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Simulation of COVID-19 outbreaks *via* Graphical User Interface (GUI)

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Significance for Public Health

This research is in line with critical areas in Malaysia that are in close association with the community in dealing with the COVID-19 pandemic. This study contributes to the understanding of COVID-19 contagion in Malaysia. This model guides the policymakers to plan the 'exit strategy' of the COVID-19 outbreak as it can forecast the spreading dynamics of the disease in the population accompanied by the intervention measures of quarantine, isolation, lockdown lifting time and the percentage of the people who follow the SOP. The key ingredients to win the battle against the pandemic are embracing the new normal and community responsibility empowerment. This research showed that the individual act of following SOP can prevent the spread of the disease.

Abstract

Background: This research aimed to model the outbreak of COVID-19 in Malaysia and develop a GUI-based model.

Design and Methods: The model is an improvement of the susceptible, infected, recovery, and death (SIRD) compartmental model. The epidemiological parameters of the infection, recovery, and death rates were formulated as time dependent piecewise functions by incorporating the control measures of lockdown, social distancing, quarantine, lockdown lifting time and the percentage of people who abide by the rules. An improved SIRD model was solved via the 4th order Runge-Kutta (RK4) method and 14 unknown parameters were estimated by using Nelder-Mead algorithm and pattern-search technique. The publicly available data for COVID-19 outbreak in Malaysia was used to validate the performance of the model. The GUI-based SIRD model was developed to simulate the number of active cases of COVID-19 over time by considering movement control order (MCO) lifted date and the percentage of people who abide the rules.

Results: The simulator showed that the improved SIRD model adequately fitted Malaysia COVID-19 data indicated by low values of root mean square error (RMSE) as compared to other existing models. The higher the percentage of people following the SOP, the lower the spread of disease. Another key point is that the later the lifting time after the lockdown, the lower the spread of disease.

Conclusion: These findings highlight the importance of the society to obey the intervention measures in preventing the spread of the COVID-19 disease.

Introduction

The COVID-19 outbreak had affected 222 countries with 78,604,532 infected cases and 1,744,235 deaths worldwide.[1] Malaysia reported the first COVID-19 case on 25 January 2020, followed by the unexpected COVID-19 infections during the mass gathering of a Tabligh cluster at a Sri Petaling mosque complex from 27 February to 1 March 2020. The Malaysian government imposed the Movement Control Order (MCO) nationwide, which was also known as the lockdown, on 18 March 2020 with 673 cases. Several methods were suggested in order to break the COVID-19 pandemic infection chain in the community. In Malaysia, the Ministry of Health (MOH) introduced the Standard Operating Procedures (SOPs) based on the avoidance of crowded places, confined spaces and close conservation. The public needs to exercise physical distancing and practice the 3Ws (Wash your hands, Wear a facemask, and Warn self and others against risks, symptoms, prevention and treatment).

Understanding the disease trend and mitigating its effect are crucial to control the spread of the disease. Mathematical modelling is a way to provide insights of the disease's dynamic. Complex models were often used as black boxes by beginners because of the complex theory behind them. The black boxes model is viewed in terms of its inputs and outputs without any knowledge of its internal workings, whereby its implementation is opaque or "black". In this study, the focus was on a compartmental model for describing the time evolution of the pandemic. To facilitate users from different technical backgrounds, a model for COVID-19 outbreak was developed and coded from the "command line mode" to a Graphical User Interface (GUI) for Windows. In response to the current COVID-19 pandemic[21], recently there were several research on the coronavirus (COVID-19) pandemic that aimed to study the dynamics modelling of the disease spread and predict its future progression, including the behaviour of the disease.[2-5] There were various types of models that could be used to describe this dynamic evolution, such as analytical, stochastic[4], phenomenological[2] and machine learning models[3,5].

In a previous study, Kermack & McKendric developed models which consisted of compartments models that assumed an infectious individual may spread the disease to any susceptible members of the population.[6] In the compartmental model, the interest population was divided into a number of groups based on infectious status, for example, dead, recovered, infectious, and susceptible. These compartments make up the model's name, i.e. SIRD, where each letter represents each of the compartment, S for susceptible, I for infectious, R for recovered and D for dead. Recent methods considering simple mean-field models can be implicitly used to gather a quantitative representation of the epidemic spreading, and particularly the height and time of the peak of confirmed infected individuals.[7,8] Moreover, the unusual occurrence of epidemiologic data, due to the ongoing infection outbreaks, makes it difficult to predict and primarily only based on heuristic (fitting) models.[9,23,24]

Recently, Rahman et al. used data driven dynamic clustering framework to model real-time prediction of potential COVID-19 patients.[3] The machine learning models were developed using deep neural network (NN) method where significant features were extracted and used in the model. In addition, the value of hyperparameters were adjusted for ideal solutions and the model was evaluated further until the results satisfied the main goal.[3] Another study by Umar et al.[5] designed different computational heuristics using stochastic intelligence for the numerical treatment of a nonlinear system, denoted as SITR system, where T is treatment which represented the dynamics of novel COVID-19. The numerical analysis is for better understanding of the spread which uses stochastic approaches through the manipulation of artificial intelligence algorithms.[5] Most prediction models have incorporated several major factors such as lockdown. However, these studies have not demonstrated a meaningful scale to predict the effect of lifting time and the percentage of people who abides by the rules. The incorporation of these factors will add value to the model and also increase understanding.

