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Covid-19 Transmission Modeling (Case Study of Jawa Timur Province and Daerah Khusus Ibukota Jakarta Province, Indonesia)

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Abstract: Covid-19 is a vicious virus that attacks the respiratory tract. In Indonesia, the provinces that have been detected with the most infections are Jawa Timur and DKI Jakarta. On July 3 2020 the number of infected detected in Jawa Timur and DKI Jakarta was 13048 people and 11961 people, respectively. From the results of the mathematical model simulation, it is predicted that on January 3, 2021 the infected detected in Jawa Timur and DKI Jakarta are 43,840 people and 16,450 people, respectively.

Keywords: Covid 19, DKI Jakarta, Jawa Timur, Mathematical Modeling.

Introduction

The Corona Virus Disease 2019 (Covid 19) outbreak is an outbreak that is of concern to the world, including Indonesia (Sugiyanto et. al., 2021). As of July 3, 2020, there were 60,595 infected cases in Indonesia and 3,036 people who died (Zonautara, 2020). In Indonesia this disease spreads quickly, all provinces are infected with this disease. The five provinces with the most cases of Covid 19 in Indonesia are Jawa Timur, Daerah Khusus Ibukota (DKI) Jakarta, Sulawesi Selatan, Jawa Tengah and Kalimantan Selatan. Provinces that exceed the number of tens of thousands infected with Covid 19 are Jawa Timur and DKI Jakarta (Zonautara, 2020).

MODELING THE TRANSMISSION OF COVID-19

This modeling develops from the model of Sugiyanto & Abrori (2020) and Ndii et al. (2020).

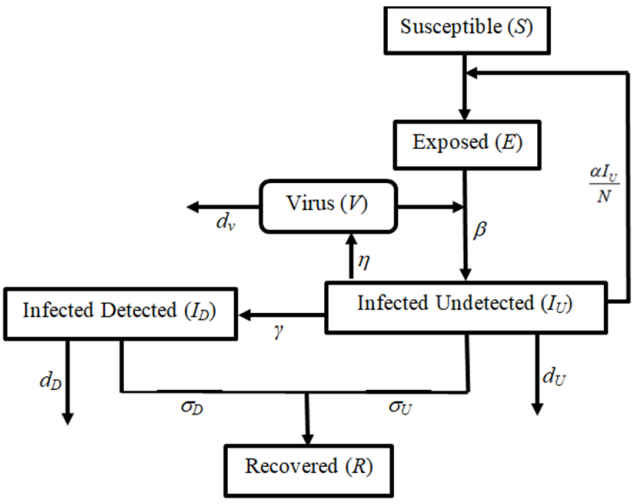

Figure 1. Transfer Diagram of the Covid-19 Spread Model

Figure 1 is a diagram of the transfer of the spread of Covid-19. Based on Figure 1, a mathematical model for the spread of Covid -19 is formed as follows, hereinafter referred to as System (1).

$$\frac{dS}{dt} = a - \alpha \frac{SI_U}{N}, \tag{1a}$$

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$$\frac{dE}{dt} = \alpha \frac{SI_U}{N} - \beta VE \,, \tag{1b}$$

$$\frac{dI_U}{dt} = \beta VE - \gamma I_U - \sigma_U I_U - d_U I_U \,, \tag{1c}$$

$$\frac{dI_D}{dt} = \gamma I_U - \sigma_D I_D - d_D I_D \,, \tag{1d}$$

$$\frac{dR}{dt} = \sigma_U I_U + \sigma_D I_D \,, \tag{1e}$$

$$\frac{dV}{dt} = \eta I_U - d_V V \,. \tag{1f}$$

Solution of System (1a) – (1f) is in the domain:

$$D = \Omega_1 \times \Omega_2$$
$$= \left\{ \left(S, E, I_U, I_D, R\right) \in \mathrm{Re}_+^5 : S + E + I_U + I_D + R \le \frac{a}{b} \right\} \times \left\{ V \in \mathrm{Re}_+ : \mathrm{V} \le \frac{\eta a}{b} \right\}$$

where $b = \min\left\{d_U, d_D\right\}$ and $\mathrm{Re} = \mathrm{Real}$.

Theorem 1. If the initial condition lies in D, then System (1a) – (1f) has a single solution that exists and remains in the domain D for each t ≥ 0. In other words, domains D is a finite set which is a positive invariant set.

