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MODIFIED SEIRD MODEL: A NOVEL SYSTEM DYNAMICS APPROACH IN MODELLING THE SPREAD OF COVID-19 IN MALAYSIA DURING THE PRE-VACCINATION PERIOD

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ABSTRACT: Mathematical modelling is an effective tool for understanding the complex structures and behaviors of natural phenomena, such as coronavirus disease 2019 (COVID-19), which is an infectious disease caused by a life-threatening virus called SARS-CoV-2. It has rapidly spread across the world in the last three years, including Malaysia. Adopting a novel system dynamics approach, this paper aims to explain how mathematics can play a significant role in modelling the COVID-19 spread and suggests practical methods for controlling it. It forecasts the data of infected (*I*), recovered (*R*) and death (*D*) cases for decision-making. This paper proposes a modified Susceptible-Exposed-Infected-Recovered-Death (SEIRD) model with time-varying parameters considering the sporadic cases, the reinfection cases, the implementation of a movement control order, and the percentage of humans abiding by the rules to forecast future growth patterns of COVID-19 in Malaysia and to study the effects of the consideration on the number of forecasted COVID-19 cases, during the pre-vaccination period. This study implemented the preliminary stage of forecasting the COVID-19 data using the proposed SEIRD model and highlighted the importance of parameter optimization. The mathematical model is solved numerically using built-in Python function *'odeint'* from the Scipy library, which by default uses LSODA algorithm from the Fortran library Odepack that adopts the integration method of non-stiff Adams and stiff Backward Differentiation (BDF) with automatic stiffness detection and switching. This paper suggests that the effects of factors of sporadic cases, reinfection cases, government intervention of movement control order and population behavior are important to be studied through mathematical modelling as it helps in understanding the more complex behavior of COVID-19 transmission dynamics in Malaysia and further helps in decision-making.

ABSTRAK: Pemodelan matematik adalah alat berkesan bagi memahami struktur kompleks dan tingkah laku fenomena semula jadi, seperti penyakit coronavirus 2019 (COVID-19), iaitu penyakit berjangkit yang disebabkan oleh virus pengancam nyawa yang dipanggil SARS-CoV-2. Ia telah merebak dengan pantas ke seluruh dunia sejak tiga tahun lepas, termasuk Malaysia. Mengguna pakai pendekatan baharu sistem dinamik, kajian ini bertujuan bagi menerangkan bagaimana matematik boleh memainkan peranan penting dalam membentuk model penyebaran COVID-19, dan mencadangkan kaedah praktikal bagi mengawalnya. Model ini dapat meramalkan data sebenar kes yang dijangkiti, pulih dan kematian bagi membuat keputusan. Kajian ini mencadangkan model populasi Rentan-Terdedah-Terjangkiti-Pulih-Mati (SEIRD) yang diubah suai bersama parameter masa berbeza seperti kes sporadis, kes jangkitan semula, pelaksanaan perintah

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kawalan pergerakan, dan peratusan manusia patuh peraturan bagi meramal pertumbuhan corak kes COVID-19 di Malaysia pada masa hadapan dan mengkaji kesan–kesan pertimbangan parameter tersebut ke atas bilangan kes COVID-19 yang diramalkan ketika tempoh sebelum vaksinasi. Kajian ini melaksanakan peringkat awal ramalan data COVID-19 menggunakan model SEIRD yang dicadangkan dan menekankan kepentingan pengoptimuman parameter. Model matematik ini diselesaikan secara berangka menggunakan fungsi terbina Python *'odeint'* daripada perpustakaan Scipy, yang menggunakan algoritma LSODA daripada perpustakaan Fortran Odepack menerusi kaedah penyepaduan Adams tidak kaku dan Pembezaan Belakang (BDF) kaku dengan pengesanan dan pertukaran kekakuan automatik. Kajian ini mencadangkan kesan faktor kes sporadis, kes jangkitan semula, campur tangan kerajaan terhadap perintah kawalan pergerakan dan tingkah laku penduduk adalah penting untuk dikaji melalui pemodelan matematik kerana ia membantu dalam memahami tingkah laku yang lebih kompleks dalam dinamik penularan COVID-19 di Malaysia dan seterusnya membantu dalam membuat keputusan.

KEY WORDS: *SEIRD model; system dynamics; systems thinking approach; COVID-19; simulation; Malaysia*

1. INTRODUCTION

Coronavirus disease 2019 is an infectious disease caused by a newly discovered coronavirus called SARS-CoV-2, which is a type of virus known to cause respiratory infections in humans [1]. SARS-CoV-2 has been identified and characterized as 75 to 80% identical to the SARS-CoV which refers to the virus that emerged during the SARS outbreak of 2002 and 2003 that was first recognized in Guangdong Province, China [2][3]. Furthermore, it is found to be categorized within the subgenus *Sarbecovirus* of the genus *Betacoronavirus* that is even more closely related to two bat-derived SARS-CoV which are bat-SL-CoVZC45 and bat-SL-CoVZXC21 [4].

Besides the general characteristics of SARS-CoV-2, some common clinical symptoms of the patients are fever, dry cough, fatigue, and gradual dyspnea (which refers to shortness of breath) [5]. Further development of the disease can lead to complications including pneumonia, acute respiratory distress syndrome (ARDS), septic shock, and kidney failure that eventually may cause death [6]. Although, COVID-19 is believed to be a disease that primarily affects the lungs, it can also cause damage to many other organs, including the heart, kidneys, and the brain as long-term effects when the disease is not treated well [7]. COVID-19 not only affects human health, but also the economy, which decreases the performance and profit of many industries. For instance, in Malaysia, the aviation and tourism industry were affected as 67.8% stated that they had no sales and revenue within the period of the movement control order, MCO [8].