Modelling the COVID-19 outbreaks is one of the important parts of studying the disease. Another important part is the development of the GUI of the COVID-19 outbreaks prediction model. The proposed GUI is important especially to those who has limited background of understanding in mathematical models and programming skills. In this paper, a user-friendly GUI was developed which functions as a tool to forecast the spreading dynamics of the disease in the population accompanied by the intervention measures of quarantine, isolation, and the percentage of the people who follow the SOP. This GUI might help provide recommendations and advise on the government's policy and prevention action (education, economy, and social) during the pandemic based on the projected cases. Other than that, the GUI could help the government to identify the appropriate date of reopening after lockdowns and SOP enforcement based on the future projection of the cases indirectly. So far, to the best of our knowledge, an established GUI for predictive model of COVID-19 outbreaks has not yet been developed and only found a dashboard which show descriptive statistics of COVID-19 [10], mobile apps such as MySejahtera[11], simulation package[12] to predict the development of the current pandemic and website modelling application[13].

This study aimed to model the outbreak of COVID-19 based on improvement SIRD model, which can provide better fit and understanding of the behaviour observed in the infected population curve in the majority of countries specifically in Malaysia, and to develop the GUI of the predictive COVID-19 model. Generally, in this paper, this research is divided into two parts which are modelling the outbreak of the COVID-19 and the GUI-based predictive model development. Then, the developed model was tested by using available data of Malaysian COVID 19 cases from 25th January till 18th September 2020, and the results are discussed. Finally, the conclusion and recommendation of the study is presented in the last section of the paper.

Design and Methods

The entire work was divided into two major objectives. The first one was to develop an improved model for COVID-19 outbreaks. The second task was to create a GUI, which would provide a user-friendly interface to the user so that the simulations can be performed by a semi-skilled professional. This study was carried out in September 2020.

A compartmental model known as SIRD originate from the work of Kermack and McKendric[6] in 1927 was used to describe the COVID-19 outbreaks in Malaysia. The total population was categorised into four compartments. Let day 1 be the first day that COVID-19 cases were detected in Malaysia which was on 25th January 2020.[22] $S(t)$ is the total number of individuals who is capable of being infected by the disease from day 1 until day t, while $I(t)$ is the total number of people who have been infected and can spread the disease to group S from day 1 until day t. The total number of people who have already caught the disease and have recovered from the disease from day 1 until day t is labelled as $R(t)$. The last category is $D(t)$, which resembles the total number of people who have died from the disease from day 1 until day t. The modelling of the outbreaks was performed under the following assumptions.

(a) the total population of Malaysia is constant ($N = 32\,\text{million}$) and the natural birth and death are ignored

(b) the disease is spread by infected individuals coming into close contact with susceptible individuals (the sporadic case is not considered)

(c) the recovered individuals could be reinfected[20]

By considering of all these assumptions, the model was formulated as follows.

$$\frac{dS}{dt} = -\underbrace{\beta \frac{I}{N} S}_{\text{new infections}} + \underbrace{\delta R}_{\text{reinfections}} \tag{1}$$

$$\frac{dI}{dt} = \underbrace{\beta \frac{I}{N} S}_{\text{new infections}} - \underbrace{\gamma I}_{\text{recover}} - \underbrace{\mu I}_{\text{die}} \tag{2}$$

$$\frac{dR}{dt} = \underbrace{\gamma I}_{\text{recover}} - \underbrace{\delta R}_{\text{reinfections}} \tag{3}$$

$$\frac{dD}{dt} = \underbrace{\mu I}_{die} \tag{4}$$

$$\beta(t) = \begin{cases} \beta_1 t + \beta_2, & t < t_{lockdown} \\ \beta_0 \exp\left(-\frac{(t - t_{lockdown})}{\tau_\beta} \right), & t_{lockdown} \le t < t_{lift} \\ (1-r)(\beta_1 (t - t_{lift}) + \beta_2), & t \ge t_{lift} \end{cases} \tag{5}$$

$$\gamma(t) = \begin{cases} \gamma_2 t + \gamma_3, & t < t_{lockdown} \\ \gamma_0 + \frac{\gamma_1}{1 + \exp(-t + t_{lockdown} + \tau_\gamma)}, & t \ge t_{lockdown} \end{cases} \tag{6}$$

$$\mu(t) = \begin{cases} \mu_2 t + \mu_3, & t < t_{lockdown} \\ \mu_0 \exp\left(-\frac{(t - t_{lockdown})}{\tau_\mu} \right) + \mu_1, & t_{lockdown} \le t < t_{lift} \\ \mu_2 (t - t_{lift}) + \mu_3, & t \ge t_{lift} \end{cases} \tag{7}$$

$$\delta(t) = 0 \tag{8}$$

where $\beta(t)$ is the infection rate, $\gamma(t)$ is the recovery rate, $\mu(t)$ is the death rate, and $\delta(t)$ is the reinfection rate. Equation (1), $\frac{dS}{dt}$ describes how the number of susceptible is changing in time. The susceptible individuals would be infected if they had close physical contact with infected people. The first term on the right hand side (RHS) of equation (1) resembled that the more connection and interaction between susceptible and infected people, the more people were going to be infected. It was an output value for group *S* and input value for group *I*, which was depicted by the first term on the RHS of equation (1) and (2), respectively. The recovered people had the probability to be reinfected. Hence, in this case, group *R* would be losing a certain value (the second term on the RHS of equation (3)), as they were added to the number of susceptible (the second term on the RHS of equation (1)). For equation (2), the number of infected people could be reduced if they recovered (enter group R) or deceased (enter group D) as portrayed in equation (3) and (4), respectively.

The initial conditions $S(0) = N - I(0) - R(0) - D(0)$, $I(0) = 3$ and $R(0) = D(0) = 0$ were obtained from the actual data reflecting the first case of COVID-19 in Malaysia on 25 January 2020. N is the total population such that

$$N = S(t) + I(t) + R(t) + D(t)$$

The reinfection rate in equation (8) was set to zero because in Malaysia, no record has shown that the infected people were re-infected.

