 1 - \omega_1 B - \cdots - \omega_c B^c$, $\delta_r(B) = 1 - \delta_1 B - \cdots - \delta_r B^r$, $I_t^{(T)}$ is the intervention variable (step function or pulse function), and B is the backshift operator [28]. The time series modeling stage with the addition of intervention factors is presented in Figure 1.

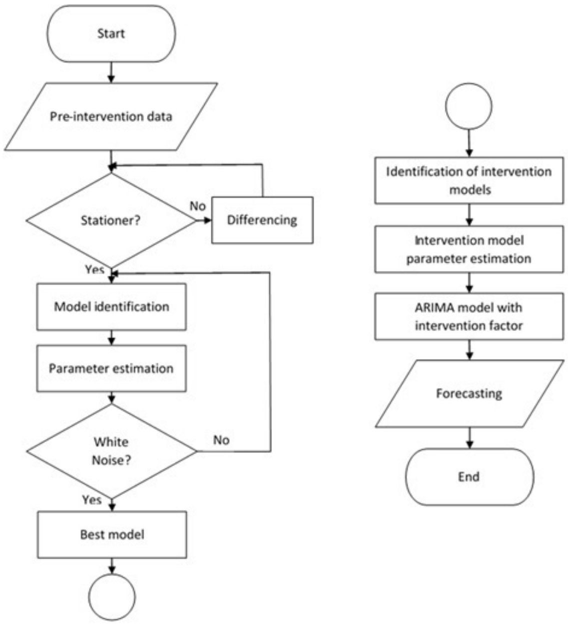


Figure 1. Flowchart of time series modelling with intervention factors

4. DATA ANALYSIS

The number of daily new cases of COVID-19 that occurred in Bali between April 24, 2020, and May 31, 2021, was used as a data source for this investigation. The data came from the National Disaster Management Agency and included multiple observations of 403 cases. Meanwhile, there are two intervention factors, namely: Restrictions on the Activities of Panca Yadnya Ceremonies and Crowds in Bali in the Gering Agung situation (stated as the first intervention) and Restrictions on Activities for Traveling Outside the Region and/or Homecoming and/or Leave for State Civil Apparatus Employees during the Corona Virus Disease 2019 (Covid-19) Pandemic (stated as second intervention). The first step in modeling time series with intervention factors is to classify data from before or after the intervention. This study's pre-intervention data started from April 24, 2020, to September 13, 2020. The Figure 2 presents the number of new daily cases of Covid-19 in Bali in detail.

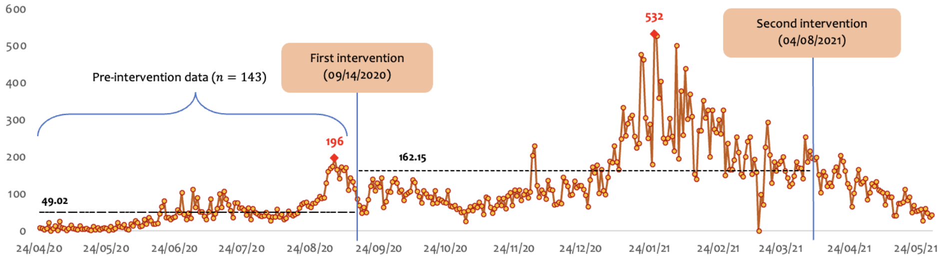


FIGURE 2. Time-series plot of the number of new daily cases of Covid-19 in Bali

The intervention implemented by the Bali provincial government is expected to prevent more comprehensive transmission of Covid-19. However, the average number of new cases increased from 49.02 to 162.15 (see Figure 2). This indicates that the intervention did not impact the number of new cases. Even after the first intervention was implemented, new Covid-19 cases in Bali reached 532 cases on January 26, 2021. This number was the highest number during the observation period. So the government implemented a second intervention to prevent more comprehensive transmission on April 8, 2021. As seen in Figure 2, the number of new cases decreased after this second intervention's implementation.