The Malaysian Government, through the Ministry of Health, Malaysia (MOH) responded to this outbreak. Several phases of movement restriction order and standard operating procedure (SOP) were introduced to break the chain of COVID-19 spread among citizens, resulting in a significant drop in the daily data of COVID-19 cases which ended the second wave of the pandemic on 8th July 2020 [9]. However, the third wave which was more critical and challenging with the emergence of new variants of SARS-COV-2 caused sporadic cases [10] and reinfection cases [11].

According to World Health Organization (WHO) [12], dynamics of the SARS-CoV-2 are very complex, with the virus changing itself over time as it replicated through random "copying error" in a process called mutation. The variants were labelled in a simple and easy way, using letters of the Greek alphabet which were categorized into two types of variants. The first type is the Variants of Interest (VOIs) which included Lambda and Mu, and the second type was Variants of Concern (VOCs) which included Alpha, Beta, Gamma, and Delta. Different variants may have their own properties with respect to ease of spread, the associated disease severity, or the performance of vaccines, as well as the possibility of reinfection [12]. This highlights the complexity of the transmission dynamics of the virus.

This paper explains the transmission dynamics of COVID-19 in Malaysia using compartmental models from the basic to the more complex as it helps to divide the population in Malaysia with regards to the daily data of COVID-19 cases based on each compartment. This type of mathematical model may help to reliably forecast the number of infected, recovered, and death cases in Malaysia. Thus, a System Dynamics (SD) approach through mathematical modelling can play an important role in understanding the behavior of this complex health phenomena in real life, which refers to the COVID-19 pandemic as evolving epidemiology, which may guide informed prevention and control policies.

The main purpose of this study is to modify the classical SEIRD model by considering sporadic cases, reinfection cases, government interventions of movement control order and population behavior. In this paper, we firstly (1) present the classical compartmental models of infectious disease: SI, SIR, SEIR and SEIRD and highlight its limitation, then we show how we (2) construct a new modified SEIRD model considering the aforementioned factors based on a System Dynamics (SD) approach to deal with all those limitations. This study provides a detailed explanation of how mathematics plays a significant role in modelling the COVID-19 spread and surely can contribute to understanding the transmission dynamics of COVID-19 in Malaysia and create awareness among society to apply future intervention measures in curbing COVID-19 spread.

2. MATHEMATICAL MODELLING

Mathematical modelling is an effective tool to understand the complex systems of the real world. According to Lich [13], "systems science" is a broad term referring to a family of analytical approaches that aims to explain the behavior of complex systems of the real phenomenon that occurs. Its three important methodologies are Social Network Analysis (SNA), Systems Dynamics (SD) and Agent-based Modeling (ABM). In Systems Dynamics (SD) approach, is called as 'Hard' systems approach which refers to the quantitative systems dynamic modelling that enables scientists and decision makers to examine real life system components, and the dynamic relationships between them. Generally, SEIRD model is one of the SD approaches and it is one of such methods of modelling for infectious disease. This model consists of susceptible (S), exposed (E), infected (I), recovered (R) and death (D) and is called a compartmental model since the model can be broken down into distinct compartments, and may describe the interactions between those compartments. Basically, this type of model can be constructed in terms of ordinary differential equations (ODEs) that can be interpreted as the rate of change in the amount of the substance in the compartment referring to the input rate minus output rate for each dynamic or process as mentioned in Eq. (1) and the schematic representation of a one-compartment system as in Fig. 1.

$$\frac{dx}{dt} = \text{input rate} - \text{output rate} \tag{1}$$

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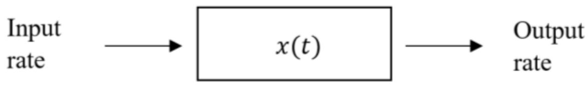

Fig. 1: Schematic diagram of one-compartment system.

This section consists of two subsections which are the classical compartmental model: SI, SIR, SEIR, SEIRD and the modified SEIRD model that we proposed.

2.1 Classical Compartmental Model: SI, SIR, SEIR, SEIRD

The origin of this deterministic epidemiological model was started from basic classical compartmental models of infectious disease which are the SI model, SIR model, and SEIR model. It was proposed by Kermack & McKendrick [14] in 1927 to study the number and distribution of cases of an infectious disease as it is transmitted through a population over time. The SI model is a basic model, and other stated models are derived models that were built according to research needs. SEIRD is the extended model of the SIR and SEIR models. The SIR model divides the population into three groups: susceptible (*S*), infected (*I*) and recovered (*R*). In understanding the transmission dynamic of infectious disease or how the real phenomenon, which refers to the disease spread, the schematic diagram of SIR model is framed as Fig. 2.

Fig. 2: Schematic diagram of SIR model

The SIR model is constructed in terms of non-linear differential equations as shown in Eq. (2) to Eq. (4) where $N=S+I+R$ is the total population, β is the infection rate, a coefficient accounting for the susceptible people who get infected by infectious people and γ is the parameter of infectious people which become resistant per unit of time (immune to COVID-19).

$$\frac{dS}{dt} = \frac{\beta}{N} SI \tag{2}$$

$$\frac{dI}{dt} = \frac{\beta}{N} SI - \gamma I \tag{3}$$

$$\frac{dI}{dt} = \frac{\beta}{N} SI - \gamma I \tag{4}$$

Figure 3 shows a more extended model of SIR, which is the SEIR model, where it considered a latent period, a new compartment *E* representing the exposed individuals that are in the incubation period. It is added between the compartment of susceptible (*S*) and infected (*I*). Many diseases, especially infectious disease, have a latent phase that refers to the very beginning part of the disease progression where the individual has been exposed or had contact with an infected (*I*) person yet remain asymptomatic and are typically regarded as not infectious.

