Personal Protective Equipment Demand Forecasting and Inventory Management during COVID-19 Case Study: Public Hospital at Bandung, Indonesia

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Abstract.

Until January 2021, the number of COVID-19 in Indonesia cases is still increasing, especially in West Java. The COVID-19 hospital's occupancy rate in West Java, especially Bandung, is around 80 percent. This makes the prediction of the hospital's personal protective equipment (PPE) essential to accommodate the increasing demand, especially Public Hospital in Bandung, which is also a national referral for COVID-19. Lack of prediction methods leads to a shortage in PPE, affecting the hospital's service to its patients. This study aimed to find the best forecasting method for COVID-19 patients hospitalized in Public Hospital in Bandung, determine the PPE demand, and find the hospital's best inventory models. This study compares three methods to forecast the COVID-19 patients hospitalized in several facilities in the hospital. The methods are ARIMA (Auto-Regressive Integrated Moving Average), Single Exponential Smoothing, and Double Exponential Smoothing. The COVID-19 hospitalized patients forecast is then inputted to the PPE Calculator to be translated into PPE demand. The best method is chosen based on the forecast accuracy measurement using MAPE, RMSE, and MAD. The method with the smallest forecast accuracy value is considered as the best method. This study compares the EOQ (Economic Order Quantity) Model, Fixed-Time Period Model, and Naïve Model for the inventory model. As a result, the best method to forecast the COVID-19 patients hospitalized is using ARIMA because it has the least MAD, MAPE, and RMSE. Interestingly, the EOQ model is still the best inventory control method even during the COVID-19 pandemic because EOQ has the best AIL among all methods.

Keywords: ARIMA; Inventory Control; Demand Planning; Economic Order Quantity (EOQ); Average Inventory Level

1. Introduction

The Coronavirus Disease 2019 (COVID-19) pandemic started in Wuhan, China, in December 2019 (Hui et al., 2020). COVID-19 is a new disease caused by a new coronavirus that has not been seen before in humans (CDC, 2020). COVID-19 may represent the most severe public health threat from a respiratory illness since the 1918 Spanish flu pandemic (Ferguson et al., 2020). Indonesia becomes the country with the most confirmed COVID-19 cases in Southeast Asia (Nurbaiti, 2020). Indonesia's first COVID-19 patient was recorded on March 2, 2020 (Gorbiano, 2020), and until now, the number of confirmed patients is still increasing. The COVID-19 pandemic presents the healthcare system with a severe scarcity problem: the inevitable constraint of limited resources when demand surges (Christen et al., 2020). Until now, PPE is considered the most visible control measure to prevent COVID-19 transmission while waiting for the COVID-19 vaccines to be given to people. There is a shortage of medical equipment, such as PPE in Indonesia (Lauren et al., 2020). They were causing the medical staff challenging to get adequate protection. This issue was raised when the public was going through panic-buying, stock-piling medical-grade masks (N-95 respirator, surgical masks), hand sanitizers, and gloves, which caused the price of medical equipment to jump significantly (Lauren et al., 2020). Some medical workers are forced to reuse masks and gloves, and others do not use any protection (Lauren et al., 2020).

At the beginning of the COVID-19 pandemic, there are 34 COVID-19 referral hospitals in West Java. Nevertheless, as the number of confirmed cases is increasing, the local government of West Java is adding more COVID-19 referral hospitals. As per February 4, 2021, there is 105 COVID-19 referral hospital in West Java.

Indonesia's healthcare is still not ready to handle the effect of COVID-19. At the beginning of the COVID-19 pandemic, the hospital experienced a PPE shortage. However, as time goes by, when the supply is back on its track from the PPE manufacturer, the hospital seems to purchase many PPE to prevent stock out. Having so much PPE stock in hands does not mean that it can be use dissipatedly. The PPE stock should be used wisely.