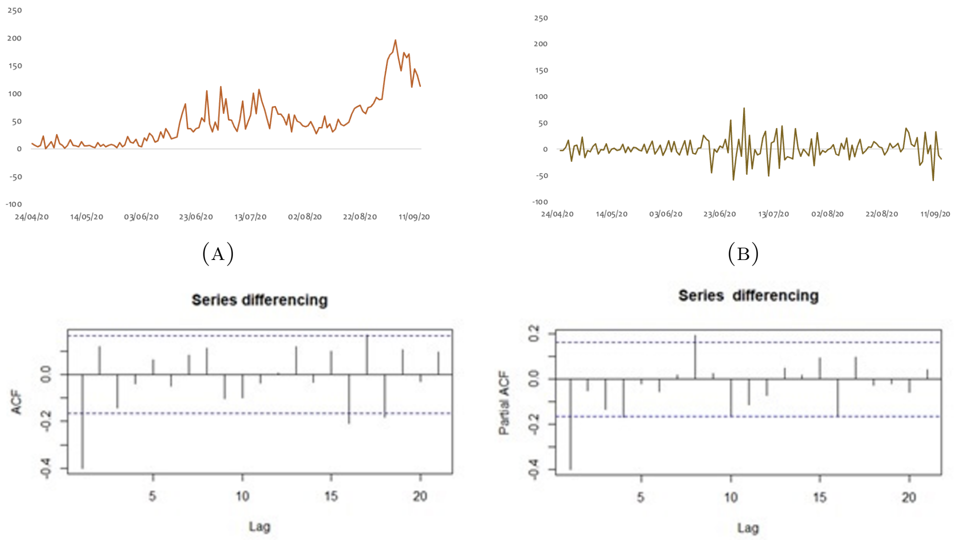
The first thing that needs to be done in the data modeling process is to apply the ARIMA (p, d, q) model to the data collected before the intervention. Figure 3 presents a plot of the pre-intervention data. Based on Figure 3(A), it can be seen that the pre-intervention data was not stationary. Therefore, differentiation is carried out to eliminate trend patterns in the data to fulfill a constant average.

After doing the first differencing, it can be seen that the pre-intervention data is stationary because it has a constant mean and variance (see Figure 3(B)). Furthermore, the ACF and PACF plots will be reviewed from the stationary differencing results to identify the order in the ARIMA model. Based on Figure 3(C), several candidate models were obtained, namely ARIMA $(1, 1, 0)$, ARIMA $(0, 1, 1)$ and ARIMA $(1, 1, 1)$. The parameter estimation, AIC values, and plot of residual diagnostic tests for each model are presented in Table 1.

In determining the model for the pre-intervention, the model must fulfill the assumption of white noise; namely, the residuals are independent and normally distributed. Based on Table 1, it can be seen that the ARIMA $(0, 1, 1)$ model is the model with the smallest AIC value (red text) and fulfill the assumption of white noise (third column in Table 1). Therefore, it can be concluded that the ARIMA $(0, 1, 1)$ model is the best model for pre-intervention data, namely:

$$Y_t = -0.45559\theta + e_t$$

where Y_t is the number of new daily cases at time t, and e_t is an error at time t with $t = 1, 2, \ldots, 143$.



(A) (B)

(C)

Figure 3. Plot of the pre-intervention data; (A) actual observation; (B) first differencing; (C) ACF and PACF Plot from (B)

In time series modeling with intervention factors on the data on the number of new Covid-19 cases in Bali, the intervention model used is as follows:

$$f_{144}(\omega, \delta) = \omega_0 P_t^{(144)} + \frac{\omega_1}{1 - \delta B} P_t^{(144)} \tag{2}$$

and

$$f_{350}(\omega, \delta) = \omega B S_t^{(350)}. \tag{3}$$

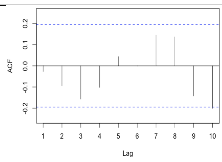
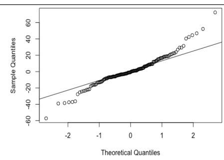
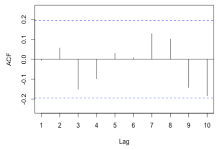
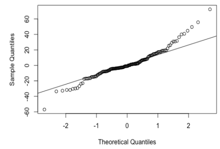
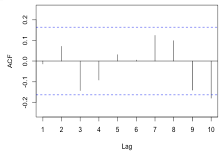
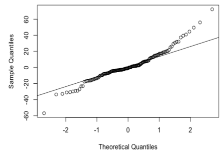
Equation (2) is a model for the first intervention on September 14, 2020. The model is a pulse function type to describe that the intervention applied has an effect that will disappear gradually. At the same time, Equation (3) states a model with a step function type for the second intervention that occurs on April 8, 2021. The second intervention model shows that the intervention applied can bring a permanent effect. The following is a complete model of time series modeling with intervention factors in this study.

$$Z_t = \frac{(1 - \theta B) e_t}{(1 - B)} + \omega_0 P_t^{(144)} + \frac{\omega_1}{1 - \delta B} P_t^{(144)} + \omega_2 B S_t^{(350)}$$

so that

$$Z_t - Z_{t-1} = (-\theta - \delta) e_{t-1} + \delta\theta e_{t-2} + (\omega_0 + \omega_1) P_t^{(144)} + (-\delta\omega_0 - \omega_0 - \omega_1) P_{t-1}^{(144)} + \delta\omega_0 P_{t-2}^{(144)} + \omega_2 S_{t-1}^{(350)} + (-\delta\omega_2 - \omega_2) S_{t-2}^{(350)} + \delta\omega_2 S_{t-3}^{(350)} + e_t. \tag{4}$$

