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Dewa Putu Wiadnyana Putra and Marcellinus Andy Rudhito

Solution of the SIR Mathematical Model with Births and Deaths for COVID-19 Spread using Microsoft Excel

Dewa Putu Wiadnyana Putra[a)] and Marcellinus Andy Rudhito

Department of Mathematics Education, Universitas Sanata Dharma, Yogyakarta, Indonesia

[a)] Corresponding author: dewa@usd.ac.id

Abstract. This study aims to find the solution of SIR (susceptible, infectious and recovered) modelling which considers natural births and deaths for the spread of Covid-19 in populations of an area for normal, new normal and lockdown conditions using Microsoft Excel. This research consists two stages, 1) study the numerical solution SIR model using spreadsheet of Microsoft Excel, and 2) build Microsoft Excel Applets for simulation of the system. The results show that the SIR model with consider births and deaths for spread of Covid-19 can be solved numerically by Microsoft Excel, by changing the system of differential equations into system of difference equations. Furthermore, by using existing facilities in Microsoft Excel, the Microsoft Excel Applets can be built to simulate system in normal, new normal, and lockdown conditions. The simulation shows there are 58% individual are infected in normal condition. In new normal and lockdown conditions there are respectively 28% and 6% individuals who are infected by Covid-19. Pandemic peak also can be predicted by this model. In Normal condition, pandemic peak at Seventh week. In New normal and lockdown condition, the pandemic peak occurs at eleventh ant sixth week respectively.

INTRODUCTION

There are at least five types of mathematical model in Epidemiology, namely Compartment model, Stochastic model, Phenomenological model or time growth curve model, Time series or Predictive classes of data mining and AI, and Hybrid model classes (a combination of two or more model classes) Experts in modeling the spread of the disease have started to conduct studies on Covid-19. One of the studies made was a mathematical modeling of the spread of Covid-19. [1] and [2] conducted a study of the spread of Covid-19 in Wuhan using the SEIR (Susceptible-Exposed-Infectious-Removed) Model.

The SIR model is a compartment model for the spread of disease. The simplest compartment model for the spread of disease is the SIR model without considering natural mortality and mortality factors. In this article, we will discuss the SIR model by consider the natural factors of birth and death. This model will be applied to three different conditions, 1) normal conditions (without intervention), 2) new normal conditions (by applying healthy living habits, using mask, and physical distancing) and lockdown conditions (quarantine area). Furthermore, the solution and the simulation will be investigated using the Microsoft Excel Applets. This simulation can be carried out interactively and can be easily understood by the general public.

The mathematical concept used in this model is differential equations. There are some mathematical models on spreading of Covid-19 [1,2,3,4]. All of these model use system of differential equation. The solution determine by analytical solution of each models. This model construction and the solution are technically difficult for the general public to understand. The assumptions and conditions in the model after being converted into parameters are also not easy to understand. Therefore, the public needs to be given a simple understanding of the concept of mathematical models used for the spread of Covid-19, for example assumptions, modeling, solutions, simulation results and predictions. We construct the simple mathematical model and determine a simple method to solve the solution of the model on spreading of Covid-19.

The solution and simulation of a mathematical model is an important part. The simulation results can show visually about the current situation and predictions of a situation. Software that can be used to simulate a mathematical model

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of the spread of disease includes MATLAB, Mathematica, GeoGebra, Microsoft Excel, and others. Microsoft Excel is a spreadsheet software that is very well known and has very good capabilities. The solving of a particular mathematical model can be solved numerically using Microsoft Excel and then graphs its model solution. Model simulation activities using Microsoft Excel can also be designed interactively, namely by utilizing the slider facility which can be used to change the parameters in the mathematical model according to the assumed conditions. Interactive exploration of Applets is expected to make it easier to carry out or understand the simulation results of the Covid-19 spread mathematical model.

RESEARCH METHODOLOGY

This study consisted of two stages, 1) investigates the solution of the SIR mathematical model which consider natural birth and death numerically and 2) completing it using a spreadsheet and compiling an Applet for system simulation using Microsoft Excel. The data used in this study are daily Covid-19 case data in Indonesia from March to August 2020 [5]. The data of Crude Birth Rate (CBR) and Crude Death Rate (CDR) are CBR and CDR Indonesia from 2018 until 2020 [6]. Model simulation will be built in an Applet of Microsoft Excel. Facilities in Microsoft Excel for simulation views, including Input, Graph (Chart) and Spreadsheet (numerical display). The parameters in the model will be displayed and can be shifted using a slider to make it more interactive.

