Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number 0000000

SEIR Model of COVID-19 and the Analysis in Florida

Summary

For COVID-19, which has a very high infection rate, it is essential to make preventive measures in order to decrease the infection rate. Since Florida has canceled all preventive measures, it might probably be an very suitable example to study how COVID-19 spreads in natural state. In this paper, we will analyze the data of COVID-19 in Florida such as: The population of susceptible, exposed, infected, recovered and so on to study the rules of the spread of COVID-19 in Florida, the closest state to nature.

Firstly, based on SEIR model, to discover the impact of different measures and some parameters on the COVID-19, we consider changing three different things: Recovery Rate, vaccine, isolation, in which the first two depend on the government's medical level, and the third depends on the government's policy.

Secondly, according to the real situation in Florida, we improved our SEIR model: Introduce three new groups: the vaccinated(V), the infected and diagnosed(A), the infected but not diagnosed(I), then further refine the relationship between these 7 groups, so that we can reformulate the mathematical expression. And the model will be apply in the next step.

Finally, it is data fitting. Due to the variation of vaccination, epidemic prevention Policies and the virus mutation, the data we collect is mainly two waves: One is from 5th of October 2020 to 14th of March 2021, and the other is from 25th of December 2021 to 10th of March 2022. And our prediction is based on the second wave. The result we get is: The daily infected in Florida will be around 1400 in the next 40 days.

Contents

1 Introduction

1.1 Problem Background

Officially discovered and identified by the medical community on December 26, 2019 for the first time, COVID—19 has lasted for over 2 years. And after Florida announced canceling of quarantine measures in May 2021, the state reduced the frequency of reporting COVID-19 data to the public at the same time.

Two major problems are discussed in this paper, which are:

- What's the impact of different measures or some relative parameters?
- What are the rules of the spread of COVID-19 and future prediction of daily infected in Florida?

1.2 Our work

In order to give a good solution to these two problems, We do the following steps:

1. Firstly, we introduce the basic SEIR model.

2. Secondly, we study the impact of three different changes about COVID-19.

3. Then we improved our model by adding more people groups after having a knowledge of Florida's situation.

4. Finally we collect and fit the data of COVID-19 in Florida, and predict.

2 Preparation of the Models

2.1 Assumptions

- The exposed don't infect others, only the infected do.
- The recovery and death rate are independent from infectious' population size; the medical resources remain constant for each single patient.
- Once a patient is recovered or died, it will never be infected nor infect others. Thus, the virus mutation and strands variation are not taken into consideration.
- Human migration is not considered.

2.2 Notations

The primary notations used in this paper are listed in Table 2.

Table 1: Notations

Symbol	Definition
N	Total Population
S	The population of the susceptible
E	The population of the exposed
I	The population of the infected but not diagnosed
A	The population of the infected and diagnosed
V	The population of the vaccinated
R	The population of the recovered
D	The population of the dead
r	The population of the susceptible an infected people has connected with Each Day
B	Infection Rate
a	Probability that the Exposed Converted to the Infected
y	Recovery Rate
d	Death Rate

3 SEIR Model

3.1 Basic SEIR Model Considering Deaths

3.1.1 Introduction About SEIR

The basic SEIR model contains four basic groups: susceptible, exposed, infected and recovered. In this model we extra consider the death. The susceptible can be infected by the infected and turned into the exposed, the exposed can be converted into the infected in certain probability. Some in the infected group may die while others finally get recovery.

And the model can be expressed below:

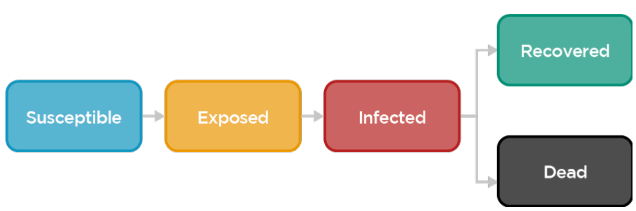


Figure 1: SEIR Model Considering Deaths

The detail of SEIR can be described by equations (7), (9), (10), (11) and (12) :

$$\frac{dS}{dt} = -\frac{rB(1-d)IS}{N} \tag{1}$$

$$\frac{dE}{dt} = \frac{rB(1-d)IS}{N} - aE \tag{2}$$

$$\frac{dI}{dt} = aE - (y+d)I \tag{3}$$

$$\frac{dR}{dt} = yI \tag{4}$$

$$\frac{dD}{dt} = dI \tag{5}$$

3.2 The Impact of Different Measures on the COVID-19 Epidemic

3.2.1 Variation on Recovery Rate

The recovery rate represents the level of medical system in some degree. By changing the recovery rate we can compare the Epidemic trend in developed countries, developing countries and third world countries.