The public hospital in this study is a grade "A" public hospital located in Bandung, Indonesia, and a COVID-19 referral hospital in Indonesia. This hospital only receives medium to critical COVID-19 patients.

2. Methods

2.1 COVID-19 Hospitalized Patient Forecasting Method

In this study, to forecast COVID-19 hospitalized patient, we compare three forecasting methods: ARIMA (Auto-regressive Integrated Moving Average), Single Exponential Smoothing, and Double Exponential Smoothing. Where:

2.1.1 ARIMA

The acronym ARIMA stands for Auto-Regressive Integrated Moving Average. ARIMA models have been widely used for detecting outbreaks of infectious diseases (Sahai et al., 2020). ARIMA also has a good accuracy for short-term forecasting. The prerequisite for fitting an ARIMA model is the stationarity of a time series. This model is expressed as ARIMA (p,d,q), where p stands for the order of auto-regression, d signifies the degree of trend difference, while q is the order of moving average.

Mathematically, an ARMA (p, q) model can be written as follows:

$$Y_t = c + \mu + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \phi_3 y_{t-3} + \cdots + \phi_p y_{t-p} + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \cdots \theta_q \varepsilon_{t-q} + \varepsilon_t \quad (1)$$

Where:

Y_t: actual value at the period t
ε_t: the error terms at period t
c: constant
μ: mean of the series
ϕ_i: model parameters, i = 1,2,3,4,...p
θ_i: model parameters, i = 1,2,3,4,...q

2.1.2 Single Exponential Smoothing

Single Exponential smoothing is a time series forecasting which is suitable for forecasting the data with no clear trend or seasonal pattern. The equation for single exponential smoothing as follows:

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \quad (2)$$

Where:

F_t : the exponentially smoothed forecast for period t
F_{t-1} : the exponentially smoothed forecast for period $t-1$
A_{t-1} : the actual value in previous period
α : smoothing constant

2.1.3 Double Exponential Smoothing

Double exponential smoothing is a forecasting method which use a level component and a trend component at each period. Double exponential smoothing uses two weights, (also called smoothing parameters), to update the components at each period. The double exponential smoothing equations are as follows:

$$L_t = \alpha Y_t + (1-\alpha)[L_{t-1} + T_{t-1}] \quad (3)$$

$$T_t = \gamma[L_t - L_{t-1}] + (1-\gamma)T_{t-1} \quad (4)$$

$$\hat{Y}_t = L_{t-1} + T_{t-1} \quad (5)$$

where:

L_t : level at time t
α : weight for the level
T_t : trend at time t
γ : weight for the trend
Y_t : data value at time t
$\hat{Y}_t$: forecasted result at time t

2.1.4 Forecast Accuracy

Forecast accuracy is the measurement of the actual forecast value. In this study, we used three forecast measurements: MAD (Mean Absolute Deviation), also known as MAE (Mean Absolute Error), MAPE (Mean Absolute Percentage Error), and RMSE (Root Mean Square Error).

MAD expresses accuracy in the same units as the data, which helps conceptualize the amount of error. The equation for MAD can be seen on Eq 6.

$$MAD = \frac{\sum_{t=1}^{n} |A_t - F_t|}{n} \quad (6)$$

where

t : period number
A_t : actual demand for period t
F_t : forecast demand for the period t
n : total number of periods

MAPE expresses accuracy as a percentage of the error. The equation for calculate MAPE can be seen on Eq 7.

$$MAPE = \frac{MAD}{Average\ demand} \quad (7)$$

Root Mean squared deviation (MSE) is always computed using the same denominator, n, regardless of the model. RMSE is a more sensitive measure of an unusually large forecast error than MAD. The equation for calculating RMSE as follows:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} |A_t - F_t|^2}{n}} \quad (8)$$

Where

t : period number
A_t : actual demand for period t
F_t : forecast demand for the period t
n : total number of periods