RESULT AND DISCUSSION

The SIR model that considers natural births and deaths in a population is a generalization of the SIR model. In the SIR model with a constant population (*N*), it is assumed that the birth and death rates in the population are the same. The SIR model which consider the demographic factors was carried out by [7] assuming the birth rate was the same as the natural death rate. The assumption in those research is that there is no demographic population growth. The birth rate (σ) and mortality rate (μ) in this study used the CBR and CDR. The interval of parameter value of σ and μ in this study, $3.33x10^{-4} \leq \sigma \leq 3.91x10^{-4}$ and , $1.17x10^{-4} \leq \mu \leq 1.57x10^{-4}$. The interval is obtained from CBR and CDR data for Indonesia, which are respectively at $18 \leq CBR \leq 20$ and $6 \leq CDR \leq 8$ [5].

The ability of an individual to transmit the virus to other individuals is denoted by which can be expressed by the following equation

$$\beta(N) = aN^{-0,95} \tag{1}$$

with a is parameter of the transmission rate [8]. The assumption in this model is that the natural deaths rate in each compartment is the same. If γ stated parameters are for the recovery rate and d is the parameters for the death rate (cause diseases), flowchart of the SIR model which consider natural births and deaths can seen bellow.

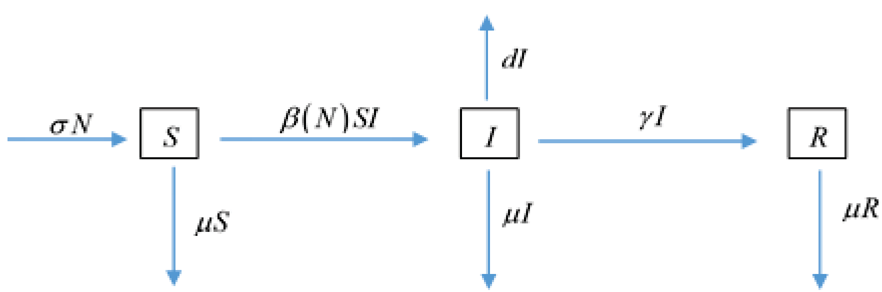

FIGURE 1. Flowchart SIR Model with Natural Birth and Death

The solution of this model will be solved numerically. Therefore, the system of differential equations in the model will be changed into a system of different equations [9]. Based on the diagram above, different equations can be drawn up as follows.

$$\begin{cases} \Delta S = (\sigma N - \beta(N)SI - \mu S)\Delta t \\ \Delta I = (\beta(N)SI - \mu I - dI - \gamma I)\Delta t \\ \Delta R = (\gamma I - \mu R)\Delta t \\ \Delta N = \big((\sigma - \mu)N - dI\big)\Delta t \end{cases} \tag{2}$$

The state population values used in this study is $N_o = 10001$, with state of subpopulation in each compartment are $S_o = 10000, I_0 = 1$, and $R_0 = 0$. Estimation of the parameter values of death rate (cause disease) and recovery rate using the data on the spread of Covid-19 in Indonesia which is available in [5] on March 2 to 13 August 2020. The parameter values d and γ respectively are $0.02 \leq d \leq 0.09$ and $0.03 \leq \gamma \leq 0.66$. Furthermore, the value of the transmission rate in equation (1) is determined by knowing the value of the Reproductive Number $(\Re_0)$. Based on [3] the equation given by

$$\Re_0 = \frac{N_0 \beta(N_0)}{\gamma + d} \tag{3}$$

The interval value of $\Re_0$ for Covid-19 spread was obtained from January 1 to February 7, 2020, is $1.4 \leq \gamma \leq 6.49$ [10]. Based on equations (1) and (3), the interval of transmission rate is $0.0443 \leq a \leq 3.1012$.

The following step to determine numerical solution of the model :

1. Select a scroll bar (form Control) from Developer menu in Microsoft Excel to fit interval value of each parameters.
2. Choose a fix value of each parameters in scroll bar. In this simulation the respective parameter values $\sigma, \mu, a, d,$ and γ are $3{,}7 \times 10^{-4}$,$1{,}39 \times 10^{-4}$,1,13,0.045, and 0.66.
3. For every of Δt, determine $\Delta S, \Delta I, \Delta R$ and ΔN base on equation 2. The variable t is in a week by delta of t is 0.14.
4. For every compartment, determine $S(t), I(t), R(t), N(t)$ by add up the previous value of each compartment with corresponding delta.
5. Graph each compartment used *scatter with smooth lines and marker* by joining each point in $(t, S(t))$, $(t, I(t))$, $(t, R(t))$ and $(t, N(t))$.

