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RESEARCH ARTICLE

Analysis Covid-19 Vaccine Effectiveness Using SIR Model

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ABSTRACT

Covid-19 is a new coronavirus disease that was labelled a pandemic by the World Health Organization (WHO) in March 2020. SIR Model is a versatile compartmental mathematical tool that may be used to simulate any pandemic dynamic, including the current Covid-19 outbreak. In the conventional SIR model, the total population (N) is divided into three categories: susceptible(S), infected(I), and recovered(R). So, this research focused on finding the basic re- productive number, Ro of Covid-19 by using the Next Generation Matrix. Ro is greater than 1 means viruses begin to spread the population and Ro less than 1 means disease is about to vanish from the population. It is also analyze and compare the transmission of Covid-19 with and without vaccination. To apply this, the data from government websites is used to find the total number of cases and recover. With the help of mathematical software such as Maple to find the result of the graph. From the result produce from Maple, it can be observed that the slope of with vaccination is bigger than the slope of without vaccination. It clearly shows the comparison between them. The findings improved by having vaccination and then transmission rate low is good to decrease virus Covid-19 from infection.

Contribution/Originality: This study found the method of analysis differential equation using SIR model. The findings also show the vaccine program was successful in preventing the epidemic from spreading.

1. Introduction

According to Wong et al. (2021) Covid-19 as known as novel coronavirus disease caused by the SARS-Cov-2 was declared by the World Health Organization (WHO) as a pandemic on March 11, 2020, since the epidemic began in Wuhan, China. As on April 14, 2020, cases reported rose above 3 million with a death rate of over 200 000 around the globe. Due to Covid-19 disease spread, many countries are taking action to prevent the virus from spreading by implementing large-scale public health and social measures (PHSM), restriction movement order and Lockdown.

As in Malaysia, the government has taken action by implementing a PHSM called Movement Control Order (MCO) to the whole country under the Prevention and Control of Infectious Disease Act 1988 on March 16, 2020. During this period, mass gathering for cultural purposes, religion and sport are banned. While in the educational system, all sectors are closed and start a new normal education via online learning.

Onward, many health facilities have started to do research in finding vaccines to fight the Covid-19 which have been approved by WHO such as Pfizer, Sinovac, Astrazeneca, Johnson and Johnson and Moderna vaccine. As in Malaysia the immunization Programme Initiated started on February 24, 2021. Government has taken this step to cope with the Covid-19 to form herd immunity in which 80% of the population has taken the vaccine.

In this study, a well known Susceptible Infectious Recovered (SIR) model was adopted from Moghadas et al. (2021). SIR is a flexible compartmental mathematical tool that may be used to model any pandemic dynamic, such as the present Covid-19 epidemic. The SIR model is simple to learn and has straightforward meanings, and it helps us understand the dynamics of pandemics with any unique characteristics. The overall population (N) is split into three divisions in the typical SIR model. The Susceptible (S) is the percentage of the entire population that is vulnerable to infection. The Infected (I), or infected people, are a group of people who have been exposed to a virus. The Recovered I is the percentage of the population who recovers.

According to Badoual et al. (2021), non-pharmaceutical interventions (NPIs) such as social distancing, the use of masks, the restriction (or even closure) of non-essential businesses, the widespread assumption of remote work policies, an unexpected transition to online education, and, on occasion, the imposition of more severe physical quarantine restrictions were the main first-line methods used by governments to suppress the spread and mitigate the impact.

Salim et al. (2020) stated that the SIR model is the direct model to predict how a disease 6 spreads, such as total number of infected or the duration of an epidemic. The population is first split into compartments, with the assumption that every individual in the same group has the same characteristics. The model content of three groups: S for the number of susceptible, I for the number of infectious, and R for the number of recovered/deceased (immune) individuals. This model is relatively predictive for infectious diseases which are spread from human to human.