TABLE 1. The result of parameter estimation and AIC value from the ARIMA (p, d, q) on preintervention data

Model	Order (p, d, q)	$\begin{bmatrix} \phi \\ \theta \end{bmatrix} \times 10^{-2}$	AIC	Residuals plots	
1	$(1, 1, 0)$	$\begin{bmatrix} -39.76 \\ 0 \end{bmatrix}$	1229.39		
2	$(0, 1, 1)$	$\begin{bmatrix} 0 \\ -45.59 \end{bmatrix}$	1227.70		
3	$(1, 1, 1)$	$\begin{bmatrix} 3.91 \\ -49.06 \end{bmatrix}$	1229.67		

After obtaining a time series model with intervention factors, the next step is to estimate the parameters contained in the model (in this case, the model in Equation (4)). The blue text in Equation (4) is the parameters to be estimated. In this study, the Least Square method is used to estimate the parameters. Equation (5) is the ARIMA $(0, 1, 1)$ model with the addition of two intervention factors so that the fitting results can be seen in Figure 4.

$$\begin{aligned} W_t = &-0.575e_{t-1} - 0.003e_{t-2} - 43.898P_t^{(144)} - 45.272P_{t-1}^{(144)} - 49.285P_{t-2}^{(144)} \\ &- 45.876S_{t-1}^{(350)} - 28.392S_{t-2}^{(350)} + 68.029S_{t-3}^{(350)}. \end{aligned} \tag{5}$$

Figure 4 presents the plot of fitted ARIMA $(0, 1, 1)$ model with two intervention factors and the plot of actual observations. Based on the Figure 4, it can be seen that the model used is quite good in modeling the data on the number of new Covid-19 cases in Bali. This is also supported by the MSE value generated from the model, which is 1,970.30. This value is smaller than the MSE generated by the ARIMA $(0, 1, 1)$ model without adding an intervention factor of 2,041.24.

5. CONCLUDING REMARKS

Two policies issued by the Bali provincial government from April 24, 2020, to May 31, 2021, impacted the number of new cases of Covid-19 in Bali. These policies

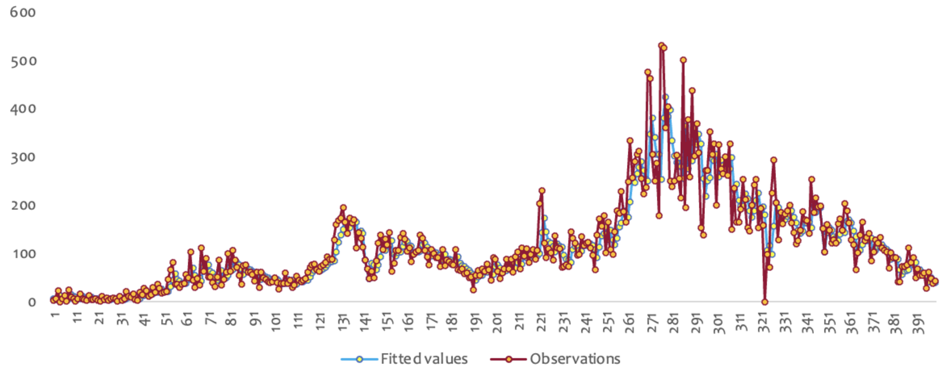


FIGURE 4. Plot of fitted values vs observations

are Restriction of Panca Yadnya Ceremony and Crowd Activities in Bali in the Gering Agung Covid-19 Situation and Restrictions on Traveling Outside the Region and/or Homecoming and/or Leave for State Civil Apparatus Employees During the Corona Virus Disease 2019 (Covid-19) Pandemic. Prior to the issuance of the policy, the average number of new Covid-19 cases had increased. Even after the first policy was issued, the number of new cases had reached 532 per day. This value is the highest number during the observation period. Therefore, the Bali provincial government issued a second policy to suppress the number of new cases added. The data before the implementation of the policy (pre-intervention data) followed the ARIMA $(0, 1, 1)$ model. The addition of two intervention factors (policies issued by the provincial government of Bali) to the ARIMA $(0, 1, 1)$ model shows better results. This can be seen from the resulting MSE value of 1,970.30. This value is smaller than the MSE of the ARIMA $(0, 1, 1)$ model without intervention factors, which is 2,041.24. In addition, it can also be seen from the decreasing number of positive cases of Covid-19 in Bali until the end of May 2021. The impact after the implementation of the policy occurs sustainably. So, it can be said that issuing a single policy does not guarantee that the number of new Covid-19 cases will decrease. However, the provincial government of Bali must issue further policies to get optimal results (a decrease in the number of new cases).

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