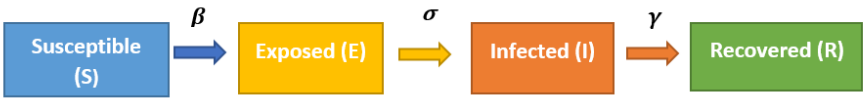

Fig. 3: Schematic diagram of SEIR model.

This delay between the acquisition of infection and the infectious state can be incorporated within the SIR model by adding an exposed (*E*) population, and letting individuals who have contact with infected (*I*) but are not yet infectious move from *S* to *E* and from *E* to *I* once they have tested positive accompanied by illness symptoms. In a closed population, assuming no births or natural deaths, the SEIR model can be constructed in terms of ordinary differential equations (ODE) as per Eq. (5) to Eq. (8) where is the total population, α represents the incubation rate. The difference between the exposed (*E*) and infected (*I*) is that the former has contacted the infected (*I*) person and are asymptomatic but not infectious, while the latter is symptomatic and infectious. SEIR has been used to model breakouts in Malaysia as a preliminary study.

$$\frac{dS}{dt} = \frac{\beta}{N} SI \tag{5}$$

$$\frac{dE}{dt} = \frac{\beta}{N} SI - \sigma E \tag{6}$$

$$\frac{dI}{dt} = \sigma E - \gamma I \tag{7}$$

$$\frac{dR}{dt} = \gamma I \tag{8}$$

A further model, the SEIRD, considers the group of Dead (*D*) for the forecast of the spread of COVID-19 has been proposed and adopted by many other epidemiological researchers [1]. The SEIRD model accounts for five different groups, namely, susceptible (*S*), exposed (*E*), infectious (*I*), recovered (*R*), and dead (*D*). Figure 4 shows how the population in each compartment during the pandemic progress in sequence.

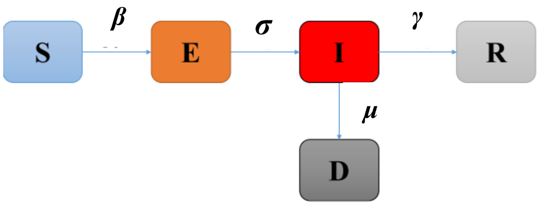

Fig. 4: Schematic Diagram of Basic SEIRD Model [18].

In their study, Shao & Shan [18] highlighted four conversions or transmission dynamics in the basic SEIRD model:

- **First, *S* → *E***. Relevant evidence shows that during the COVID-19 infection process, not only confirmed patients have infectious capacity, but also those who are asymptomatic. They have the ability to infect others as well without anyone knowing it. It can be considered as a sporadic case. Therefore, in the SEIRD model, the individual with susceptible (S) status will change to exposed (E) status with a certain probability after contacting the infected (I) individual or the exposed (E) individual.

- **Second, $E \rightarrow I$.** Relevant evidence shows that the longest incubation period for COVID-19 is 14 days and the shortest is 1 day. An individual with exposed (E) status may be transformed into an infected (I) after the incubation period ends.
- **Third, $I \rightarrow R$.** Once the infected (I) individual has been confirmed, they will be isolated and treated with a certain probability in hospital and will change to the recovered (R) or death (D) status.
- **Fourth, $I \rightarrow D$.** Relevant evidence also shows that infected patients commonly die after 15 days without effective treatment.

It can be written in terms of systems of non-linear ordinary differential equations as per Eq. (9) to Eq. (13).

$$\frac{dS}{dt} = -\frac{\beta SI}{N} \tag{9}$$

$$\frac{dE}{dt} = \frac{\beta SI}{N} - \sigma E \tag{10}$$

$$\frac{dI}{dt} = \sigma E - \gamma I - \mu I \tag{11}$$

$$\frac{dR}{dt} = \gamma I \tag{12}$$

$$\frac{dD}{dt} = \mu I \tag{13}$$

All variables related to the basic SEIRD model are defined as Table 1 while epidemiological parameters involved are as stated in Table 2.

Table 1: Variables of SEIRD model

Variables	Descriptions
Susceptible (S)	Population who can have the disease/ are vulnerable to COVID-19
Exposed (E)	Population who are in incubation period, asymptomatic but have the ability to spread the virus and are about to get infected by the disease (asymptomatic infective)
Infectious (I)	Population who already have the disease and can spread it/ symptomatic infected
Recovered (R)	Population who has been cured and immunized from the disease for a certain time
Death (D)	Population who has died because of the disease

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Table 2: Epidemiological Parameters of SEIRD model

Symbols	Parameters	Descriptions
β	Infection rate	Probability accounting for the Susceptible get infected by the Infected
σ	Incubation rate	Rate of latent individuals becoming infectious (probability of susceptible people becoming exposed), 1/average latency or incubation.
γ	Recovery rate	Probability infectious people who become resistant per unit time, 1/average recovery time or the period between onset of symptom and recovered
μ	Mortality rate	Probability infectious people who died due to COVID-19 per unit time

Sporadic cases occur due to contact between susceptible (S) and exposed (E), Muka & Sannyal [10] later consider two types of infectious rate in their proposed SEIRD model, as shown in Fig. 5 below.