The following figure is the table of iteration using Microsoft Excel.

Iteration Table of SIR Model

t	N	ΔN	$\beta(N)$	S	ΔS	I	ΔI	R	ΔR
0	10001	0.27093	0.00018	10000	0.02592	1	0.15261	0	0.0924
0.14	10001.3	0.26997	0.00018	10000	-0.01242	1.15261	0.17589	0.0924	0.1065
0.28	10001.5	0.26887	0.00018	10000	-0.0566	1.3285	0.20272	0.1989	0.12275
0.42	10001.8	0.2676	0.00018	9999.96	-0.10752	1.53122	0.23365	0.32165	0.14148
0.56	10002.1	0.26614	0.00018	9999.85	-0.16621	1.76487	0.26928	0.46313	0.16306
0.7	10002.3	0.26445	0.00018	9999.68	-0.23384	2.03415	0.31035	0.62619	0.18794
0.84	10002.6	0.2625	0.00018	9999.45	-0.31178	2.34449	0.35767	0.81413	0.21662
0.98	10002.9	0.26026	0.00018	9999.14	-0.4016	2.70216	0.41219	1.03075	0.24966
1.12	10003.1	0.25767	0.00018	9998.74	-0.50509	3.11435	0.47502	1.28041	0.28774
1.26	10003.4	0.25468	0.00018	9998.23	-0.62435	3.58937	0.5474	1.56815	0.33163
1.4	10003.6	0.25124	0.00018	9997.61	-0.76176	4.13677	0.63079	1.89978	0.3822
1.54	10003.9	0.24727	0.00018	9996.84	-0.92007	4.76757	0.72686	2.28198	0.44048
1.68	10004.1	0.2427	0.00018	9995.92	-1.10245	5.49443	0.83752	2.72246	0.50763
1.82	10004.4	0.23743	0.00018	9994.82	-1.31255	6.33195	0.96497	3.23009	0.58501
1.96	10004.6	0.23136	0.00018	9993.51	-1.55455	7.29692	1.11175	3.8151	0.67416
2.1	10004.9	0.22436	0.00018	9991.96	-1.83327	8.40867	1.28076	4.48926	0.77687
2.24	10005.1	0.2163	0.00018	9990.12	-2.15424	9.68943	1.47534	5.26613	0.8952
2.38	10005.3	0.20701	0.00018	9987.97	-2.52381	11.1648	1.69931	6.16133	1.0315
2.52	10005.5	0.19631	0.00018	9985.44	-2.94927	12.8641	1.95708	7.19284	1.1885
2.66	10005.7	0.18398	0.00018	9982.49	-3.43897	14.8212	2.25365	8.38134	1.36931
2.8	10005.9	0.16979	0.00018	9979.06	-4.00251	17.0748	2.59478	9.75065	1.57752
2.94	10006.1	0.15345	0.00018	9975.05	-4.65084	19.6696	2.98704	11.3282	1.81725
3.08	10006.2	0.13464	0.00018	9970.4	-5.3965	22.6566	3.43792	13.1454	2.09322
3.22	10006.3	0.11298	0.00018	9965.01	-6.25383	26.0945	3.95597	15.2386	2.41084
3.36	10006.5	0.08806	0.00018	9958.75	-7.23917	30.0505	4.5509	17.6495	2.77632
3.5	10006.5	0.05939	0.00018	9951.51	-8.37112	34.6014	5.23374	20.4258	3.19677
3.64	10006.6	0.02642	0.00018	9943.14	-9.67084	39.8352	6.01695	23.6226	3.68031

Graph | Data

FIGURE 2. Table Iteration using Microsoft Excel

Solution of Model in Normal Condition (without intervention)

This situation is a normal situation without any intervention by the people or government on the spread of Covid-19. People carry out activities such as before the pandemic occurred in their area. The assumption used in this study is that the virus transmission rate is constant. The parameter values used in this situation can be seen in the following table.

TABLE 1. Value of Parameter of the Model

Parameter	Value	Reference
σ	3.7×10^{-4}	CBR Indonesia 2018
μ	1.39×10^{-4}	CDR Indonesia 2018
a	1.13	Assume
d	0.45	Assume
γ	0.28	Assume

Base on the value of each parameter in table 1, the solution of the model is graph in following figure.