In this work, novel formulations for epidemiological parameters $\beta(t)$, $\gamma(t)$, and $\mu(t)$ were introduced, as displayed in equations (5), (6), and (7), respectively. Factors of intervention measures included lockdown, physical distancing, quarantine, healthcare system, hospitalisation of the infected individuals and treatment, and community behaviour in terms of the percentage of people who abided by the rules. These factors were formulated in the model as piecewise functions to reflect the timely dependent epidemiological parameters. The time interval was divided into three phases as follows:

Phase I: The day when the first case wass detected until lockdown, $t < t_{lockdown}$

Phase II: Lockdown until reopening, $t_{lockdown} \leq t < t_{lift}$

Phase III: After the reopening, $t \geq t_{lift}$

Supposedly, $t_{lockdown}$ would be the day when Malaysia imposed the lockdown on 18 March 2020 (day 54), which was calculated from the first day of case detection. The t_{lift} was known as the lifting time, which referred to the reopening date after the lockdown. There were 14 unknown parameters, which were β_0, β_1, β_2, τ_β, γ_0, γ_1, γ_2, γ_3, τ_γ, μ_0, μ_1, μ_2, μ_3, τ_μ. This set of parameters was known as set b.

When the outbreak started and people had high mobility and freedom to move anywhere, the infection rate, $\beta(t)$, was assumed to be a linear function, i.e., $\beta(t) = \beta_1 t + \beta_2$ with β_2 as its initial value. Similarly, the recovery rate, $\gamma(t)$, and death rate, $\mu(t)$, were assumed to be a linear function with γ_3 and μ_3 as their initial value, respectively.

When the MCO was introduced, the infection rate decayed due to the isolation of people and physical distancing, and this behaviour was described by an exponential function

$\beta(t) = \beta_0 \exp\left(-\frac{(t - t_{lockdown})}{\tau_\beta}\right)$ with β_0 as its initial value and τ_β was the characteristic time of transmission. Similarly, the death rate decreased due to the reduced number of infected people and its behaviour was described by an exponential function, $\mu(t) = \mu_0 \exp\left(-\frac{(t - t_{lockdown})}{\tau_\mu}\right) + \mu_1$. Moreover, $\mu_0 + \mu_1$ was the initial death kinetics during the lockdown and μ_1 was the death kinetic at infinite time. The τ_μ wass the characteristic time of death.

During the enforcement of the lockdown and thereafter, the recovery rate was described by a logistic function $\gamma(t) = \gamma_0 + \frac{\gamma_1}{1 + \exp(-t + t_{lockdown} + \tau_\gamma)}$. The recovery rate was growing with time and approached a certain saturation value $\gamma_0 + \gamma_1$. The improvement of recovery rate was due to better healthcare providers and treatment to those infected. The τ_γ was the characteristic time of recovery.

When the lockdown was lifted, the infection and death rates were assumed to follow the trend at the beginning of the outbreak when no lockdown was implemented. However, based on the experience in facing the pandemic, a fraction of compliance to the SOP was included in the infection rate, i.e., $\beta(t) = (1-r)(\beta_1(t - t_{lift}) + \beta_2)$. Here, r was the percentage of Malaysians who followed the SOPs and practised the 3Ws, even after the government had lifted the lockdown. The numeric value of *r* was between 0 and 1.

The system of ordinary differential equations from equations (1)-(8) were solved by using the 4th order Runge-Kutta method that was embedded with parameter fitting techniques in MATLAB. In the parameter fitting process, the values of the 14 unknown parameters in Table 2 were firstly gained by using Nelder-Mead algorithm[25], then the obtained root mean square error (RMSE) between the real data and model was further minimised by using pattern-search. The flowchart in Figure 1 illustrates the steps involved in the process to achieve the first objective of developing an improved SIRD model.

Table 1 shows the comparison of root mean square error (RMSE) for the SIRD model by various researchers consisting of Anastassopoulou et al.[7], Fernández & Jones[14], Fanelli & Piazza[8] , and Caccavo[9]. Different researchers used different functions of infection rate, recovery rate, and death rate. Their functions were explicitly applied to the case of COVID-19 outbreaks in Malaysia[19] recorded from 25th January until 13th May 2020. The proposed function of this study that was listed in the last row produced the smallest error. From the finding, the proposed function clearly improved the fit of the SIRD model as compared to the other methods and produced the closest similarity between model and data.

Program description

The second phase of programming in the form of GUI will support the modelling procedure discussed in the previous section. A graphical user interface (GUI) is an interactive surface of a program that has a friendly appearance and intuitive menus such as input text and pushbuttons. The GUI program was created with MATLAB 19b under Windows operating system. It was constructed using the embedded designer called “Guide” in MATLAB[15] which provided an easy way to build the GUI with three principal elements, namely components, figures, and callbacks. The GUI would benefit people who are not familiar with the command line and has minimal experience in programming, as they can focus more on using the application rather than write and understand the coding.[39,40]

By using the estimated value of 14 parameters resulted from the parameter fitting technique in the previous section, the model was then coded in the GUI environment. The flowchart of developing a GUI for COVID-19 outbreaks is depicted in Figure 2. The purpose of the GUI predictive model is to display the cases projection graphically, quickly, and easily. It is designed to monitor and forecast the evolution of the number of active cases of COVID-19 in Malaysia along the time.

Figure 3 shows the users screen for modelling and simulation of the COVID-19 outbreak in Malaysia. It contains two input text, one pushbutton and a graphical space. At the top of the GUI simulation are the input texts where the user needs to enter the values in the appropriate box. A user will enter two parameter values, namely the re-opening date after lockdown and the percentage of Malaysians who will follow the standard operation procedure (SOP) and practise 3W (wash, wear, warn) even after the government has lifted the lockdown. The user should define those values as inputs to the program.