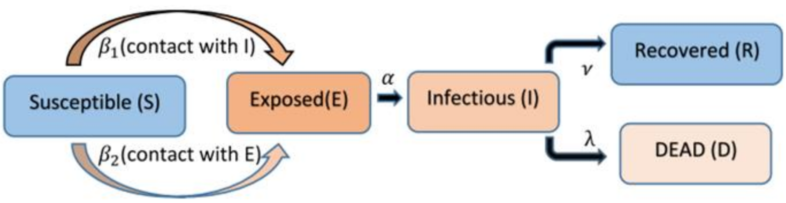

Fig. 5: Schematic diagram of basic SEIRD model considering two types of infectious rate that are constant [9].

The constructed SEIRD model may be expressed in terms of the following non-linear ordinary differential equations, as in Eq. (14) to Eq. (18), where the total population is $N = S + E + I + R + D$. The infectious rates, β_1 and β_2, control the rate of tranmission for contact with infected (I) and exposed (E) respectively. In this model, β_1 represents the probability of infection per exposure when a susceptible (S) individual has contact with an infected (I) patient and becomes a latent exposed (E) individual. While β_2 represents the potential rate per exposure when a susceptible (S) individual has mutual contact with an exposed (E) individual and becomes a latent exposed (E) individual. A detailed diagram is shown in Fig. 5. Since the probable contact between susceptible (S) and exposed (E) individuals are larger than that of between susceptible and infected individuals, Muka & Sannyal [10] assumed that $\beta_2 = 5\beta_1$. The incubation rate, α, is the rate of latent individuals becoming infectious.

$$\frac{dS}{dt} = -\frac{1}{N}(\beta_1 IS) - \frac{1}{N}(\beta_2 ES) \tag{14}$$

$$\frac{dE}{dt} = \frac{1}{N}(\beta_1 IS) + \frac{1}{N}(\beta_2 ES) - \sigma E \tag{15}$$

$$\frac{dI}{dt} = \sigma E - \gamma I - \lambda I \tag{16}$$

$$\frac{dR}{dt} = \gamma I \tag{17}$$

$$\frac{dD}{dt} = \lambda I \tag{18}$$

Moreover, Piccolomiini & Zama [15] have also proposed an adaptive SEIRD model which is a SEIRD rational model or can be simply named as SEIRD (rm) that considers several restricting measures imposed in Italy. Since there are such considerations, the whole-time interval [0, T] has been partitioned into two sub-intervals: [0, t_0] and [t_0, T] where t_0 corresponds to time when the restrictions start to produce a valuable change. Applied restrictions should decrease the number of contacts between I and S, consequently, decrease the value of transmission rate β. Thus, they model coefficients of β as a decreasing time-varying function $\beta(t)$ as follows:

$$\beta(t) = \begin{cases} \beta_0 & if\ t < t_0 \\ \beta_0\left(1-\rho\,\frac{t-t_0}{t}\right) & otherwise \end{cases} \quad , \quad \rho \in (0,1) \tag{19}$$

In their present, the constant value of ρ = 0.75 has been used but might be calibrated in the future. By substituting $\beta(t)$ in the S and E equations in basic SEIRD model, the SEIRD rational model, SEIRD (rm), is obtained. There is much limitation that can be considered and assumptions that can be reduced to model the real phenomenon of the systems specifically the systems that refer to the transmission dynamics of COVID-19.

2.2 Modified SEIRD model (Proposed Model)

In this study, the basic epidemiological model, Susceptible-Exposed-Infected-Recovered-Death model (SEIRD), will be modified considering four main factors: sporadic cases, reinfection cases, government intervention of movement control order, and population behavior. These will be implemented as time-varying parameters in this model, since a few of the epidemiological parameters, especially transmission rate that refers to the infection rate β, are believed to naturally change over time and are not constant. This is due to the government interventions taken to curb the spread of COVID-19 in Malaysia. Generally, once government interventions are taken to restrict the movement of the population, contact between them can be reduced, which may consequently reduce the value of the infection rate β.

The SEIRD model is a deterministic compartmental model that consists of five different compartments [15]. It is represented by a set of non-linear ordinary differential equations (ODE) that describe how the system evolves in time. The total population of Malaysia in 2020, which was $N \sim 32657300$ individuals as reported by Department of Statistic Malaysia [19], are divided into five different compartments: susceptible (S), exposed (E), infected (I), recovered (R) and death (D). The word 'compartments' signifies the division of the population into mutually exclusive groups.

Susceptible (S) refers to the population who can be infected by the disease. Exposed (E) refers to the population who are in the incubation period where they are not yet showing any symptoms, however they are silently infectious and called asymptomatic patients. Contact with exposed (E) may be addressed as sporadic cases. Infected (I) refers to the population who already have the disease by showing symptoms and can infect others who have close contact with them called symptomatic patients. Recovered (R) refers to the population who has been cured of the disease, while death (*D*) refers to the population who died because of COVID-19.

Several assumptions have been made to model the reliable transmission dynamics of COVID-19 during the pre-vaccination period due to the limited data. The assumptions are as follows:

1. Malaysia population was a closed population due to the implementation of international travel restrictions enforced on 25th January 2020 which limits the movement of travelling foreigners into Malaysia, $N = S + E + I + R + D$.
2. There has yet to be an immunization for SARS-CoV-2 since the period of this study is during pre-vaccination. Thus, all of the Malaysian population regardless of gender and age is susceptible to COVID-19.
3. The population in Malaysia was assumed to be unchanged due to the short time of the model development and projection. Newborn and natural death were not considered. These were negligible because the outstanding period of the disease is shorter than the lifetime of a human.
4. There was a chance for the recovered (*R*) population to be reinfected again.
5. The sporadic case is now considered where we assume the disease can also probably be spread by exposed (*E*) individuals.