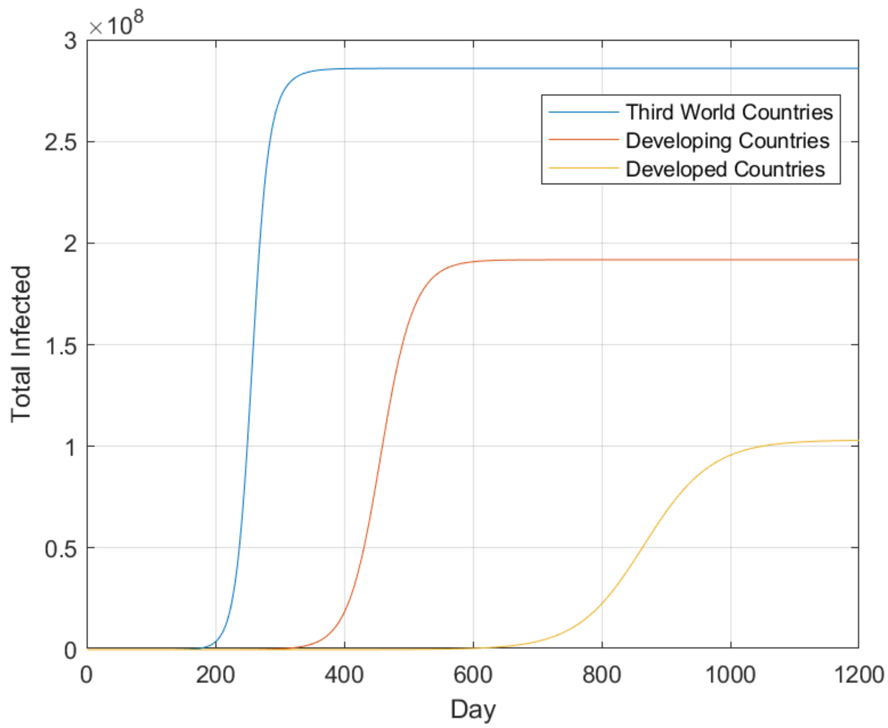


Figure 2: Infection Trend in Different Medical Level

From the figure above, we find that the countries which have lower medical level will receive an outbreak earlier and have a higher total infection number. The infected increasing rate is also sharper. That means the developed countries can treat outbreaks in countries with lower medical level as an early warning. Even if the epidemic has broken out, developed countries can still have ample time to take measures because the epidemic curve is smooth. In a word, developed countries have great advantage dealing with COVID-19 epidemic than other countries due to higher recovery rate.

3.2.2 The Influence of Vaccine

Vaccine is an important measure dealing with epidemic these years. At some point in the trend of COVID-epidemic, we proceed mass vaccination. We set sigma as the percentage of people that have been vaccinated. We also set S_1 as the susceptible who have been vaccinated and E_1 as the exposed who have been vaccinated. S and E are represented as those who haven't been vaccinated. Vaccine does not change the infection rate but changes the probability that the Exposed Converted to the Infected from a to a_0. The SEIR equations will be the ones below in this condition :