According to Badoual et al. (2021), the extensive and inconsistent deployment of NPIs, on the other hand, resulted in severe social disturbance and poor economic consequences. At this time, it's critical to investigate a wide range of intervention tactics in order to find the best mix of NPIs for maximizing benefits while reducing unwanted consequences. To this goal, a number of epidemic simulators (compartmental, agent-based, and particle-based) have been created to evaluate the effectiveness of current interventions as well as the trade-offs associated with governmental policies and the consequent economic and social impacts. One subtle issue that is largely neglected in our approach is that in certain nations, the accepted policy is to vaccinate persons who have been ill and recovered. As far as their model is concerned, this is not a significant issue because they do not allow re-infections. 'Once removed, always removed' is their motto. However, if a finer structure of the population is considered, vaccination of previously infected individuals might have a role.

Wong et al. (2021) stated that to assess the Covid-19 pandemic condition, an optimum control problem was designed to design vaccination regimens with different effectiveness rates. As clinical studies are focused on protocols and assessment based on efficacy, it was challenging to determine how well the vaccine would protect recipients.
According to Deng et al. (2021), a key concern in impoverished regions, such as isolated rural parts of developing nations, where medical facilities are limited, is a shortage of medical resources. As a result, optimum resource allocation is a crucial issue in controlling the epidemic's spread.

Karabay et al. (2021) uses the SIR model and divides the population based on age groups. Karabay et al. (2021) presented that in order to estimate illness propagation and vaccination tactics, a deterministic compartmental SEIR model that additionally separates the population by age is used. This model assumed two-stage vaccination. The population's age range was assumed to be 0 to 80 years old, and it was divided into 16 five-year groups. To account for differences in transmission rates between age groups, age categories were employed. To determine the coverage needed to achieve herd immunity, several vaccination effectiveness rates were simulated. Only susceptible and pre-symptomatic individuals were vaccinated in this paradigm.

The purpose of this project are to find the basic reproductive number, R0 of Covid-19 using next generation method and also to analyze and compare the transmission of Covid-19 with and without vaccination. The slope of the graph from the SIR formula can be obtained by applying SIR Model and make a prediction from it to counter the spread of Covid-19. Thus, this can help the government to take actions to do what is a must. This is important for the future researcher to understand how to control the predictability rate of Covid-19 and any other diseases in the certain state.

2. Materials and Methods

2.1. Model SIR

Roda et al. (2020) stated that they considered both SEIR and SIR models for model predictions and applied model-selection analysis. For the identified dataset of confirmed cases, they determined that the SIR model is a preferable choice than the SEIR model, and more likely than models that are more complex than an SEIR model.

The SIR Model is the simplest model of infectious diseases where the population is divided into three categories: susceptible disease, infected with disease and removed from the disease either death or recovery. Throughout this paper will assume that those who are in the removed group are not going to be affected again. The number of individuals in each group is given by certain functions of time S(t), I(t), R(t) respectively. Moreover, the dynamics of the model are given by the set of the ordinary differential equations:

$$\frac{dS}{dt} = -\beta I \left(\frac{S}{N}\right) \quad (1)$$

$$\frac{dI}{dt} = \beta I \left(\frac{S}{N}\right) - \gamma(I) \quad (2)$$

$$\frac{dR}{dt} = \gamma(1) \quad (3)$$

Which depends on the following parameters:

i. Total population N
ii. The transmission rate β, measured as the average number of contacts per person per time, multiplied by the probability of transmission between an infected and s usceptible person
iii. The removal rate λ given by 1 where D is the length of the period for which a pers on is infected.

In the early of an epidemic, transmission between a person to another is statistically in-dependent, which means that the probability that an infectious individual encounters someone no longer susceptible is probabilistically low. In fact, during the early stage in an epidemic, transmission between individuals are statistically independent.

2.2. Parameter Values

In this project, standard values for ODE parameters used were acquired from various sources. The simulations and analysis made were based on these standard values which are displayed in Table 1 shows the list of parameter.