Proof. The right side of System (1a) – (1f) is a continuous function and its partial derivatives are continuous on D, so System (1a) – (1f) have a single solution. Next, any initial conditions are taken $\left(S\left(t_0\right), E\left(t_0\right), I_U\left(t_0\right), I_D\left(t_0\right), R\left(t_0\right)\right) \in \Omega_1$, it will be shown that the solution of Equations (1a) – (1e),

$$\left(S(t), E(t), I_U(t), I_D(t), R(t)\right) \in \Omega_1 .$$

$P = S + E + I_U + I_D + R$ represents the density of cells in the current population t. By adding up Equations (1a) – (1e) is obtained

$$\frac{dP}{dt} = a - d_U I_U - d_D I_D$$

For example $b = \min\left\{d_U, d_D\right\}$, so obtained $\frac{dP}{dt} \le a - bP$.

For example x is a solution of Equation (2).

$$\frac{dx}{dt} = f\left(x,t\right) = a - bx \tag{2}$$

where $x\left(t_0\right) = x(0) = x_0$. Solution of Equation (2) with initial conditions x_0 is

$$x = e^{-bt}\left(\frac{a}{b}\left(e^{bt} - 1\right) + x_0\right).$$

In Equation (2), function f is a continuous function with t and satisfy the Lipschitz condition locally to t. So based on the Comparison Theorem applies

$$S + E + I_U + I_D + R = P \le e^{-bt}\left(\frac{a}{b}\left(e^{bt} - 1\right) + P_0\right),$$

where

$P_0 = P\left(t_0\right) = S\left(t_0\right) + E\left(t_0\right) + I_U\left(t_0\right) + I_D\left(t_0\right) + R\left(t_0\right)$

. Then for value t menuju tak hingga, didapat

$$\lim_{t\to\infty}\left(S + E + I_U + I_D + R\right) = \lim_{t\to\infty} P \le \lim_{t\to\infty} e^{-bt}\left(\frac{a}{b}\left(e^{bt} - 1\right) + \frac{a}{b}\right) = \frac{a}{b}$$

so that the System domain (1a) – (1e) is finite. It will be proved that the set Ω_1 positive invariant. Take any initial value $P_0 \in \Omega_1$ which mean $P_0 < \frac{a}{b}$.

Next, for each $t \in \mathrm{Re}$ where $t \ge 0$ obtained

$$P = S + E + I_U + I_D + R \le e^{-bt}\left(\frac{a}{b}\left(e^{bt} - 1\right) + P_0\right) < e^{-bt}\left(\frac{a}{b}\left(e^{bt} - 1\right) + \frac{a}{b}\right)$$

$$\rightarrow P = S + E + I_U + I_D + R < \frac{a}{b} \tag{3}$$

Set Ω_1 is a finite set and is a positive invariant set. From Equation (1f) and Equation (3) is obtained

$$\frac{dV}{dt} \le \frac{ea}{b} - d_V V .$$

For example y is a solution to the following equation.

$$\frac{dy}{dt} = f(y,t) = \frac{ea}{b} - d_V y , \tag{4}$$

where $y(t_0) = y(0) = y_0$. Solution of Equation (4) with initial conditions y_0 is

$$x = e^{-d_V t}\left(\frac{ea}{b}\left(e^{d_V t} - 1\right) + y_0\right)$$

In Equation (4), function f is a continuous function with t and satisfy the Lipschitz condition locally to t. So based on the Comparison Theorem applies

$$V \le e^{-d_V t}\left(\frac{ea}{b}\left(e^{d_V t} - 1\right) + V_0\right)$$

where $V_0 = V(t_0)$. Then for value t goes to infinity, gets

$$\lim_{t\to\infty} V \le \lim_{t\to\infty} e^{-d_V t}\left(\frac{ea}{b}\left(e^{d_V t} - 1\right) + \frac{ea}{b}\right) = \frac{ea}{b},$$

so that the domain of Equation (1f) is finite. It will be proved that the set Ω_2 positive invariant. We take any initial value $V_0 \in \Omega_2$ which mean $V < \frac{ea}{b}$. Next, for each $t \in \mathrm{Re}$ where $t \ge 0$, we get

$$V \le e^{-d_V t}\left(\frac{ea}{b}\left(e^{d_V t} - 1\right) + V_0\right) < e^{-d_V t}\left(\frac{ea}{b}\left(e^{d_V t} - 1\right) + \frac{ea}{b}\right) = \frac{ea}{b}$$

Set Ω_2 is a finite set and is a positive invariant set. So, there is a single solution. ■

Table 1 is the subpopulation, parameters and units used in this model.