After inserting the input parameters, the user can monitor the behaviour of the model. When the pushbutton ‘Run the Simulator’ is clicked, the projection graph of the number of infected people from COVID-19 cases will appear as shown in Figures 3 - 5. The blue and red curves show the prediction of the evolution of the cases. Note that the red curves forecast at a longer time than the data points. To know the prediction of number of cases in numeric value, the user can click along the curves. The click gives information on the coordinates of a point in order for the user to find the value. The black square symbol plots real data of the number of cases for COVID-19 in Malaysia. Through the GUI simulation with two input values, the generated graph can be observed and analysed accordingly.

Testing and Results

The predictive GUI based model was tested with publicly available data of Malaysian COVID 19 cases from 25th January till 18th September 2020. Since the cases showed a soaring trend in March 2020, Malaysia had implemented partial lockdown including movement control order (MCO) on 18th March 2020, conditional movement control order (CMCO) on 4th May 2020, and recovery movement control order (RMCO) on 10th June 2020.[16] MCO signified a major step of countermeasures taken by the Malaysia government and successfully flattened the COVID-19 outbreak curve. The description of the different types of MCO implementation in Malaysia are summarised in Table 3.

The model-based GUI was tested by assuming the percentage of people who abided by the rules, which were 80%, 60%, 50% and 30%. The GUI simulated results were depicted in Figures 3 - 5. The vertical axis represented the total number of COVID-19 active cases in Malaysia on a particular day, whereby the black squares resembled the actual data, while the lines were from the prediction model. Day 1 (25th January 2020) was referred to the first date of case detection and day 54 (18th March 2020) was the MCO enforcement. The main focus was on the prediction number of cases on 15th October 2020 (day 265) in all testing.

The graphs in Figure 3 show the number of COVID-19 active cases if the GUI user sets the reopening date to 10th June 2020 with different percentage of people who abide by the rules. This date was chosen in the simulation because it was when interstate travel was allowed since the first lockdown on 18th March 2020. From the simulation, the number of active cases on 15th October 2020 was 12, 814, 6542, and 408832 if 80%, 60%, 50%, and 30%, people abide by the rules, respectively.

The first phase of school reopening after the MCO took place on 24th June 2020 with priority given to students taking public examinations namely Malaysian Certificate of Education (SPM), Malaysian Vocational Certificate (SVM), Malaysian Higher School

Certificate (STPM), Malaysian Higher Religious Certificate (STAM), and equivalent international school examinations.[17] Figure 4 illustrates the effect of different percentage of people abides by the rule to the spread of the pandemic for the reopening date of 24th June 2020. School reopening for Year 1 to Year 4 pupils in primary schools started on 22nd July 2020.[17] The simulation test for this reopening date is displayed in Figure 5.

As shown in Figures 3 – 5, the predictive model worked well as it matched the data and successfully predicted the first peak around April 2020. However, there were some slight differences between the data and the prediction model around June 2020. One reason for this could be the surge of COVID-19 clusters from the immigration detention centres. Malaysia recorded 776 positive cases on 19th June 2020 at four immigration depots – Bukit Jalil, Semenyih, Sepang and Putrajaya.[18]

An interesting observation from Figures 3-5 is that the higher the percentage of people follow the SOP, the lower the number of infected cases was projected. In other words, if the number of people who abide by the rules shows a decreasing trend (in percentage), an increasing trend of the number of the people who will be infected by the disease will be observed. This highlights the evidence that responsible act and prevention measures from each individual is significant and crucial.

In addition, if 80% of people abide by the rules for the three simulations' reopening dates was entered, as illustrated in Figures 3-5, the trend line will be levelled off to zero cases. Therefore, to curb the pandemic, at least 80% of people should follow the SOP.

Table 4 records the expected number of active cases on day 265 (15th October 2020) based on the percentage of people who abide by the rules. The results were obtained from Figures 3-5 with additional simulations for 99% and 70% of people who abide by the rules. It allows comparisons between the reopening dates versus the expected number of active cases with a particular percentage of people who follow the SOP.

With only 50% of people practice 3W (wash, wear, warn) and the MCO lifted date of 10th June 2020, it was estimated that the projected number of cases will be 6542 on day 265. The number of cases decreased to 1404 with reopening date of 24th June 2020. The estimated figure dropped to 87 cases if the lockdown duration is longer with reopening date of 22nd July 2020. Overall, the later the MCO lifted date, the lower the projected number of cases. An evaluation of this result suggests that the longer the duration for lockdown, the better the control of the pandemic.

Based on the testing and obtained results, it could be concluded that the higher the percentage of people who abided by the rules, the lower the spread of COVID-19. Furthermore, the later imposing of reopening the country after the lockdown, the lower the spread of the disease. MCO is necessary to curb the spread of COVID 19. However, in another context, prolonged MCO would paralyse the global economic growth[26,36,37], affect the educational system[28,29,34], alter the lifestyle[31,32,38] and increase the probability of mental health problem[27,30,33,35]. To ensure minimum impact of the disease, nations need to learn to live with the virus under a new norm by obeying the SOP setup by the government. If the nations work together with the government in the fight against COVID 19, all countries will be able to save lives and minimise the impact of the disease, as depicted in Figures 3 - 5. The GUI-based model can facilitate users from various technical backgrounds to predict the projection of infected cases according to the countermeasures taken by the respective parties. In Malaysia, the GUI is intuitive to the government and public health officials. The required input values on the GUI and the projection output were easy to understand and was related to the normal operating system in Malaysia.

Conclusion

The study presented in this paper facilitated efficient and effective predictive COVID-19 outbreaks model based on improved SIRD model. The novel formulations for epidemiological parameters included factors of intervention measures which it gave the smallest root mean square error (RMSE) compared to the existing model. The factors considered were lockdown, social distancing, quarantine, healthcare system, hospitalisation of the infected individuals and treatment, and community's behaviour in terms of the percentage of people who abides by the rules. These factors were formulated in the model as piecewise functions to reflect the timely dependent epidemiological parameters. Then, the model was used to develop the GUI of the prediction model of the COVID-19 outbreaks. This GUI based model was developed with several information which can be used to layman people and to understand the COVID-19 situation better. Based on the testing and obtained results, it can be concluded that the higher the percentage of people following the SOP, the lower the spread of the disease. Another key point is that the later the lockdown lifting time, the lower the spread of the disease. However, it is not possible to impose a lockdown for a long time. In order to reopen the country at a certain date, at least 80% of people should abide by the rules to effectively curb the pandemic. In Malaysia, further strict governmental interventions should be chosen. However, in order to maintain and improve global economic growth, people should live within the new norm suggested by the authorities and WHO.