Table 1 shows List of Parameters

Parameter	Parameter	Standard Value	Source
β	Transmission rate	0.1080/day	Wong et al. (2021)
β_W	Transmission rate after vaccine	0.065/day	Kementerian Kesihatan Malaysia (2022)
γ	Removal rate	0.0714/day	Ram et al. (2021)

N	Number of population	32700000	Department of Statistics Malaysia (2021)
D	length period of infected	14 day	Ram et al. (2021)

- For the standard value β , it is taken from Wong et al. (2021) that the transmission rat e is 0.1080 per day.
- For the standard value βw and N is retrieved from Malaysia Government official webs ite which is Kementerian Kesihatan Malaysia (2022) and Department of Statistics Malay sia Official Portal (2021) respectively.

2.3. Parameter Values

In the model, the basic reproduction number R_o is the number of people an infected person has, it can be computed given that the parameters of SIR Model as:

$$R_0 = \frac{\beta}{\gamma} \quad (4)$$

Should note that the R_o value is not a constant as its value depends on factors which are individual contact patterns. Even so, the number of R_o of the disease is generally consistent among newly susceptible populations and can be taken to predict the trajectory of an epidemic or calibrate the initial conditions of a model. If Ro > 1 indicates a disease will begin to spread in a population and if Ro < 1 indicate a disease is about do vanish from population. In order to know the scale of a disease's spread, a parameter is required.

2.4. Comparison of without and with vaccine

The information below is taken from the government's website. The information can be served from Covid Now website. There are Infected and Recovery data for computation. The choosing data is on March 2020 and August 2021 for data with and without vaccine shows in Table 2, which is the number of recovered 2020 and infected and Table 3, number recovered and infected in 2021.

Table 2: The Number Infected and Recovered for March 2020

March 2020	Daily Cases	Daily Recovered
1	0	4
2	0	0
3	7	7
4	6	13
5	5	5
6	28	26
7	10	11
8	9	5
9	18	18
10	12	11
11	11	19
12	9	11
13	39	31
14	84	37
15	190	190

16	125	120
17	120	111
18	117	201
19	110	117
20	130	110
21	153	43
22	123	63
23	212	187
24	106	96
25	172	137
26	235	214
27	130	57
28	159	119
29	150	77
30	201	59
31	340	80
Total	3011	2179

Source: Covid Now (n.d.)

Table 3: The Number Infected and Recovered for August 2021

August 2021	Daily Cases	Daily Recovered
1	17150	4620
2	17290	4500
3	17105	4468
4	19819	6500
5	20135	6698
6	20889	4137
7	19257	1555
8	18688	2359
9	19876	1744
10	19991	2232
11	20780	3612
12	20676	3687
13	21468	3409
14	20,670	3510
15	19878	3312
16	19740	2367
17	19631	2543
18	21037	2284
19	22948	660
20	23564	2194
21	20971	3438
22	19807	1304
23	17672	111
24	18654	272
25	22642	1609
26	24599	534
27	23091	1095
28	22597	2867
29	20579	553
30	19268	1315
31	18934	535
Total	629406	80024

Source: Covid Now (n.d.)

3. Implementation

3.1. Basic Reproduction Number R_0

R_0 can be obtained from the dominant eigenvalue of matrix $G = FV^{-1}$ where F is the term containing the secondary infection rate (β) and V is the other terms.

3.2. Basic Reproduction Number R_0 by using Next Generation Matrix

Step in deriving reproductive number, R_0 using Next Generation Matrix is by regrouping the equation SIR Model above into disease class and non-disease class. Thus, from equation SIR model in (1) until (3) will be into ISR.