2.2 Translating COVID-19 Hospitalized Patient Forecast into PPE Demand

The PPE calculator from PennMedicine[1] is used to translate the patient projections into PPE demand projections. The calculation for PPE usage is based on two scenarios: staff-based consumption and contact-based consumption. Staff-based consumption, the PPE usage in which the number of times consumed only depends on the number of staff in shift and not on their contact with patients (Lum et al., 2020). The average number of PPE item used per day is calculated as follows:

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[1] https://penn-chime.phl.io/

$$Average\ number\ of\ PPE\ item\ per\ day = \frac{number\ of\ patients\ that\ day \times number\ of\ shifts\ per\ day}{number\ of\ patinets\ per\ provider \times number\ of\ shifts\ item\ is\ used} \quad (9)$$

Then the total PPE demand for the hospital can be found by summing the demand across all clinical units and clinical roles (Lum et. al, 2020).

In contrast, contact based consumption refers to PPE usage in which the number of item utilized is a direct function of the number of contacts staff members have with COVID-19 patients (Lum et al., 2020). The projected number of a particular PPE item needed for a particular day can be computed as:

$$Number\ of\ PPE\ item\ on\ a\ particular\ day = \frac{number\ of\ patients\ that\ day \times number\ of\ daily\ contacts\ per\ patient}{number\ of\ patient\ contacts\ before\ discarding\ item} \quad (10)$$

Then the total PPE demand for hospital for a given item on a given day can be found by summing the demand across all portions of the hospital (Lum et. al, 2020).

2.3 PPE Inventory Management

An inventory system is the set of policies and controls that monitor levels of inventory and determine what levels should be maintained, when stock should be replenished, and how large order should be (Jacobs and Chase, 2018). There are several cost that must be considered in making any decision which related inventory size:

a) Holding (or carrying) costs
   The holding costs includes the opportunity cost, cost of space, spoilage cost, and any other cost that vary depends on the inventory on hand
b) Setup (or production change) costs
   The setup cost includes the cost for time and effort to place an order, transporting the ordered material, receiving cost, and the other cost that vary depending on the number of orders
c) Ordering costs
   Ordering costs are the costs incurred at the time of ordering supplies
d) Shortage cost
   Shortage costs is the costs that incurred when the demand is not met or the order is canceled, which is referred as a stock out or shortage.

The objective of inventory-control management is to make inventory decisions that minimize the total cost of inventory not to minimizing inventory (Hughes, 1984). There are several models regarding to inventory management:

2.3.1 Fixed-Order Quantity Model

Fixed-Order Quantity Model, also known as EOQ (Economic Order Quantity Model), is a model that is used when the objective is to maintain an item on hands when the item is resupplied, a certain number of units must be ordered each time. The Inventory for the item is monitored until it gets down to a level where the risk of stocking out is great enough.

Fixed-order quantity models aim to determine the specific point R, at which order of size Q will be placed. L is the lead time, a time between the order placed and the buyer received their order. The amount of ordering goods when it reaches the reorder point is always the same.

While constructing any inventory model, the initial step is to develop a functional relationship between the variables of interest and the measure of effectiveness. Because we are concerned with the cost, the equation is as follow:

$$TC = \frac{D}{Q}S + \frac{Q}{2}H \tag{11}$$

Where

TC: Total annual cost
D: Demand (annual)
Q: Quantity to be ordered (the optimal amount is termed the EOQ or Q_{opt})
S: Setup cost or cost of placing an order
H: Annual holding and storage cost per unit of average inventory

The next step is to find the optimal order quantity (Q_{opt}) at which total cost is minimum. By using calculus, take the derivative of total cost with respect to Q and set this equal to zero from Eq 11. Then we get the equation for Q_{opt} as seen on Eq. 13.