$$\frac{dS}{dt} = -\frac{rB(1-d)IS}{N} \tag{6}$$

$$\frac{dS_1}{dt} = -\frac{rB(1-d)IS_1}{N} \tag{7}$$

$$\frac{dE}{dt} = \frac{rB(1-d)IS}{N} - aE \tag{8}$$

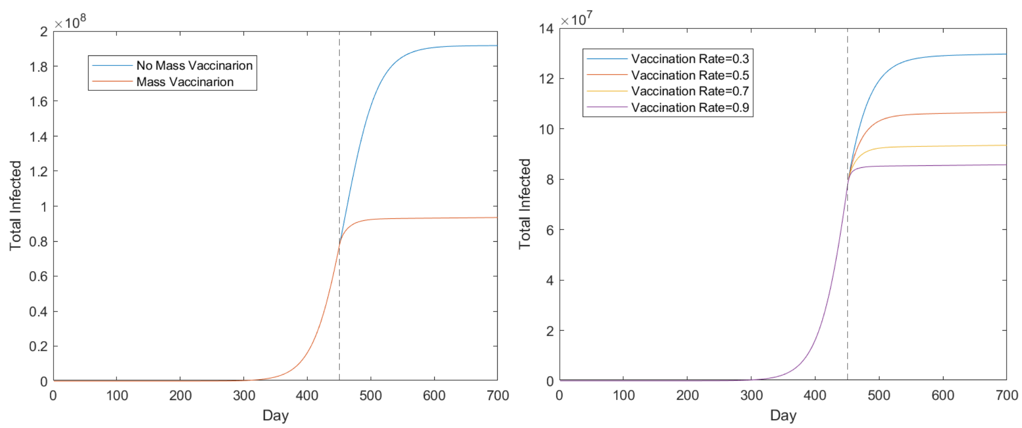
$$\frac{dE_1}{dt} = \frac{rB(1-d)IS_1}{N} - a_0E_1 \tag{9}$$

$$\frac{dI}{dt} = aE + a_0E_1 - (y+d)I \tag{10}$$

$$\frac{dR}{dt} = yI \tag{11}$$

$$\frac{dD}{dt} = dI \tag{12}$$

To visually demonstrate the role of vaccines, we make some comparison in 3. We compare the infection trend of a condition that mass vaccination was proceed with the one that didn't in 3a, and we compare the effect of vaccine in different number of vaccinations in 3b.



(a) Mass Vaccination or Not (b) Different Vaccination Rate

Figure 3: Comparison

We see that mass vaccination can be an efficient way to prevent epidemic from spreading but this should be done in short time. It seems obvious that higher vaccination rate leads to better control of epidemic, but we should notice that when the vaccination rate reaches some point like 0.7, the improvement effect is no longer obvious when continue improve the vaccination rate.

3.2.3 Isolation Control Measures

Isolation Control Measures is also a useful way to prevent epidemic from spreading. We consider two sub-measure: limit social activities and isolate the infected. In limit social activities, people's outdoor activities are restricted, that is, we simply make the value of parameter r smaller. If we isolated the infected, all the infected today will be isolated and not take part in the spreading of epidemic the next day. The only infected that will take part in are the ones that converted from the exposed. In this condition, the SEIR equations will be like the ones below :

$$\frac{dS}{dt} = -\frac{raBIE}{N} \tag{13}$$

$$\frac{dE}{dt} = \frac{raBIE}{N} - aE \tag{14}$$

$$\frac{dI}{dt} = aE - (y+d)I \tag{15}$$

$$\frac{dR}{dt} = yI \tag{16}$$

$$\frac{dD}{dt} = dI \tag{17}$$

We compare these two measures with original SEIR infection trend :

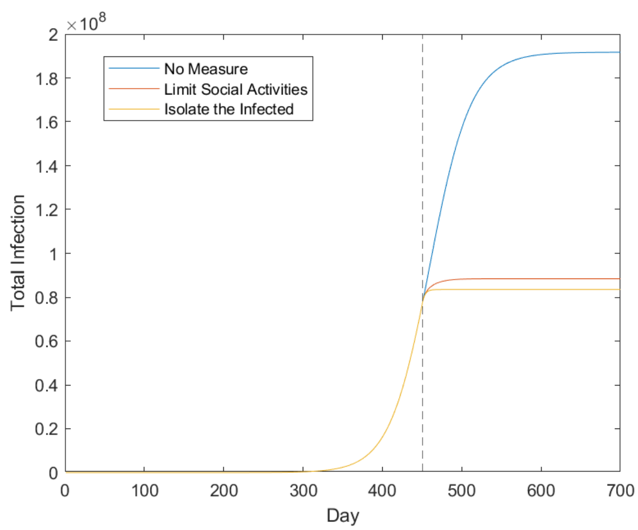


Figure 4: Two Control Measures

We can see that both measures have a significant effect on controlling epidemic, but there are still limits. We can't keep people indoor for long due to the need of social production. Most of the time we cannot guarantee that the infected can be found and get isolated at once.We now compare the epidemic trend in different lasting time of social activities limit :

It is very dangerous to lift the lockdown when the epidemic is not completely under control, which may lead to a second recurrence. we also need to notice that even if the epidemic is under control, we still need to stay alert after we lift the lockdown.