Table 1. Subpopulasi, Parameters and units

No.	Symbol	Explanation	Unit
1.	S	Subpopulasi of susceptible	person
2.	E	Subpopulasi of exposed	person
3.	I_U	Subpopulasi of infected undetected	person
4.	I_D	Subpopulasi of infected detected	person
5.	R	Subpopulasi of recovery	person
6.	V	Covid-19 population in the environment	virus
7.	a	The number of births minus the number of natural deaths, not due to Covid-19	person
8.	α	The degree of interaction between susceptible subpopulations to exposed subpopulations.	1/day
9.	β	The level of interaction between exposed subpopulations to infected undetected subpopulations.	1/day
10.	γ	The level of interaction between infected undetected subpopulations becomes infected detected subpopulations.	1/day
11.	σ_U	The level of undetected recovery interaction between the infected undetected and infected detected subpopulations becomes the recovery subpopulation. Parameter σ_{UT} represents East Java Province, while the parameters σ_{UJ} representing DKI Jakarta Province.	1/day
12.	σ_D	The level of detected healing interactions between the infected undetected and infected detected subpopulations becomes the recovery subpopulation. Parameter σ_{DT} represents East Java Province, while the parameters σ_{DJ} representing DKI Jakarta Province.	1/day
13.	d_U	Undetected death rate due to disease caused by Covid -19. Parameter d_{UT} represents East Java Province, while the parameters d_{UJ} representing DKI Jakarta Province.	1/day
14.	d_D	The death rate is detected due to the disease caused by Covid -19. Parameter d_{DT} represents East Java Province, while the parameters d_{DJ} representing DKI Jakarta Province.	1/day
15.	η	Rate of emergence of Covid -19 in the environment	1/day
16.	d_v	Natural mortality rate of Covid -19 in the environment	1/day
17.	N	Total human population	person

SIMULATION

In this paper, case studies are taken in DKI Jakarta and East Java Provinces. The selection of these two provinces was because as of July 13 2020 the most infected cases were, namely 13,048 people and 11,961 people respectively. In this simulation, it is assumed that the number of births equals the number of natural deaths. In other words, we have $a = 0$.

Parameter $\alpha_T, \beta_T, \gamma_T, \sigma_T, d_T, e_T N_T$ represents the East Java province parameters and parameters $\alpha_J, \beta_J, \gamma_J, \sigma_J, d_J, e_J N_J$ represents the parameters of DKI Jakarta province. The population of East Java is 39,890,000 people, so N_T = 39890000. The population of DKI Jakarta is 10,370,000 people, so N_J = 10370000.

Parameter α obtained from estimates that do not comply with government orders, such as not wearing masks. For example, the number of residents in East Java and Surabaya who go out in crowds and do not wear masks, that is, 1/10 of the population, so α_T = 3989000 and α_J = 1037000.

Parameter β obtained from the estimated ten times people who are detected as infected with Covid 19 divided by the total population. Because

the number infected in East Java is 13,048 people, then β_T = 130480/39890000. Because the number infected in DKI Jakarta is 11,961 people, then β_J = 119610/10370000.

Parameter γ obtained from the number of infected people divided by the total population in the province. Because the number infected in East Java is 13,048 people, then γ_T = 13048/39890000. Because the number infected in DKI Jakarta is 11,961 people, then γ_J = 11961/10370000.

Parameter σ_U obtained from the estimated ten times the number of people who have recovered from Covid 19 divided by the total population in the province. Because the number who have recovered in East Java is 4,638 people, then σ_{UT} = 46380/39890000. Because the number who have recovered in DKI Jakarta is 7,109 people, then σ_{UJ} = 71090/10370000.

Parameter σ_D obtained from the number of people who recovered divided by the total population in the province. Because the number who have recovered in East Java is 4,638 people, then σ_{DJ} = 4638/39890000. Because the number who have recovered in DKI Jakarta is 7,109 people, then σ_{DJ} = 7109/10370000.

Parameter d_U obtained from the estimated ten times the number of people who died from Covid 19 divided by the total population in the province. Because the number who died in East Java was 969 people, then d_{UT} = 9690/39890000. Because the number who have recovered in DKI Jakarta is 643 people, then d_{UJ} = 6430/10370000.

Parameter d_D obtained from the number of people who died divided by the total population in the province. Because the number who died in East Java was 969 people, then d_{DT} = 969/39890000. Because the number who have recovered in DKI Jakarta is 643 people, then d_{DJ} = 643/10370000. Value e = 0.001 and d_v = 0.0000000077 obtained from Sugiyanto & Abrori (2020). Briefly shown in Table 2.