$$\frac{dTC}{dQ} = \left(\frac{-DS}{Q^2}\right) + \frac{H}{2} = 0 \tag{12}$$

$$Q_{opt} = \sqrt{\frac{2DS}{H}} \tag{13}$$

Where:
D: Annual Demand in units
Q: Quantity to be ordered
S: Setup cost or cost of placing an order
H: Holding and storage cost per unit of average inventory per year

To prevent stock outs, safety stocks is used to mitigate the demand uncertainty and lead time variability while still providing high service levels to customers. The equation to calculate the safety stock in Fixed-Order Quantity model is:

$$SS = z\sigma_L \tag{14}$$

$$\sigma_L = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 + \cdots + {\sigma_L}^2} = \sqrt{L} \times \sigma_d \tag{15}$$

Where:

SS : safety stock

z : number of standard deviations for a specified service probability

σ_L : standard deviation of usage during lead time

σ_d : standard deviation of daily demand

While the reorder point $R$is the minimum unit quantity that a business should have in available inventory before reorder more product. Reorder point provide the information about when is the right time to purchase. Reorder point for Fixed-Order Quantity is calculated as follows:

$$R = \bar{d}L + SS \tag{16}$$

Where:

R: reorder point

$\bar{d}$: average demand

L: lead time

SS: safety stock

Furthermore, AIL (average inventory level) is the average amount of inventory available in stock for a specific period. The AIL for Fixed-Order Quantity method is calculated using Eq. 17.

$$AIL = \frac{Q}{2} + SS \tag{17}$$

Where:

AIL: average inventory level

SS: safety stock

Q: order quantity

2.3.2 Fixed-Time Period Model

The Fixed-Time Period model is similar to the EOQ model, the differences that in a fixed-time period model, inventory is counted and the reorder point is placed in pre-determined intervals. In this case, rather than monitoring the inventory level and ordering when the level gets down to a critical quantity, the item is ordered at certain intervals of time.

The equation for fixed-time period model is as follows:

$$q = \bar{d}(T + L) + z\sigma_{T+L} - I \tag{18}$$

Where
q: the quantity to be ordered
T: the number of days between reviews
L: lead time in days (time between placing an order and receiving it)
$\bar{d}$: forecast average daily demand
z: number of standard deviations for a specific service probability
σ_{T+L}: standard deviation of demand over the review and lead time

I: current inventory level (includes items on order)

The safety stock for Fixed-Time period is calculated as follows:

$$SS = z\sigma_{T+L} \tag{19}$$

$$\sigma_{T+L} = \sqrt{\sum_{i=1}^{T+L} {\sigma_d}^2} = \sqrt{(T+L){\sigma_d}^2} \tag{20}$$

Where:

SS : safety stock

z : number of standard deviation for a specified service probability

σ_{T+L} : standard deviation of demand over the review and lead time

σ_d : standard deviation of daily demand

The AIL for Fixed-Time Period model is calculated as follows:

$$AIL = \frac{dT}{2} + SS \tag{21}$$

Where:

AIL : average inventory level

SS : safety stock

d : average daily demand

T : review cycle

3. Results

3.1 COVID-19 Hospitalized Patient Forecasting Result

This case study is conducted at Public Hospital in Bandung City, Indonesia. Where this hospital has four main facilities for COVID-19 patients. These are Negative Pressure Isolation Room, Natural Air Flow Isolation Room, ICU-Intermediate, and ICU-Isolation. Due to fluctuations and uncertainty of Indonesia's COVID-19 case, the forecast horizon is only two weeks.

Based on the forecast accuracy result in Table 1, Auto-Regressive Integrated Moving Average (ARIMA) has the best forecast accuracy among all other forecast methods (Single Exponential Smoothing, Double Exponential Smoothing). The error measurement using MAD/MAE, MAPE, and RMSE of ARIMA is the smallest. Therefore, it is suggested to use the ARIMA method to forecast the patient in Public Hospital in Bandung.