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Table 1. Comparison of the root mean square error (RMSE) by using different settings for SIRD model to the case of COVID-19 outbreak in Malaysia.

No	Source	RMSE
1	Anastassopoulou et al.[7]	6.128918×10^{2}
2	Fernández & Jones[14]	3.0655465×10^{2}
3	Fanelli & Piazza[8]	1.6815126×10^{2}
4	Caccavo[9]	0.9072268×10^{2}
5	Our proposed model	0.8007761×10^{2}

Table 2. The 14 parameters determined by parameter fitting techniques of the proposed model based on real data.

Parameter	Value	Parameter	Value
β_0	0.152804543338299	μ_1	0.000153164803984
γ_0	0.025909834357211	β_1	0.001423470338643
μ_0	0.001510617364145	β_2	0.073733345187117
τ_β	21.732155377825364	γ_2	0.000083004911911
τ_γ	12.359300607126448	γ_3	0.006066878694908
γ_1	0.026700039069596	μ_2	0.000080126119201
τ_μ	26.359322685088163	μ_3	0.000250643745785

Table 3. Movement control order implemented in Malaysia.

Movement Control Order	Description of the Control Measure
MCO (18th March 2020)	Closure of all government, private and education sectors. Only those involved in essential services were allowed to operate. These include telecommunications, electricity, water, energy, irrigation, postal, transportation, oil, gas, fuel, lubricants, broadcasting, finance, banking, cleaning, retail, health, pharmacy, port, airport, fire, prison, safety, defence, and food supply. During MCO, interstate travels were not permitted.
CMCO (4th May 2020)	Schools and universities were closed while sports activities were heavily restricted. Economic activities were allowed but operating hours were limited. More activities can be operated compared to MCO but under strict standard operating procedures.
RMCO (10th June 2020)	The sectors under the Ministry of Tourism, Arts and Culture began to open on 1st July 2020. Tourism businesses are required to abide by the rules of social distancing measures, checking the customer temperatures, enforce the wearing of the face masks, crowds are limited to 200-250 people and need to provide the hand sanitizer in their premises. Kindergartens, government and private pre-schools, nurseries and daycare centres can resume operations starting from 1st of July. Some of the businesses and activities have been allowed to resume operations including wellness and foot massage centres, spas, meetings, seminars, weddings, and religious gatherings. Social activities which include swimming in public, hotel and private pools have also been permitted. Interstate travel is allowed.

Table 4. The expected number of active cases on day 265 (15th October 2020) based on the percentage of people who abide by the rules.

People who abide by the rules (%)	Reopening date		
	10th June 2020	24th June 2020	22nd July 2020
99	0	0	0
80	12	7	2
70	265	43	8
60	814	246	28
50	6542	1404	87
30	408832	45582	860