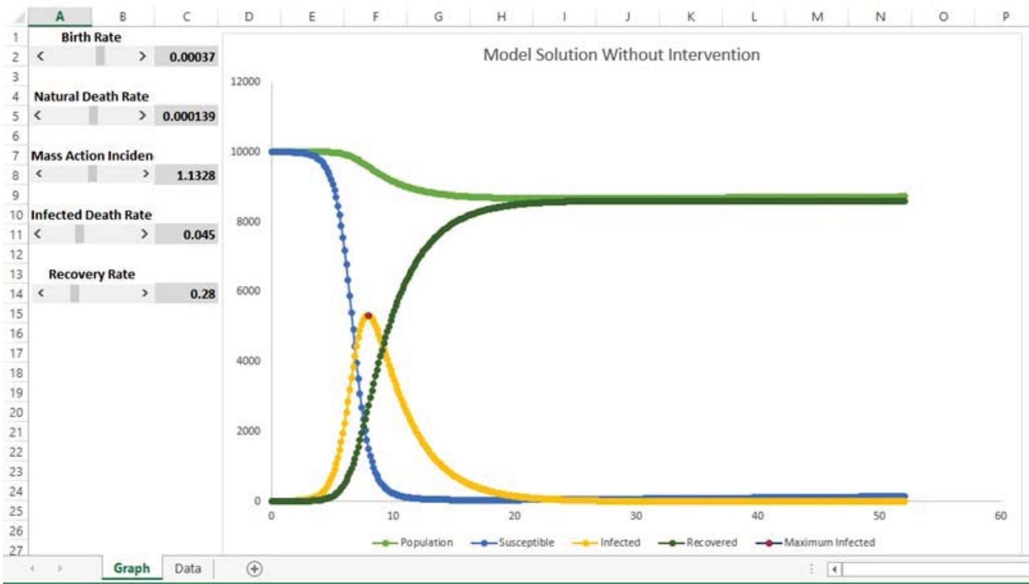

FIGURE 3. Solution Model in Normal Condition using Microsoft Excel

The peak of the pandemic occurs in the seventh week. The total population infected was 5312 people. Meanwhile, population growth originates from differences in values and causes an increase in susceptible class. The increase began to occur in the seventeenth week, with . This increase will potentially lead to a second wave of the spread of Covid-19 in Indonesia.

Solution of Model in New Normal Condition

People and government intervention in the spread of Covid-19 needs to be done. In this situation, the intervention carried out is in the form of implementing a healthy life habits. Washing hands, using masks when doing outdoor activities, not touching the nose, mouth and eyes with hands, and social and physical distancing are interventions carried out in this situation (new normal). The mobility of the people is not limited in this situation. Interventions were initiated in the fourth week after the start of the pandemic. This intervention assumes that the transmission rate can be reduced about 50% from the initial state. Based on table 1, the parameter values change to since the fourth week. The other parameter values are fixed as given in table 1. The solution of model in the new normal condition are graphed in figure bellow.

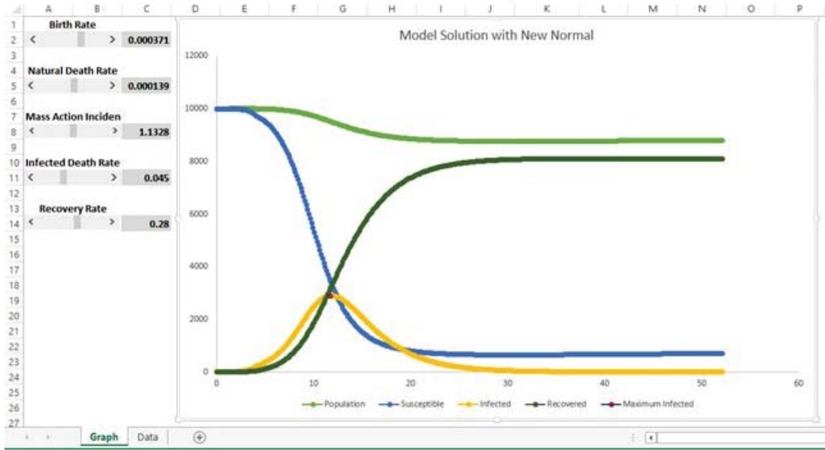

FIGURE 4. Solution Model with New Normal Condition using Microsoft Excel

The peak of the pandemic occurred in the eleventh week with the infected population was 2893. As a result of population growth, in this situation there is also the potential for a second wave of pandemic to occur, namely in the thirtieth week.

Solution of Model in Lockdown Condition

The government can implement a policy to quarantine an area (lockdown) to limit the transmission of Covid-19. Regional quarantines can reduce transmission rates very quickly. In this model, the lockdown starts in the fourth week of the pandemic. After this intervention, the parameter values were reduced by 50% up to the sixth week. After that, the transmission rate will be 0, because mobility and community interaction do not occur in this situation. The parameter values (except) use the values in table 1. The following is the solution of the model with lockdown intervention.