Assumption 4 and assumption 5 in this study will extend the model-making assumption that fits well with the real phenomenon of the spread of COVID-19. Considering different transmission dynamics in the community and the assumptions made above, Fig. 6 shows the schematic diagram that portrays how the population in each compartment progresses in sequence with a certain transition rate that considers reinfection cases. Referring to Fig. 6, the *black line arrow* and *black arrow curved down* indicate how the population progresses in sequence from one compartment to another subsequent compartment with certain probabilities, while the *yellow arrow curved down* shows the interaction or contact between everyone in stated compartments.

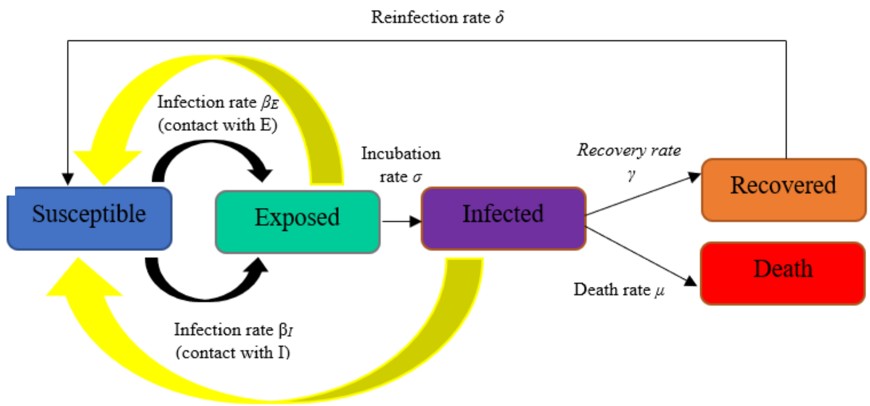

Fig. 6: Schematic diagram of modified SEIRD model.

In addition, the recovery rate γ is the probability of the infected population to become resistant, recovered, and immunized from COVID-19, which will progress the population to the recovered population, where $\gamma = \frac{1}{T_i}$ with T_i as the average of recovery duration [6] and can be called the infectious period as well [22]. Mortality rate μ may also be determined using this formula ($\mu = \frac{D}{N}$) over a certain period where D refers to the cumulative death up to a certain date and N refers to the total population in the country. Moreover, the reinfection rate δ can easily be calculated using the simple formula of $\delta = \frac{Re}{I}$ where R_e refers to number of reinfected while I refers to number of infected persons involved in the study. Malhotra [11] highlighted that fully vaccinated health care workers in India had lower risk of reinfection compared to unvaccinated and partially vaccinated with the percentage of 1.6%, 12.7% and 11% respectively. However, this study will neglect the vaccination status of individuals and will use the aforementioned formula for the reinfection rate δ.

By following the assumptions, the modified SEIRD model that has been proposed by Jamil & Muhammad [23] that considers reinfection cases and modified SEIRD model that has been proposed by Muka & Sannyal [10] that consider sporadic cases which highlighted on two types of infection rates can be used for constructing a new form of modified model in this study. This modified model is based on five compartments in terms of a system of the non-linear ordinary differential equations (ODEs) as shown in Eq. (20) to Eq. (25) with the initial conditions of $E_0 = 3375,\ I_0 = 1,\ R_0 = 22, D_0 = 0$.

$$\frac{dS(t)}{dt} = -\frac{\beta_I(t)\,S(t)I(t)}{N} - \frac{\beta_E(t)\,S(t)E(t)}{N} + \delta R(t) \tag{20}$$

$$\frac{dE(t)}{dt} = \frac{\beta_I(t)\,S(t)I(t)}{N} + \frac{\beta_E(t)\,S(t)E(t)}{N} - \sigma E(t) \tag{21}$$

$$\frac{dI(t)}{dt} = \sigma E(t) - \gamma I(t) - \mu I(t) \tag{22}$$

$$\frac{dR\,(t)}{dt} = \gamma I(t) - \delta R(\mathrm{t}) \tag{23}$$

$$\frac{dD\ (t)}{dt} = \mu I(t) \tag{24}$$

$$N = S(t) + E(t) + I(t) + R(t) + D(t) \tag{25}$$

Equations (20) to (25) are the rate of change in the amount of population in each compartment. Firstly, $\frac{dS}{dt}$ refers to the rate of change of population in the susceptible compartment. The input rate refers to δR as recovered (R) will be leaving recovered (R) compartment and move into the susceptible (S) compartment again once reinfected with SARS-CoV-2. Meanwhile, $-\frac{\beta(t)\,S(t)I(t)}{N} - \frac{\beta(t)\,S(t)E(t)}{N}$ is the output rate that refers to susceptible (S) individuals that will be leaving susceptible (S) compartment. It is formulated as aforementioned to represents the fraction of population that can be infected by SARS-COV-2 and move to exposed (E) compartment. In Eq. (20) as well, the susceptible (S) population is proportional to the infected (I) population since, in reality, they will have contact with each other, especially close contact within 1 meter. It is inversely proportional. The negative sign in the formula of the total population of susceptible (S) individuals refers to the total susceptible population that will be decreasing when the susceptible (S) move to exposed (E). In addition, when reinfection cases have been considered, the number of recovered (R) individuals will be added to the susceptible (S) compartment with a certain value of reinfection rate.

Secondly, $\frac{dE}{dt}$ refers to the rate of change of the population in exposed (E) compartment where exposed move to infected. The number of individuals who are leaving the susceptible (S) compartment is added into the Eq. (21). As time goes by, the exposed (E) population will later be leaving the exposed (E) compartments and become infected (I). That is why there is subtraction of σE. Thirdly, $\frac{dI}{dt}$ refers to the rate of change in infected (I) compartment where infected move to recovered. The number of individuals who are leaving exposed (E) compartment is added into the Eq. (22). Infected will be recovered or die as time goes by so they will be leaving infected (I) compartment. That is the meaning of $-\gamma I(t) - \mu I(t)$ in the Eq. (22).