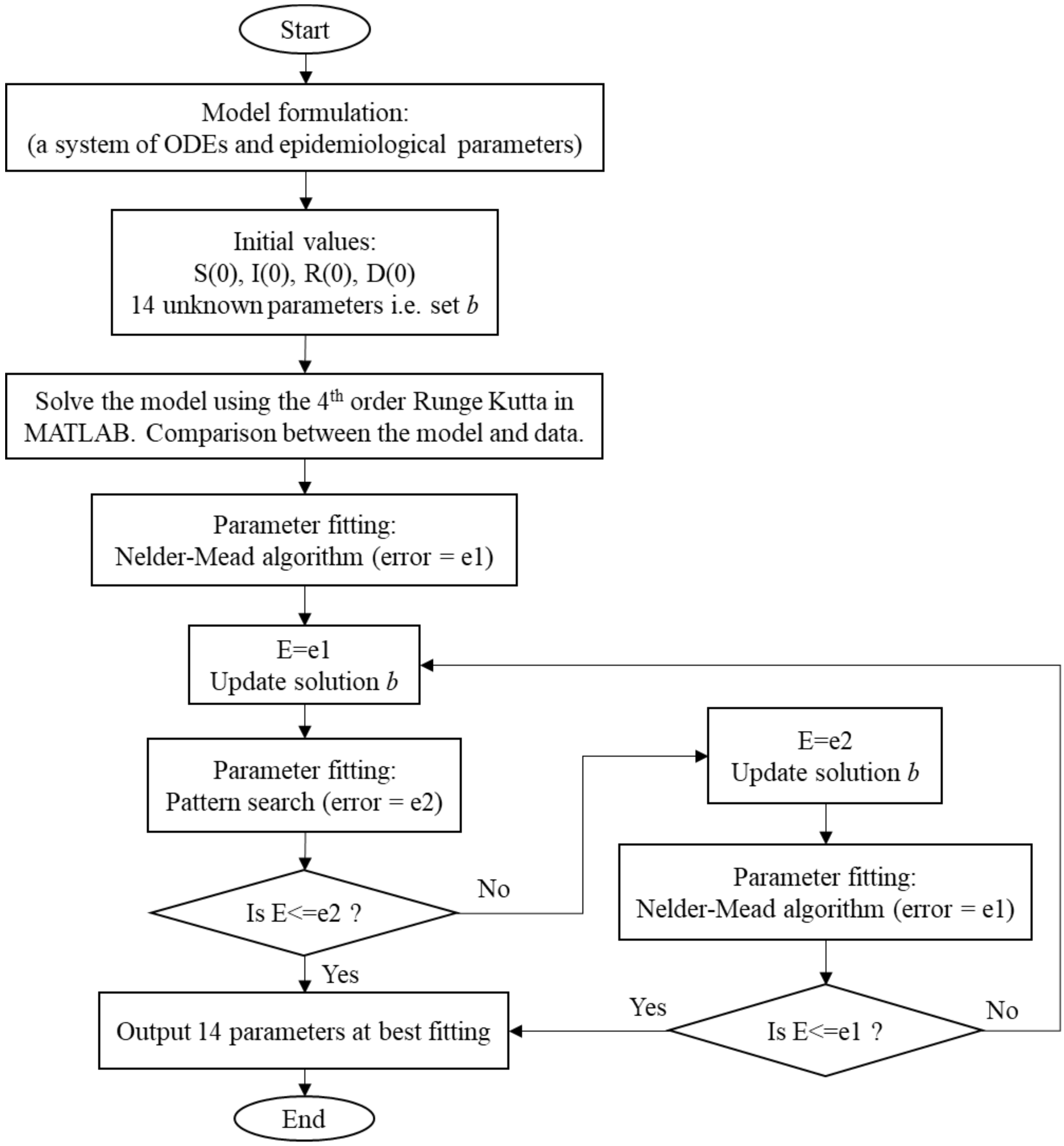

Figure 1. Flowchart of developing an improved model for COVID-19 outbreaks.

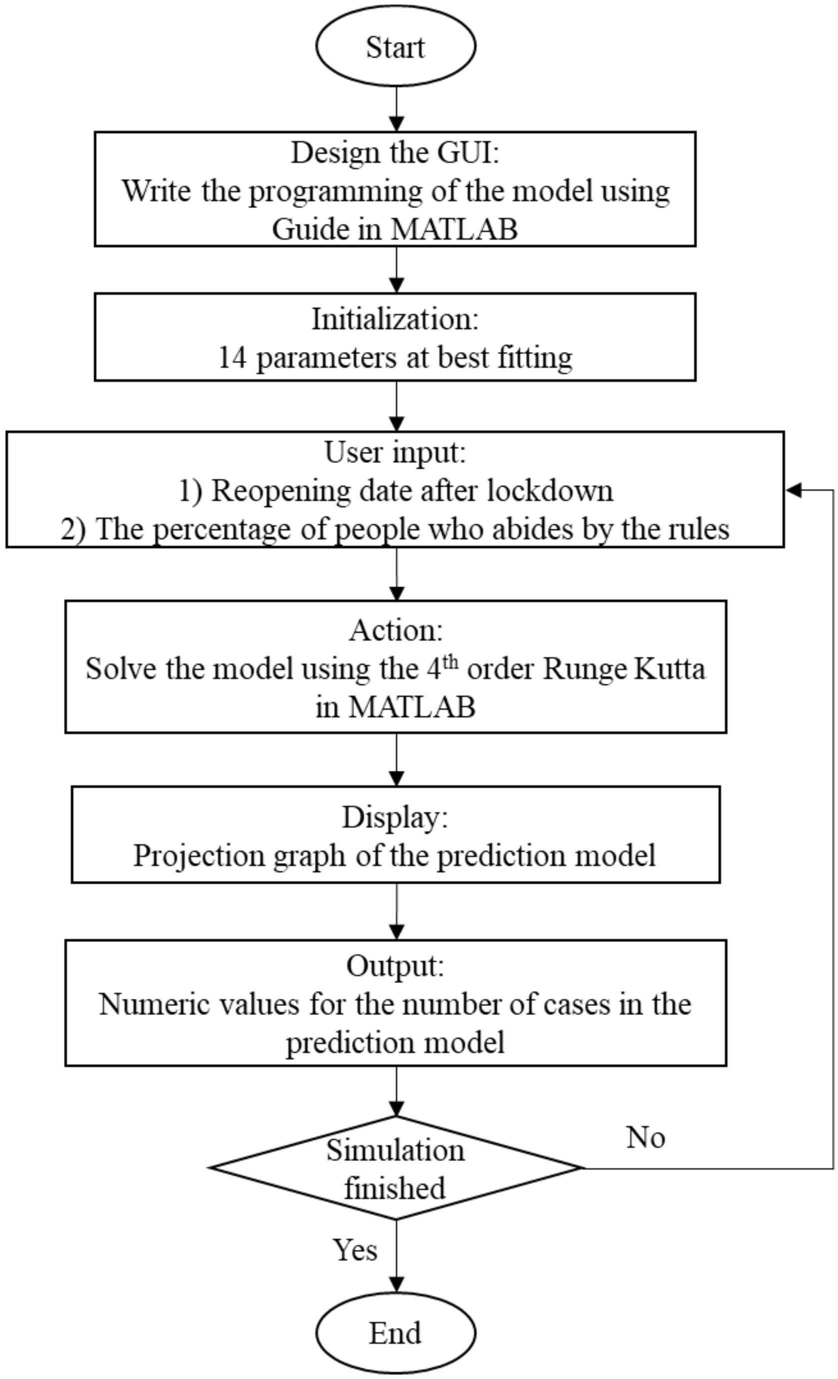

Figure 2. Flowchart of developing a GUI for COVID-19 outbreaks.