$\frac{dS}{dt} = -\beta I \left(\frac{S}{N}\right)$, (Non-Disease Class)
$\frac{dI}{dt} = \beta I \left(\frac{S}{N}\right) - \gamma(I)$, (Disease Class)
$\frac{dR}{dt} = \gamma(1)$, (Non-Disease Class)

For the disease free class (2), rearrange it in form of :

$$\frac{dx}{dt} = f(x,y) - v(x,y) \quad (5)$$

thus $\frac{dI}{dt} = f(I) - v(I)$, where $f(I) = \beta I \left(\frac{S}{N}\right)$ and $v(I) = \gamma(I)$. (6)

For value of number of population, N in the equations is scaled or fix so that it can rid out from the equation. Therefore,

$$f(I) = \beta I(S) \quad (7)$$

To obtain F and V, equation (6) and (7) will be differentiate:

$$F = \beta(S) \text{ and } V = \gamma \quad (8)$$

Evaluating F and V at disease-free equilibrium part (S^*, I^*) = (1,0),

$$FV^{-1} = \beta * \frac{1}{\gamma} \quad (9)$$

Thus, the formula for R_0 is $R_0 = \beta * \frac{1}{\gamma}$.

3.3. Basic Reproduction Number, R_0 With and Without Vaccination

For the value of R_0 without vaccination is where the value of $\beta = 0.1080$ and $\gamma = 0.0714$ will be substitute into the equation (9), $R_0 = 1.5126$. Therefore, the epidemic is occur since the reproduction number, R_0 is greater than 1. $R_0 > 1$ indicates a disease will begin to spread in a population.

For the value of R_0 with vaccination is where the value of $\beta_w = 0.0650$ and $\gamma_w = 0.0714$. $R_0 = 0.9100$. Therefore, the epidemic is not occur since the reproduction number, R_0 is less than 1. $R_0 < 1$ indicate a disease is about do vanish from population.

4. Result and Discussion

Figure 1(a) shows the susceptible class before vaccination lower compare the graph in Figure 2(a) which is susceptible after vaccinations. This is because for early 2020, Covid-19 confirmed affected Malaysia via travelers. Since elders and children are easily exposed to disease, especially viruses Covid-19. Therefore, from the susceptible slope is bigger compared to Figure 2(a). When the government gives vaccination to the citizens to overcome the Covid-19, the slope from Figure 2(a) is getting smaller indicating the effectiveness of the vaccination. Not only that, the Malaysian Government also applied Restriction Movement Order (MCO) to decrease the number of transmission rates in order to overcome the Covid-19. From Figure 1(b), the graph shows that the slope graph for infection is said to be bigger compared to Figure 2(b). This is due to the presence of vaccination, the ratio of the infected people with and without vaccine can be differ. As Malaysia Health Organization has conducted quarantine for the infected citizen this can be the alternative to fight Covid-19 before the vaccine arrives. From Figure 1(c) and Figure 2(c), the curve clearly shows that the recovery data is continuing to increase. Besides, Figure 2(c) with vaccination it can be said that the graph is in the early month of August, the slope is much bigger if compared to Figure 1(c) even though at that time the daily cases is high but the transmission rate is stable which is smaller in contrast to transmission rate Figure 1(c). Thus, this shows that the vaccination can help the recovery a bit faster and minimize the severity of Covid-19.