Table 1 Forecast Accuracy Result from Each Method

Source: Author

3.2 PPE Demand Projection Result

This research only calculates the disposable PPE demand, such as N95, surgical mask, bouffant cap, coverall gown, medical apron, medical gloves, and shoe cover. This model also does not model the needs of PPE for non-COVID patients since the PPE use assumptions are focused exclusively for only COVID-19 health care workers, such as registered nurses (RN), residents, and DPJP (Doctor in Charge). Furthermore, projections are more accurate only within a 2-3 week horizon, due to the uncertainty in the pandemic situations.

As the national COVID-19 referral hospital in West Java Province, this hospital accepts

Negative Pressure Isolation Room	**MAPE (%)**	**MAD/MAE**	**RMSE**
ARIMA (1,0,1)	7.49077	1.76389	1.98724
Single Exponential Smoothing (α=0.0893089)	7.65017	1.50795	2.12660
Double Exponential Smoothing (α=1.26787, γ=0.01000)	9.43670	1.94332	2.59785
Natural Air Flow Isolation Room	**MAPE (%)**	**MAD/MAE**	**RMSE**
ARIMA (1,1,3)	4.73554	3.69440	4.61384
Single Exponential Smoothing (α=0.870435)	4.74540	3.67770	4.68765
Double Exponential Smoothing (α=1.26787, γ=0.01000)	4.67960	3.61600	4.59714
ICU-Intermediate	**MAPE (%)**	**MAD/MAE**	**RMSE**
ARIMA (1,1,2)	6.84241	0.51389	0.58817
Single Exponential Smoothing (α=0.0234463)	8.90500	0.42660	0.59105
Double Exponential Smoothing (α=0.750403, γ=0.049858)	8.35127	0.50960	0.72513
ICU-Isolation	**MAPE**	**MAD/MAE**	**RMSE**
ARIMA(1,0,0)	4.83839	0.16667	0.33804
Single Exponential Smoothing (α=0.0230812)	5.67702	0.18817	0.34390
Double Exponential Smoothing (α=0.840651, γ=0.043166)	5.86030	0.20460	0.44664

COVID-19 patients from all over West Java who has medium to critical illness. Therefore, based on the PPE usage suggestion, all the medical staff are using level 3 PPE. The patient to staff ratio can be seen in Table 2. The shift length for registered nurse and resident is 8 hours and for DPJP is 12 hours. Each staffs are given two sets of PPE each shift. The coming 14 days cumulative PPE demand can be seen in Table 3.

Table 2 Patient to Staff Ratios

Staff	ICU-Intermediate	ICU- Isolation	Natural Air Flow Isolation	Negative Pressure Isolation
Registered Nurse (RN)	1	1	10	4
Resident	2	1	4	4
DPJP	3	3	10	4

Source: Author

Table 3 Cumulative PPE Requirement for the future 14 days

PPE Type	Cumulative Requirements
N95	6,058
Surgical Masks	6,058
Coverall Gown	6,058
Medical Apron	6,058
Bouffant Cap	6,058
Shoe Covers (pairs)	6,058
Gloves (pairs)	12,115

Source: Author

3.3 PPE Inventory Management

Table 4 shows several fixed variables (lead time, holding cos, setup cost, and service level) that are involved to calculate the PPE inventory.

Table 4 Fixed Variable of Medical Equipment Goods Order

Lead Time	45 days
Holding Cost	25% of unit price

Setup Cost	IDR 5000
Service Level	95%

Source: (Hafnika et al., 2016)

Based on the comparison of Average Inventory Level (AIL) on Table 5, the Economic Order Quantity (EOQ) method has the lowest AIL (IDR 23,977,720) and naïve method has the highest AIL (IDR 2,756,737,800). The only difference between the naïve method and the six-month fixed-time period inventory method is that the six-month fixed-time period calculates the safety stock and the naïve method does not calculate the safety stock. Safety stock is used to prevent stock out during the review period.