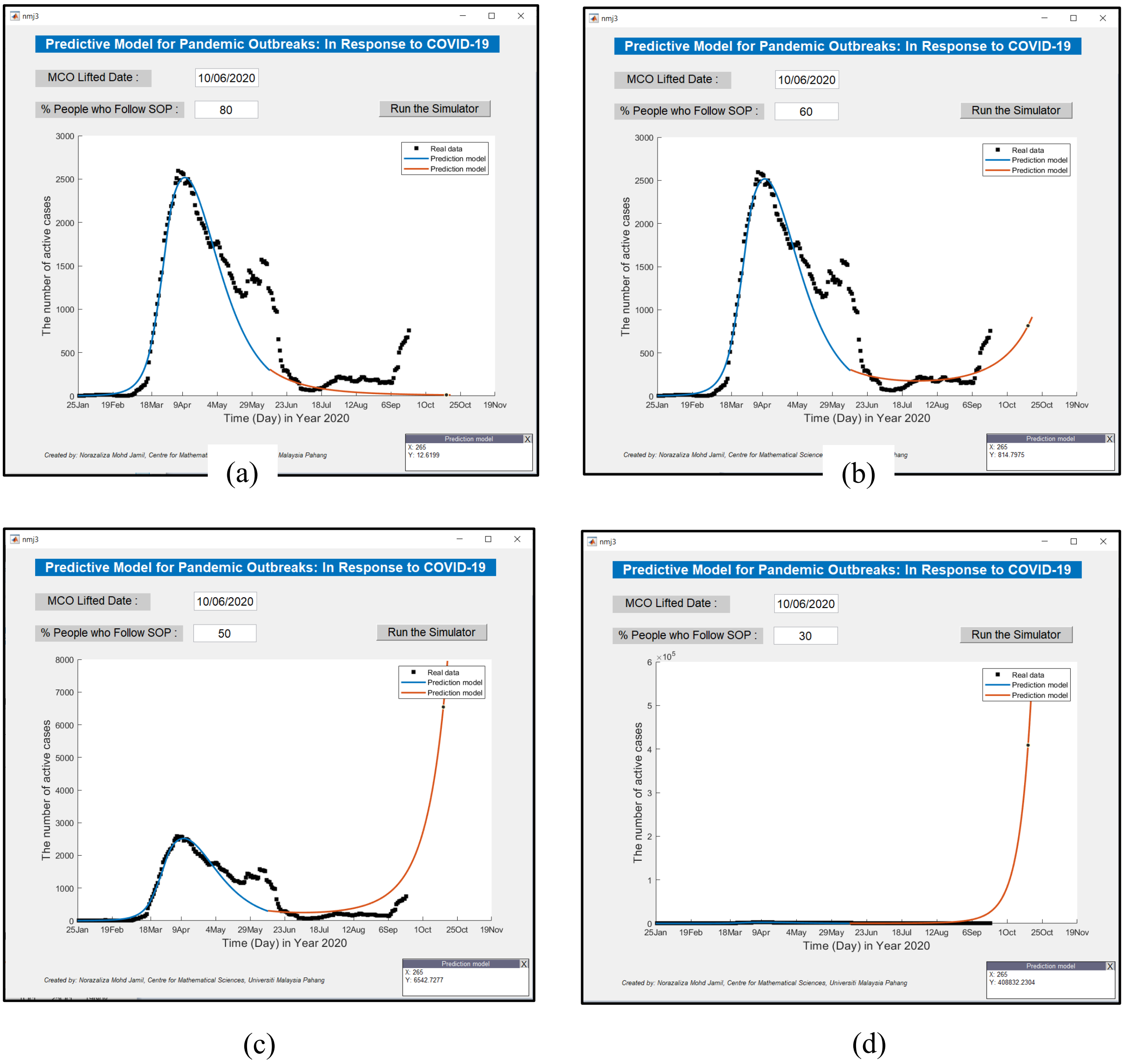

Figure 3. The GUI simulator of reopening date on 10th June 2020 at various percentages of people who abide by the rules: (a) 80%, (b) 60%, (c) 50%, and (d) 30%.