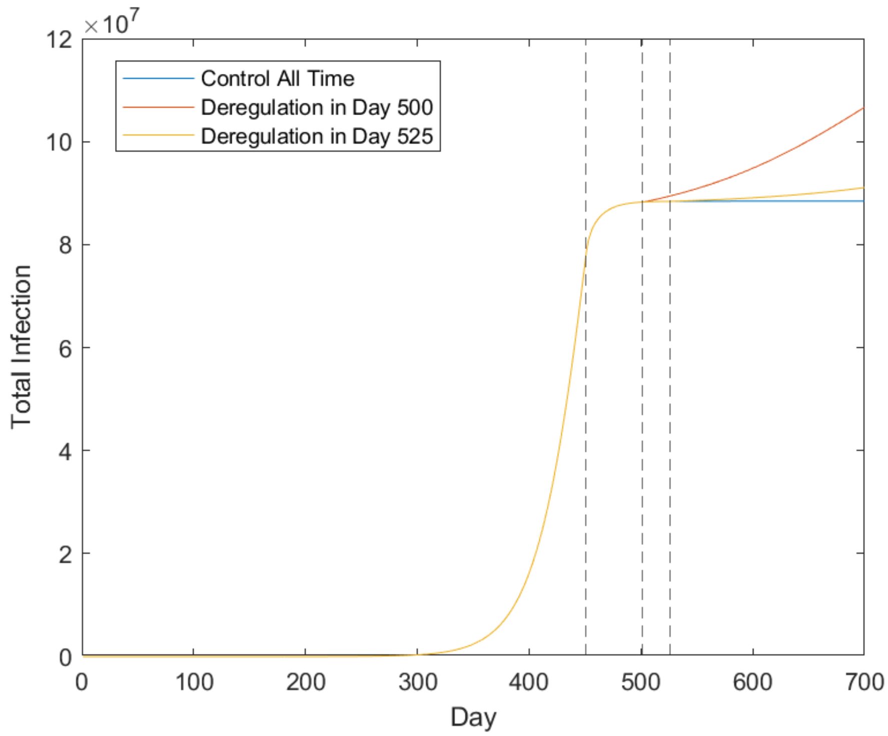


Figure 5: Deregulation at Different Time

4 Improved SEIR Model of COVID-19 in Florida

4.1 Introduction of Improved SEIR Model

In practical analysis, we need to improve basic SEIR model due to the specificity of the COVID-19 and Florida. Actually in the U.S, part of the infected are not diagnosed, We use I to represent them and A to represent those are diagnosed. In this case, the exposed might get recovered without turning to the infected. We notice that only the diagnosed are being isolated and do not take part in the spreading of COVID-19. Also, the Florida government do not proceed any policies like home isolation so we just ignore it. We also consider the influence of vaccine. The improved model is shown below :

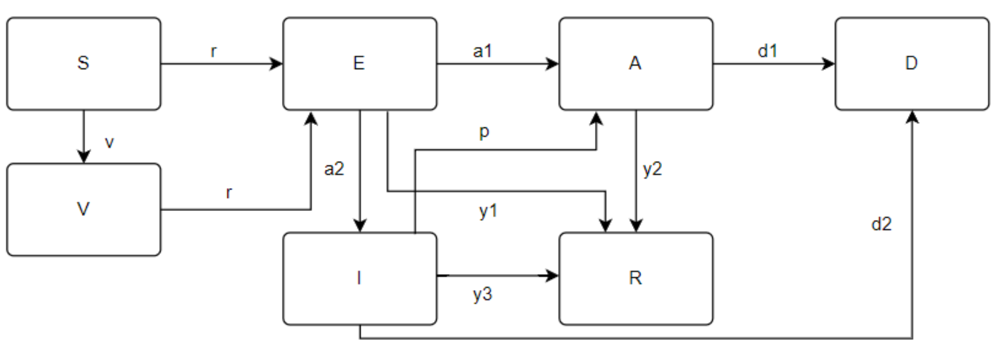


Figure 6: Improved SEIR of COVID-19

The equations improved SEIR model of COVID-19 can be expressed as :