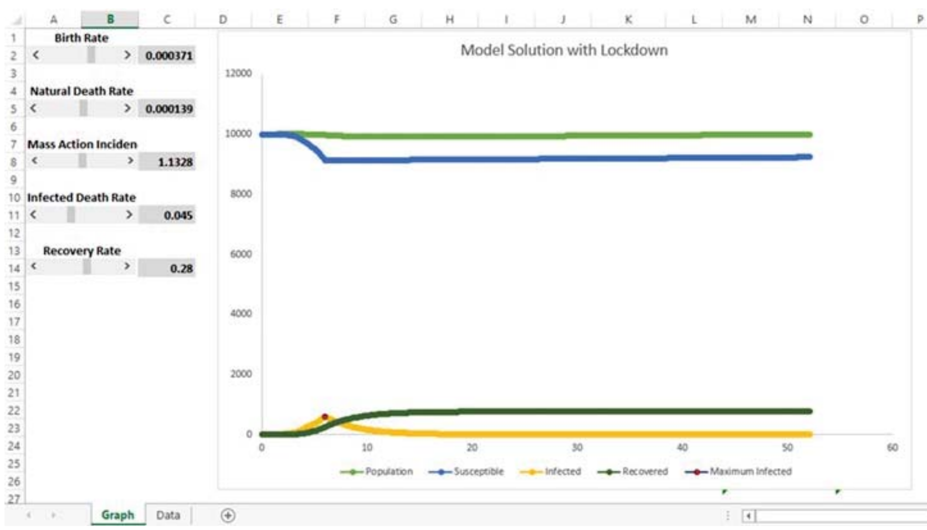

FIGURE 5. Solution Model with Lockdown Condition using Microsoft Excel

The peak of the pandemic occurred at week six with a total of 602 infected individuals. After the peak of the pandemic, individuals who are categorized as susceptible will not be infected with Covid-19. At week 18th it was seen that the infected individuals were below 1% of the population.

Based on the three situations above, the following is a summary of the SIR model solutions by considering the natural birth and death rates.

TABLE 2. Comparison Pandemic Peak and Infected People with 3 Condition

Strategy	Start Strategy (week)	Pandemic Peak (week)	Percentage of Infected People
No Intervention	-	7	52%
"New Normal"	4	11	28%
Lockdown	4	6	6%

CONCLUSION

The SIR model with natural births and deaths can be solved using Microsoft Excel. The Differential Equation System in the SIR model is changed into a system of difference equations. Simulating system built in three condition, normal, new normal, and lockdown. Intervention by government or individuals in population start in fourth week since the first infectious individuals in system. The simulation shows that 58%, 28%, and 6% people are infected by Covid-19 in normal, new normal, and lockdown conditions. Using the scroll bar in developer menu of Microsoft Excel the user can more interactively simulate the solution of the model. The people can also give an interpretation about the value of each parameters in scroll bar toward the solution of the model.

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REFERENCES

References should be numbered using Arabic numerals followed by a period (.) as shown below and should follow the format in the below examples.

1. Lin Q, et al, Int. J. of Infectious Diseases **93**, 211-6 (2020).
2. Rong X, et al, Math. Biosciences and Eng **17**(3), 2725-40 (2020).
3. Loli P E and Zama F, PLoS ONE **15**(8), e0237417 (2020).
4. Pal D, et al, "Mathematical Analysis of a Covid-19 Epidemic Model by Using Data Driven Epidemiological Parameters of Diseases Spread in India.," medRxiv preprint, India, 2020.
5. Anonymus (kawal informasi seputar COVID-19 secara tepat dan akurat).
6. Badan Pusat Statistik, "Angka Kelahiran dan Kematian Kasar," BPS, Jakarta, 2020.
7. Derdei D, et al, "A SIR Model with Differential Mortality and Constant Population," Preprint ResearchGate, New York, 2010.
8. Brauer F, Castillo-Chavez C and Feng Z, "Mathematical Models in Epidemology," Springer Science+Bussinnes Media, New York, 2019.
9. Hall J and Lingefjärd T, "Mathematical modeling : applications with Microsoft Excel," John Wiley & Sons, Inc, New Jersey, 2017.
10. Liu Y, Gayle A A, Wilder-Smith A and Rocklov J, Int. J. of Travel Medicine **27**, 1-4 (2020).