Figure 1: Graph of SIR Model without vaccination

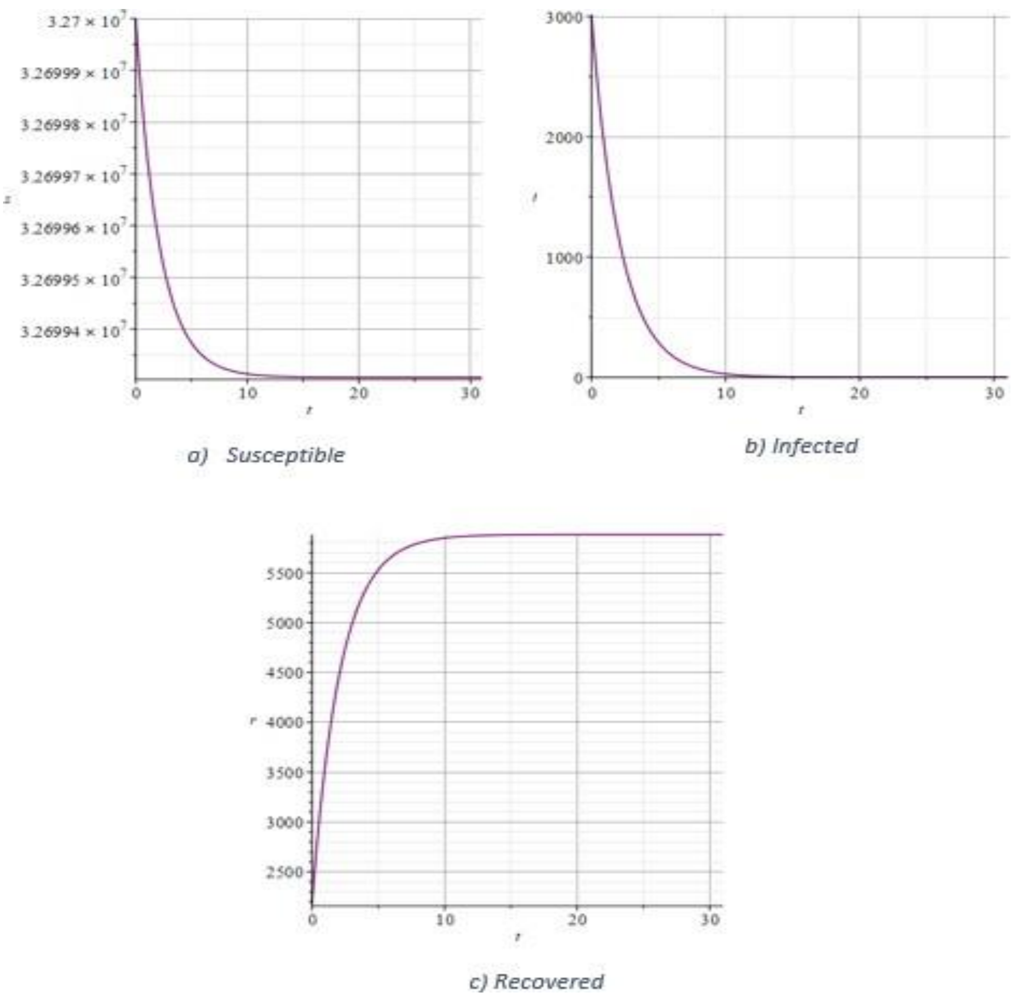
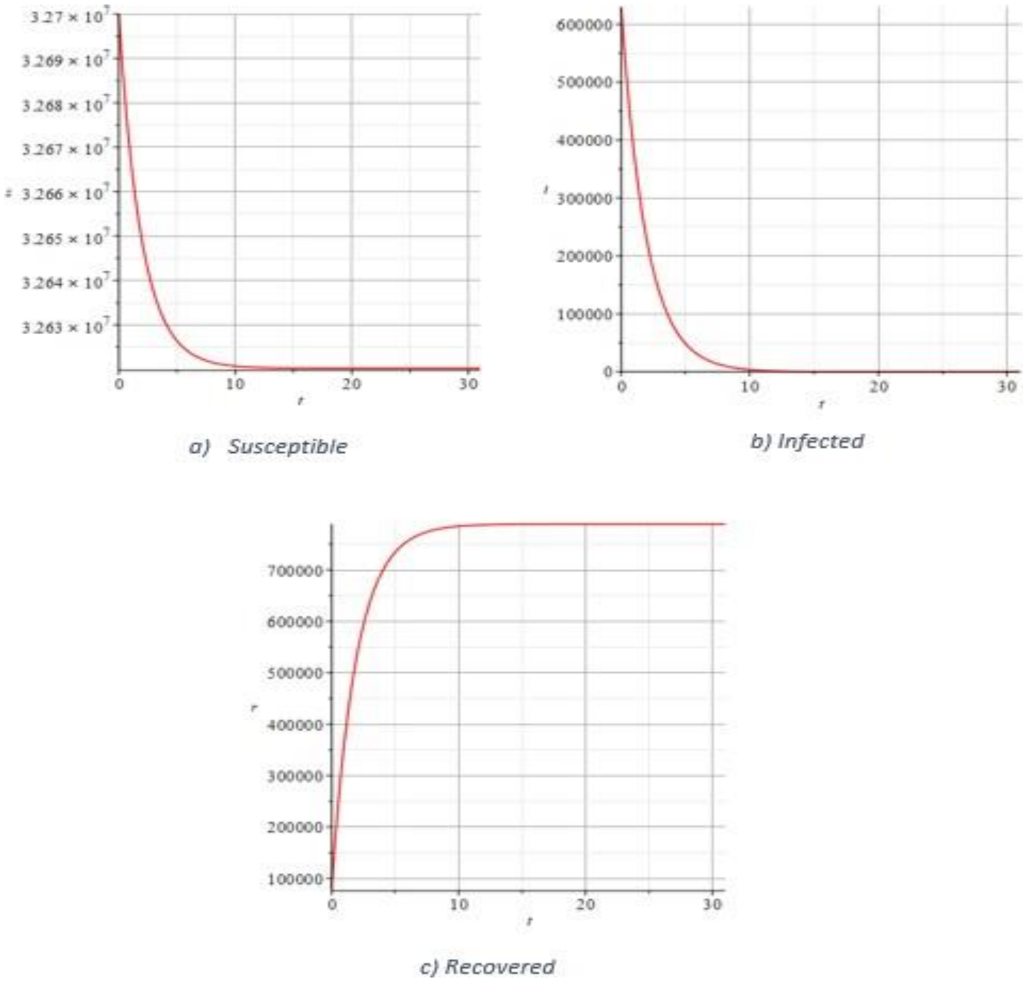