The initial value of susceptible is taken from the total population of East Java Province and DKI Jakarta divided by the total population of East Java and DKI Jakarta Province, S_0 = 39890000/39890000 = 10370000/10370000 = 1. The initial exposed value is taken from an estimated 1/10 of the population of East Java Province and DKI Jakarta who go out in crowds and do not wear masks divided by the total population of East Java Province and DKI Jakarta, E_0 = 3989000/39890000 = 1037000/10370000 = 0.1. The initial infected undetected value is taken from the estimated ten times the number of infected people on July 3 2020 divided by the total population of East Java and DKI Jakarta Provinces, I_{UT0} = 130480/39890000 and I_{UJ0} = 119610/10370000, consecutive. The initial infected detected value is taken from the number of infected people on July 3 2020 divided by the population of East Java and DKI Jakarta Provinces, I_{DT0} = 13048/39890000 and I_{DJ0} = 11961/10370000, consecutive. The initial recovery value is taken from the number of people recovered on July 3 2020 divided by the total population of East Java and DKI Jakarta Provinces, R_{T0} = 4638/39890000 and R_{J0} = 7109/10370000, consecutive. The Covid - 19 value is taken with an estimate of 1000000 per population of East Java and DKI Jakarta Provinces, V_{T0} = 1000000/39890000 and V_{J0} = 1000000/10370000, consecutive.

Table 2. Parameter Values

Symbol	Value	Reference
N_T	39890000	(Databoks1, 2020)
N_J	10370000	(Databoks2, 2020)
α_T	3989000	Estimation
α_J	1037000	Estimation
β_T	130480/39890000	Estimation
β_J	119610/10370000	Estimation
γ_T	13048/39890000	(Zonautara, 2020)
γ_J	11961/10370000	(Zonautara, 2020)
σ_{UT}	46380/39890000	Estimation
σ_{UJ}	71090/10370000	Estimation
σ_{DT}	4638/39890000	(Zonautara, 2020)
σ_{DJ}	7109/10370000	(Zonautara, 2020)
d_{UT}	9690/39890000	Estimation
d_{UJ}	6430/10370000	Estimation
d_{DT}	969/39890000	(Zonautara, 2020)
d_{DJ}	643/10370000	(Zonautara, 2020)
e	0.001	(Sugiyanto & Abrori, 2020)
d_v	0.0000000077	(Sugiyanto & Abrori, 2020)

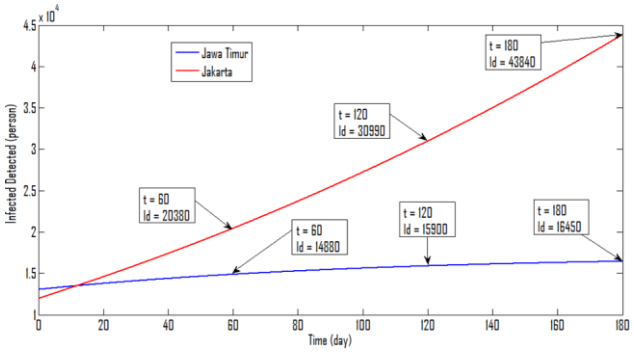

Figure 2. Infected Detected Trajectory Subpopulation Diagram in East Java and Jakarta Provinces

Figure 2 shows a diagram of the infected detected trajectories in East Java and DKI Jakarta Provinces. On the 0th day it shows July 3 2020, the 60th day shows September 3, the 120th day shows November 3 2020, and the 180th day shows January 3 2021. On July 3 2020 in East Java Province the number of infected detected was 13,048 people, on September 3, 2020 infected were detected as many as 14,880 people, on November 3, 2020, as many as 15,900 people were infected, and on January 3, 2021, as many as 16,450 people were infected. In East Java Province for 180 days showed an increase of 3408 people. On July 3 2020 in DKI Jakarta Province the number of infected detected was 11821 people, on September 3 2020 the infected were detected as many as 20380 people, on November 3 2020 infected detected were 30990 people, and on January 3 2021 infected detected were 43840 people. In DKI Jakarta Province, for 180 days it showed an increase of 32,019 people.

Conclusions

Covid-19 is a virus with a very fast spread in the world, including in the Provinces of East Java and DKI Jakarta, Indonesia. On July 3, 2020 infected detected covid 19 in the province of East Java had the highest, while the province of Jakarta had the second highest. On January 3, 2020, it is predicted that DKI Jakarta will be infected higher than East Java, namely DKI Jakarta and East Java as many as 43,840 people and 16,450 people, respectively. So, there needs to be special attention for the two provinces in Indonesia, due to an increase in infected detected.

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