Fourthly, $\frac{dR}{dt}$ refers to the rate of change of the population in the recovered (R) compartment when the patients have been isolated and treated in the hospital. The number of individuals who leave the infected (I) compartment is added into the Eq. (23) which is represented by $\gamma I(t)$ and reinfected population that will be leaving the recovered (R) compartment will be added as well into the Eq. (23) with $-\delta R(t)$. Lastly, $\frac{dD}{dt}$ refers to the rate of change of the population in death (D) compartment where infected (I) move to death (D) when there is no effective treatment taken to the COVID-19 patients. Similarly, the number of individuals who are leaving infected (I) compartment is added into the Eqn. (24) which is represented by $\mu I(t)$.

In this study, the time-varying parameters for infection rate β_I and infection rate β_E will be implemented and highlighted since transmission dynamics of COVID-19 especially infection rate change over time. Thus, time-varying infection rate β_I and infection rate β_E were formulated as piecewise functions, while recovery rate, mortality rate, incubation rate and reinfection rate were inferred from literature review. The formulated time-varying infection rate as proposed by Jamil & Muhammad [23] was shown in Eq. (26) and in this study it was referred to as the infection rate β_I. While for infection rate β_E, this study adopts a highlight by Muka & Sannyal [10] where they assumed that $\beta_2 = 5\beta_1$, in which it can be restated as $\beta_E = 5\beta_I$ and the time-varying infection rate is formulated as Eq. (27). Equation (26) considers government intervention such as the movement control order that was implemented from 18th March 2020 until 3rd May 2020 where the time interval of this piecewise function was divided by three phases as follows:

Phase I : Before Movement Control Order (MCO), $t < t_{lockdown}$ **(27/2/20-17/3/20)**

Phase II : During Movement Control Order (MCO) and Conditional Movement Control Order (CMCO), $t_{lockdown} \leq t < t_{lift}$ **(18/3/20-9/6/20)**

Phase III : During Recovery Movement Control Order (RMCO), $t \geq t_{lift}$ **(10/6/20-23/2/21)**

$$\beta_I(t) = \begin{cases} \beta_1 t + \beta_2, & t < t_{lockdown} \\ \beta_0 e^{-((t-t_{lockdown})/(\tau_\beta))}, & t_{lockdown} \leq t < t_{lift} \\ (1-r)\left(\beta_1\left(t - t_{lift}\right) + \beta_2\right), & t \geq t_{lift} \end{cases} \tag{26}$$

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$$\beta_E(t) = 5\begin{cases} \beta_1 t + \beta_2 , & t < t_{lockdown} \\ \beta_0 e^{-((t-t_{lockdown})/(\tau_\beta))} , & t_{lockdown} \leq t < t_{lift} \\ (1-r)\left(\beta_1\left(t-t_{lift}\right)+\beta_2\right), & t \geq t_{lift} \end{cases} \quad (27)$$

There were 9 unknown parameters involved in this modified SEIRD model proposed by Jamil & Muhammad [23] which were the percentage of Malaysians who followed the SOPs r, infection rate (β_0, β_1, β_2), characteristic time of transmission $\tau_{\beta,}$ incubation rate σ, recovery rate γ, death rate μ, and reinfection rate δ. All the initial parameter values will be inferred from several items in the literature, then will be implemented in the simulation of modified SEIRD model in order to study the transmission dynamics of COVID-19 in Malaysia.

For understanding the formulated time-varying infection rate β, firstly, at the beginning of the outbreak which is Phase I: Before Movement Control Order (MCO), people had high mobility and were free to move anywhere, thus the infection rate $\beta(t)$ was assumed to be a linear function, $\beta_1 t + \beta_2$ as it increased with β_2 as its initial value, when t=0, $\beta(t) = \beta_2$. For Phase II, when the Movement Control Order (MCO) was introduced in Malaysia, the infection rate decayed due to physical distancing and intentional isolation, and this behavior was described by an exponential function, $\beta_0 e^{-((t-t_{lockdown})/(\tau_\beta))}$ with β_0 as the initial value of the infection rate during that phase and 1/ (τ_β) refers to the decay rate. The Conditional Movement Control Order (CMCO) will be regarded as Phase II, which is lockdown or restricted movement even though more economic and social activities were allowed but operating hours were limited and occurred under strict standard operating procedures (SOP).

Lastly, for Phase III, when the lockdown was lifted and more economic and social activities were allowed, for instance interstate travel, tourism business, unessential premises or even schools, the infection rate was assumed to follow the trend at the beginning of the outbreak which increased when no lockdown or stringent movement order was implemented. As highlighted by Jamil & Muhammad [23], a fraction of compliance to the SOP was included in the infection rate as it affected or contributed to the new values of infection rate and was based on the experience in facing the pandemic, $(1-r)\left(\beta_1\left(t-t_{lift}\right)+\beta_2\right)$ where r was the percentage of Malaysians who followed the SOPs and practiced the 3Ws, even after the government had lifted the lockdown. The numeric value of r was between 0 and 1 as it will be regarded as percentage values. $1-r$ here refers to the percentage of Malaysians who did not follow the SOPs, which led to the increment in the infection rate β. Meanwhile, the rest of the function is linear.

Different researchers used different settings for epidemiological models in their studies, including different methods of parameter estimation or even different functions of infection rate. This highlights the varied insights that researchers do have in modelling the transmission dynamics of COVID-19. This also becomes a reason behind the existence of new extended and modified models in modeling any behavior, process, or system in a real phenomenon. The simulation of the above proposed modified SEIRD model will be presented in section 4.