Figure 2: Graph of SIR Model with vaccination



5. Conclusion

In this project, the standard SIR differential equation model will be used to figure out the spread of coronavirus infected population in Malaysia. The analysis and comparison of the transmission of Covid-19 of the model for with and with vaccination were discussed. By using Next Generation Matrix, it is proven the basic reproductive number R_0 is equal to β. Therefore, parameter shows that the basic reproductive number, R_0 of the transmission of Covid-19 with and without vaccination approximated to be $R_0 = 1.8768$ which indicates the disease will begin to spread in a population. For with vaccination, the basic reproductive number, R_0 of the transmission of Covid-19 approximated to be $R_0 = 0.9100$ which indicates the disease is about to vanish from the population. It is evident that the number is decreasing. Thus, the vaccination reduces the spread of virus Covid-19 from infection. Not only that this shows that the actions taken by the government to endure the spreading is accomplished. In addition, is the graph that generated by using Maple command also shows the positive result of using vaccination can reduce the infected rate and increase the recovery rate in the population. In general, Covid-19 transmission is said to be fatal not only to Malaysia but the other countries also faced the same thing. The outbreak caused the World Health Organization (WHO) to declare pandemic for this virus since the transmission rate grows exponentially and is hard to treat. Without the vaccination, there will be a massive potential death. Thus, the need of vaccination to overcome Covid-19 is a must just like the other diseases such as Rubella, Hepatitis A and B , Measles etc.

Ethics Approval and Consent to Participate

The researchers used the research ethics provided by the Research Ethics Committee of Universiti Teknology Mara (RECUiTM). All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the institutional research committee.

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Conflict of Interest

The authors reported no conflicts of interest for this work and declare that there is no potential conflict of interest with respect to the research, authorship, or publication of this article.

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