$$\frac{dS}{dt} = -\frac{r_1B_1(1-d_2-y_3)I(S+V)+r_2B_2(1-a_2-a_1)E(S+V)}{N} \tag{18}$$

$$\frac{dE}{dt} = \frac{r_1B_1(1-d_2-y_3)IS+r_2B_2(1-a_2-a_1)ES}{N} - (a_1+a_2+y_1)E \tag{19}$$

$$\frac{dV}{dt} = vS - \frac{r_1B_1(1-d_2-y_3)IV+r_2B_2(1-a_2-a_1)EV}{N} \tag{20}$$

$$\frac{dI}{dt} = a_2E-(p+y_3+d_2)I \tag{21}$$

$$\frac{dA}{dt} = a_1E+pI-(y_2+d_1)A \tag{22}$$

$$\frac{dR}{dt} = y_1E+y_2A+y_3I \tag{23}$$

$$\frac{dD}{dt} = d_1A+d_2I \tag{24}$$

Table 2: New Notations

Symbol	Definition
v	Vaccination Rate
d_1/d_2	Death rate of the diagnosed/undiagnosed
$y_1/y_2/y_3$	Recover rate of the exposed/diagnosed/undiagnosed
a_1/a_2	The rate that the exposed turn to diagnosed/undiagnosed
p	The rate that the undiagnosed turn to diagnosed

4.2 The Model's Fit With the Data and Future Prediction

To examine the fit with the real data, we pick two typical waves of outbreaks of COVID-19 in Florida : one is from 5th of October, 2020 to 14th of March, 2021 and the other is from 25th of December , 2021 to 10th of March , 2022. The two waves has a different infection trend due to the variation of vaccination, epidemic prevention Policies and the virus mutation.

4.2.1 The First Wave

In the first wave, since there had no mass vaccination yet, we ignore the effect of it. We give the value of parameters and compare the calculation of the model with the real data in Florida :

Table 3: Parameters in the First Wave

Parameter	Value
r_1	12.00
r_2	6.00
B_1	0.0025
B_2	0.00125

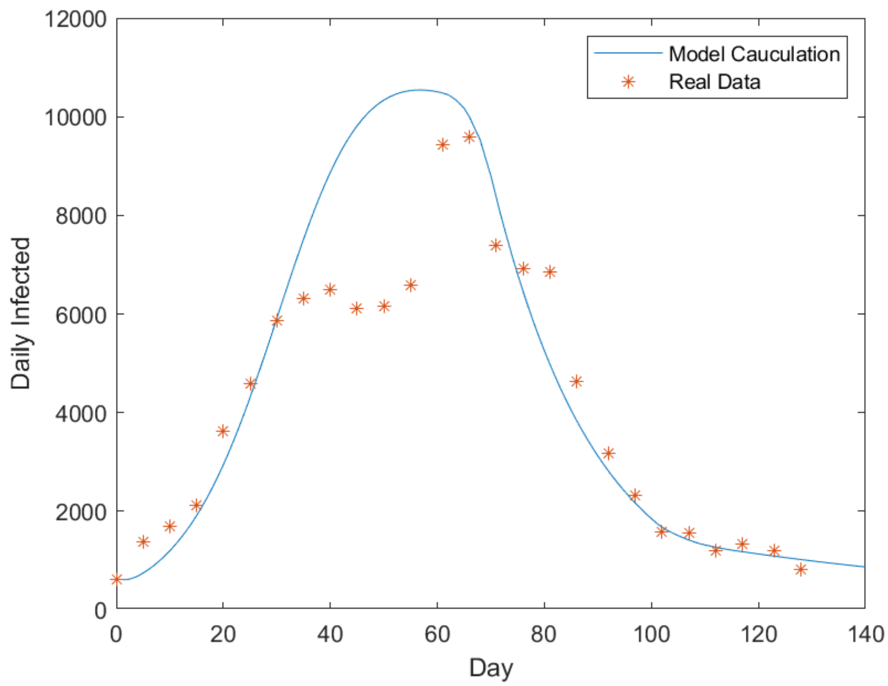


Figure 7: Comparison in the First Wave

4.2.2 The Second Wave and Future Prediction

The higher number of the infected in the second wave is mainly due to the Omicron. Omicron is more infectious and it may let those who already have antibodies get infected. It should be noticed that the Florida government did not take any policies like isolation control measures so the number contact per person will be much greater than the first wave. We also notice that the number of vaccine does per day is decreasing, which can be seen as a linear decrease. Other kinds of data such as hospitalizations should be recorded. We now give the parameter, the comparison and the future prediction in the second wave :