3. MATERIALS AND METHODS

In this section, we present the source of our data and details of parameters and variables that we used for simulation of classical and modified SEIRD model.

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3.1 Data Sources

This study is a simulation for general cases in Malaysia during the pre-vaccination period; thus, daily data of confirmed new infected (*I*), recovered (*R*) and death (*D*) cases of the COVID-19 during the second wave and early third wave, which are from 27th February 2020 until 23rd February 2021, are collected from the official data of the Ministry of Health Malaysia (MOH) [24]. The data of COVID-19 were publicly provided in the GitHub of the Ministry. The data was collected and sorted in an Excel file before being imported into the Pandas Data Frame for the purpose of Python simulation. For the simulation of the SEIRD model, the data of daily total active cases of infected (*I*), total recovered (*R*) and total death (*D*) were used.

3.2 Data Analysis

In this section, the initial values of variables and parameters used for analysis in this study are presented and summarized in Table 3 and Table 4.

Table 3: Initial values of variables used modified SEIRD model simulation

Variables	Values used for analysis	Sources
Susceptible (*S*)	*S* (0) = 32,653902	[19]
Exposed (*E*)	*E* (0) = 3375	[9]
Infected (*I*)	*I* (0) = 1	[23]
Recovered (*R*)	*R* (0) = 22	[23]
Death (*D*)	*D* (0) = 0	[23]

Table 4: Initial values of parameters from recent findings for modified SEIRD model simulation

Parameters	Values used for analysis	Sources
β = infection rate, $R_t\gamma$	R_0 = 2.52 (R_t at 18/3/2020 or MCO), $\beta_0 = 0.70308$ R_1 = 0.1 (expected increment daily or gradient), β_1 = 0.0279 R_2 = 3.91 (Rt at 27/2/2020 or pre-MCO, β_2 = 1.09	[25]
σ = incubation rate, $\frac{1}{T_c}$	T_c = 5.2 days, σ = 0.19	[21]
γ = recovery rate, $\frac{1}{T_i}$	T_i = 3.95 days γ = 0.279	[26][27]
μ = mortality rate, $\frac{D}{N}$	μ = 0.1	[24]
δ = reinfection rate, $\frac{R_E}{I}$	δ = 0.02	[28]
r = percentage obey SOP	95%	Assumption made in this study
τ_β = characteristics time of transmission	1	Assumption made in this study

As reported by the Department of Statistics Malaysia [19], the total population of Malaysia as of early April 2020 was approximately 32.7 million, *N* ~ 32,657300. Considering the assumption (2) and Eq. (25), the initial value of susceptible S was 32,653902. Due to the limited data of daily exposed, we assume the initial exposed (*E*) is

3,375 which is equal to the total number of positive COVID-19 cases in the Sri Petaling Mosque gathering cluster well known as the Cluster Tabligh. This huge cluster of COVID-19 in the second wave period was announced by the Director-General of Ministry of Health Malaysia (MOH), Datuk Dr Noor Hisham Abdullah on 8th July 2020. The gathering among tabligh was held from 27th February 2020 until 1st March 2020. It is possible to assume the total positive cases in this cluster was equal to the initial value of exposed (E) since the gathering was first held on 27th February 2020, with the understanding that the exposed population would progress to the infected population. The initial value of infected (I), recovered (R) and death (D) are 1, 22 and 0 respectively.

4. RESULTS AND DISCUSSIONS

In this section, we firstly present the historical data of Malaysian COVID-19 cases during the pre-vaccination period which is from the beginning of second wave up to the early third wave as an overview before we show the results of classical SEIRD model. Simulations of classical and modified SEIRD model in this study have been done using Python programming language via Jupyter Notebook and using the values of parameters and variables as summarized in Table 3 and Table 4. The SciPy *odeint* function is used to solved the ODEs of both classical and modified SEIRD model. Before proposing a new modified SEIRD model, the output of classical SEIRD model that we adopted in this study will be compared with other published studies that implemented classical SEIR and SEIRD models as this model's validation process. Then, the results of the simulation of our new proposed model of SEIRD is presented and the four effects that are taken into consideration in modelling the SEIRD model are highlighted.

4.1 Historical Data of Malaysian COVID-19 Cases

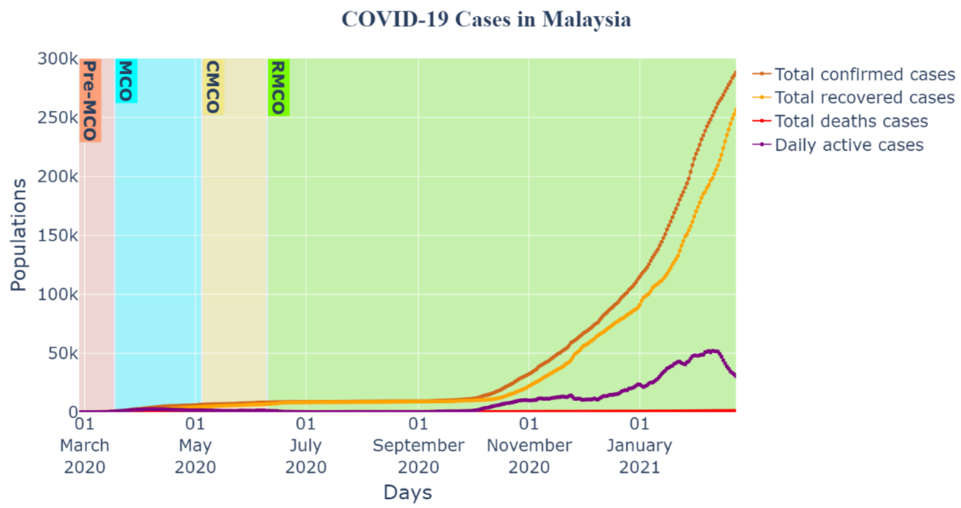

Fig. 7: Total confirmed cases, total recovered cases, total deaths cases and daily active cases of COVID-19 in Malaysia during pre-vaccination period from 27th February 2020 until 23rd February 2021.