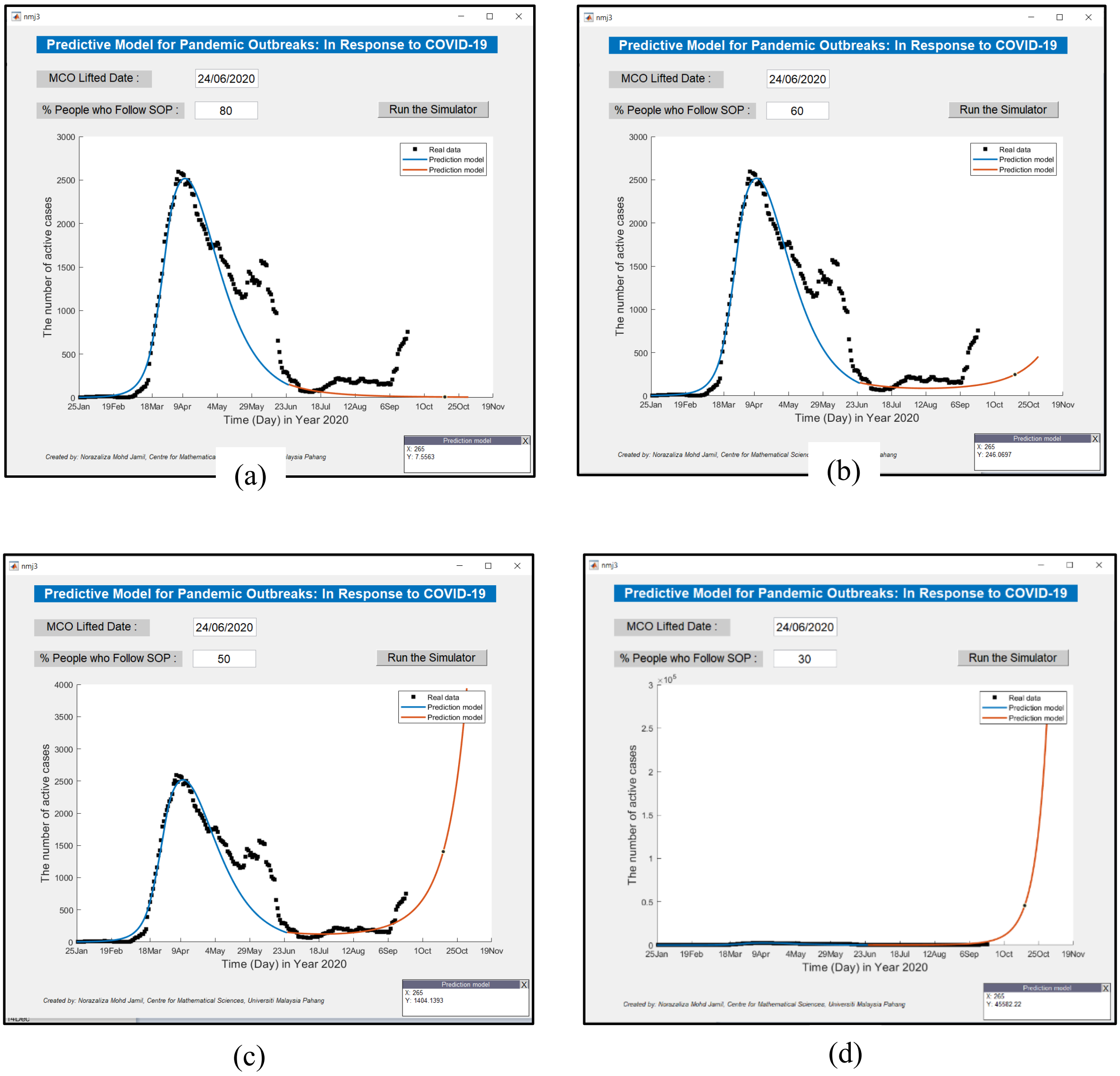

Figure 4. The GUI simulator of reopening date on 24[th] June 2020 at various percentages of people who abide by the rules: (a) 80%, (b) 60%, (c) 50%, and (d) 30%.

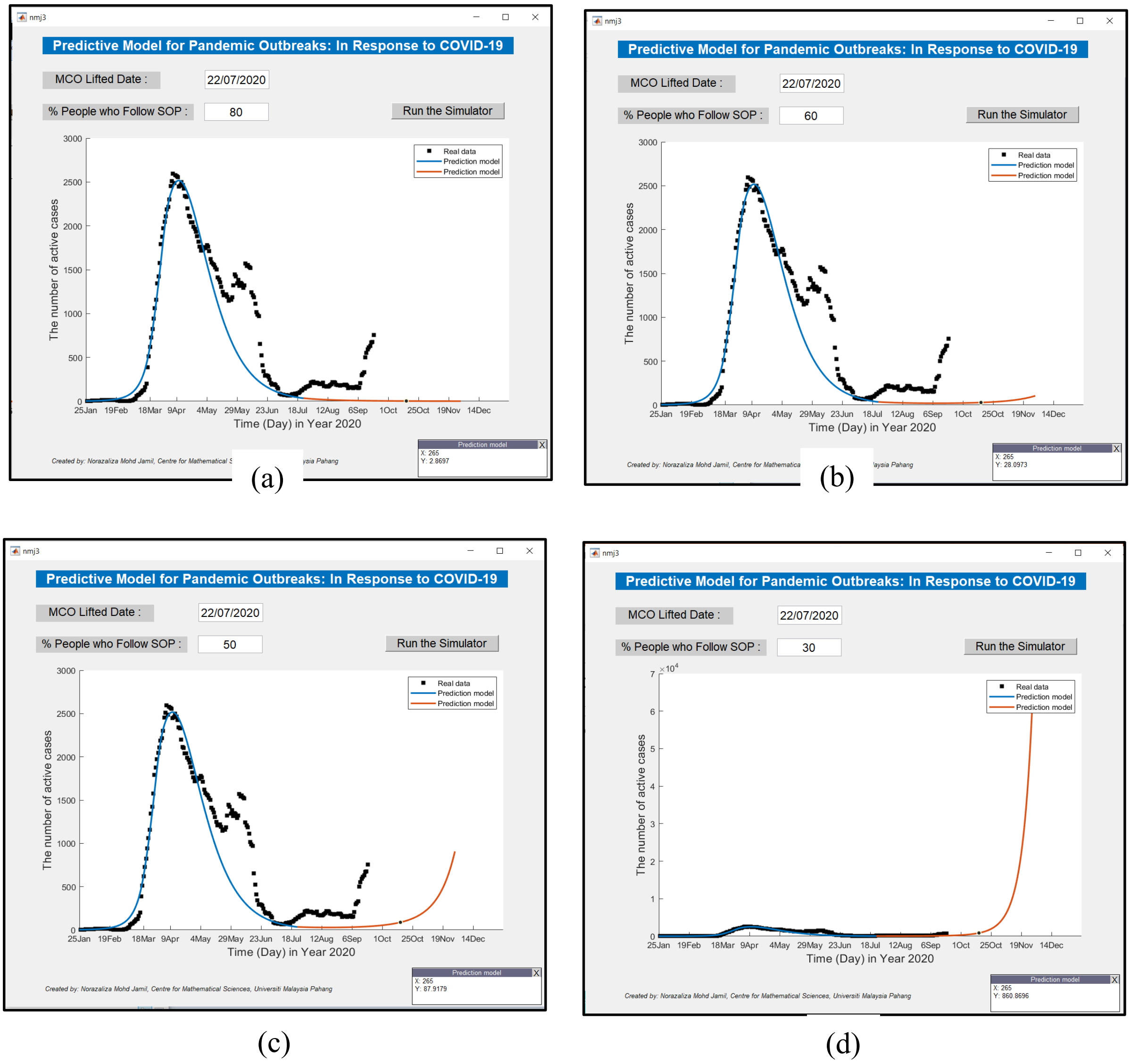

Figure 5. The GUI simulator of reopening date on 22nd July 2020 at various percentages of people who abide by the rules: (a) 80%, (b) 60%, (c) 50%, and (d) 30%.