Table 4: Parameters in the Second Wave

Parameter	Value
r_1	20.00
r_2	10.00
B_1	0.007
B_2	0.00325
v	Linear Decreasing

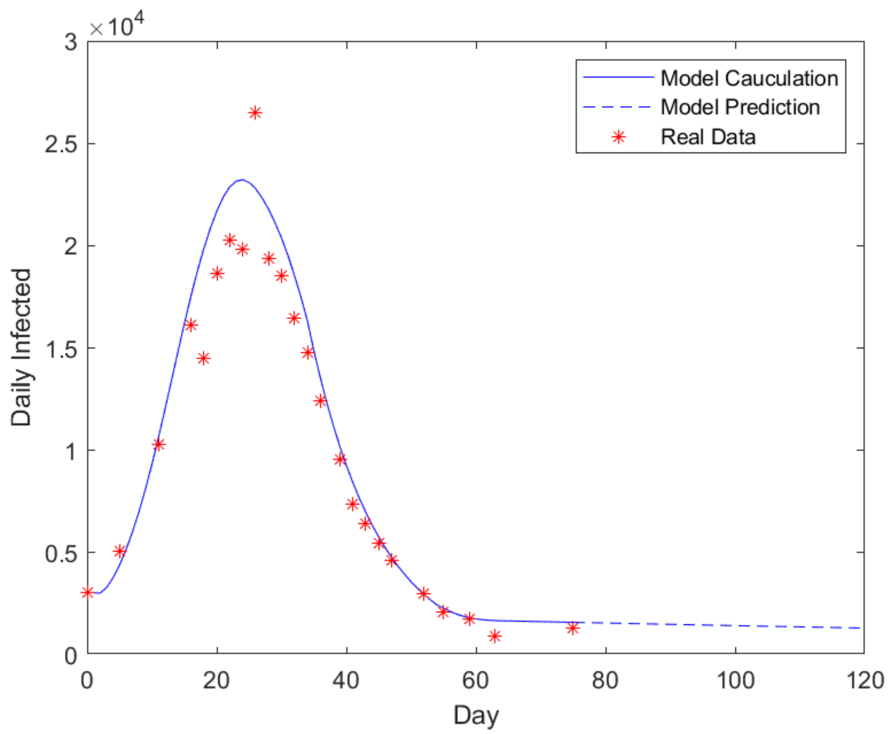


Figure 8: Comparison in the Second Wave and Future Prediction

Here is the prediction using our model: the daily infected in Florida will be around 1400 in the next 40 days. We should notice that this is based on some of the assumptions : First, no epidemic prevention measures will be done; Second, the virus will not mutate significantly in the next period of time.

5 Strengths and Weaknesses

5.1 Strengths

- First one, the model based on SEIR can more objectively reflect the general laws of the epidemic.
- Second one, it is practical to the epidemic prevention and control to consider the influence of different measures.

5.2 Weaknesses

- We don’t consider the variation of population and the foreign case, which makes the fitting and prediction results not particularly accurate.

References

[1] https://coronavirus.jhu.edu/region/us/florida

Appendix : Program Codes

Here are some of the program codes that we used in the research.

Model.m

```
t = 1:120;
for day = 1:length(t)-1
    S(day+1) = S(day) - (r1(day)*B1*(1-d2-y3(day))*S(day)*I(day)+
                r2(day)*B2*(1-a1-a2)*S(day)*E(day))/N;
    E(day+1) = E(day) + (r1(day)*B1*(1-d2-y3(day))*S(day)*I(day)+
                r2(day)*B2*(1-a1-a2)*S(day)*E(day))/N -
                (a1+a2+y1)*E(day);
    I(day+1) = I(day) + a2*E(day) - (p+y3(day)+d2)*I(day);
    A(day+1) = A(day) + a1*E(day) + p*I(day) - (y2(day)+d1)*A(day);
    R(day+1) = R(day) + y1*E(day) + y2(day)*A(day) + y3(day)*I(day);
    D(day+1) = D(day) + d1*A(day) + d2*I(day);
end
```