Table 5 Comparison of Average Inventory for Each Method

Item	**Average Inventory**				
	EOQ	**FIXED TIME T = 2 MONTHS**	**FIXED TIME T = 3 MONTHS**	**FIXED TIME T = 6 MONTHS**	**NAÏVE T = 6 MONTHS**
N95	7,440,000	390,540,000	585,300,000	1,170,060,000	1,169,100,000
Surgical mask	1,812,000	26,036,000	39,020,000	78,004,000	77,940,000
Medical apron	2,339,700	42,959,400	64,383,000	128,706,600	128,601,000
Coverall Gown	7,440,000	390,540,000	585,300,000	1,170,060,000	1,169,100,000
Bouffant cap	1,063,300	9,112,600	13,657,000	27,301,400	27,279,000
Shoe cover	1,564,500	19,527,000	29,265,000	58,503,000	58,455,000
Medical gloves	2,318,220	42,179,940	63,188,100	126,335,700	126,262,800
TOTAL	**23,977,720**	**920,894,940**	**1,380,113,100**	**2,758,970,700**	**2,756,737,800**

Source: Author

Sensitivity analysis is conducted to see whether the EOQ method still relevant during an extreme condition (product price and set up cost increasing significantly, and the lead time becomes shorter). The result is:

1. When the setup cost increases ten times than usual, the AIL increases three times, so there is no significant change. The AIL is still smaller than any other method (fixed-time period and naïve).
2. When the product price increases ten times (going back to the price when the beginning of the pandemic), the AIL is increasing by 3.5 times, so there is no significant change. The AIL is still smaller than any other method (fixed-time period and naïve).
3. When the lead time is reduced to 7 days, the hospital will get the product faster than usual, the AIL is decreasing 0.96 times than usual, so there is no significant change. The AIL is still smaller than any other method (fixed-time period and naïve).

4. When the setup cost, product price is increasing ten times, and the lead time is reduced to 7 days, the AIL is increasing 9.65 times, which is almost the same as the current conditions, so there is no significant change. The AIL is still smaller than any other method (fixed-time period and naïve).

From the sensitivity analysis that has been conducted, it is proven that the EOQ method is still relevant even with extreme conditions. The only requirement is that the PPE stock from the manufacturer is always available. By considering the present conditions where there is no shortage of PPE in the market. So there is no need for panic buying PPE, and the EOQ method can be implemented during whatever the condition is.

4. Conclusion

First, the best method to forecast the COVID-19 patient hospitalized in the Negative Pressure Isolation Room is ARIMA (1,0,1), Natural Air Flow Isolation Room is ARIMA (1,1,3), ICU-Intermediate is ARIMA (1,1,2), and ICU-Isolation is ARIMA (1,0,0). The overall result shows that ARIMA is the best method to forecast the COVID-19 patients hospitalized in Public Hospital in Bandung City, Indonesia.

Later, this forecast result for the next 14 days (January 21 – February 3, 2021) is translated into the Personal Protective Equipment (PPE) demand by using the PPE Calculator. The result is the total PPE demand for the coming 14 days (January 21 – February 3, 2021) is for N95, surgical mask, medical apron, coverall gown, bouffant cap is 6,058 pieces, and for shoe covers is 6,058 pairs, and for gloves is 12,115 pairs as can be seen on Table 4. Because the PPE given to the staff is in packages (2 packages of PPE for each shift), the PPE is calculated only by using staffing-based calculations; this is why the PPE demand is constant day by day.

Finally, by comparing the Average Inventory Level (AIL) from EOQ method Fixed – Time Period Method (with T = two months, three months, and six months), the naïve method on Table 5. With a 95% service level, 45 days' lead time, and IDR 5000 setup cost, the best inventory system for storing PPE is using the EOQ method. Because the EOQ method has the lowest AIL (IDR 23,977,720) among all methods used in this research, on the other hand, the EOQ method is robust; even if the forecast is 100 percent wrong, it only affects the cost by 25 percent.

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