Figure 7 exhibits the historical data of Malaysian COVID-19 cases starting from pre-MCO (27/2/2020), which is the beginning of second wave of COVID-19 in Malaysia, until the period of RMCO (23/2/2021) which is at the middle of third wave. They are divided into four different shaded regions according to their respective phases which are pre-MCO phase (non-intervention phase), Movement Control Order (MCO), Conditional Movement Control Order (CMCO), and Recovery Movement Control Order (RMCO). Based on the reported data [3], the peak infection that is represented by the daily active cases during the second wave was depicted on 5th April 2020 with 2587 infected (*I*) cases before following with a steady decrement in the curve. Meanwhile, the peak infection during the third wave was depicted 6 months after the date of peak infection of the second wave which is 10th February 2021 with 52,187 infected (*I*) cases. Figure 7 was generated using Python programming language via Jupyter Notebook.

4.2 Classical SEIRD Model Simulation

Using the variables and parameters as detailed in Table 3 and Table 4, the classical SEIRD model simulation based on Eq. (9) to Eq. (13) was produced, as seen in Fig. 8. The figure portrays the simulation of the classical SEIRD model when no consideration of sporadic cases, reinfection cases, government interventions of movement control order and population behavior. This classical SEIRD model uses a constant value of infection rate β because the model assumes that the dynamics of COVID-19 spread, which were represented by epidemiological parameters, were not changing over time. This assumption was made because the government interventions of movement control order was not considered. Thus, the value of the infection rate used is constant. Based on the forecasted data in Fig. 8, the peak infection of COVID-19 is estimated to reach 3.05 million infected (*I*) cases, or about 9.34% of the Malaysian population, on 25 days of simulation from 27th February 2020 which is on 23rd April 2020. The classical SEIRD model forecasts the peak infection as high as the stated numbers, which was larger than the actual data (2587 infected (*I*) cases on 5th April 2020). This huge predicted peak infection is consistent with the higher values of infection rate β before the implementation of MCO that has been used in the classical SEIRD model simulation. Besides, according to the graph shown in Fig. 8, the number of infected (*I*) cases would gradually subside and plateau on 24th May 2020 before finally ending by day 23rd August 2020. Meanwhile, the cumulative number of recovered (*R*) and death (*D*) cases in Malaysia are forecasted to reach 22.39 million and 8.02 million respectively by day 200. This classical SEIRD model uses the basic systems of non-linear ordinary differential equations that can be improved more according to new assumptions or more factors that have been considered. Thus, before proposing a new modified SEIRD model, model reliability validation has been done and will be discussed in the next subsection.

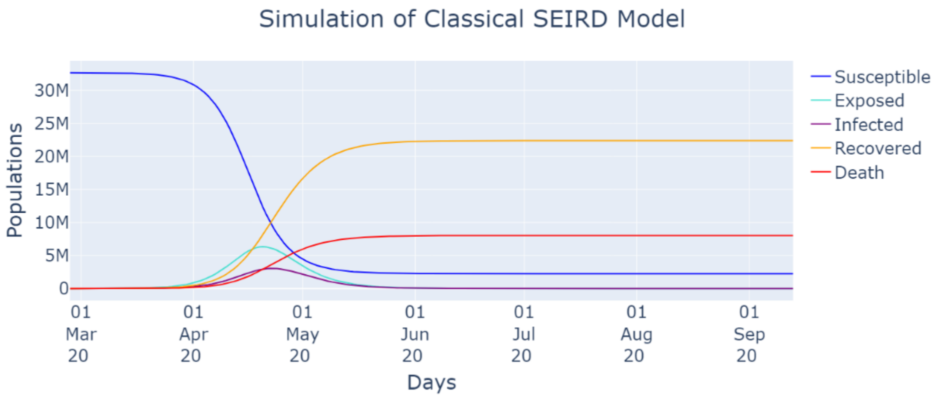

Fig. 8: Forecast of COVID-19 pandemic in Malaysia using classical SEIRD model for 200 days during pre-vaccination period with constant parameters, $\beta = 1.09$.

4.3 Model Validation

In order for this study to propose a new modified SEIRD model, model reliability validation has been done by comparing the simulation's output of published literature in Malaysia which adopted similar and almost-similar classical SEIRD models to the one in this study. The similar classical SEIRD model refers to the same systems of ordinary differential equations implemented in the study. Since there are few studies that adopted the classical SEIRD model 100% in terms of Eq. (9) to Eq. (13), we found that it was reasonable to also include another version of the classical SEIRD model (a bit modified) and the classical SEIR model that excludes the death (D) compartment, which is almost similar to our classical SEIRD model in the validation. It was reasonable to use the output to calculate the Mean Absolute Percentage Error (MAPE) to bring insight to determine the model performance. The lower the MAPE, the higher the accuracy of the model. The three studies included in the comparison consist of two studies that adopted the classical SEIR model and one study which adopted another version of the classical SEIRD model.

The percentage of peak infection is one of the crucial outputs in infectious disease modelling as it is the possible maximum total number of populations that can be infected during the simulation period. Thus, the output has been compared in terms of peak infection (%) as summarized in Table 5. In making the comparison with published works, firstly our classical SEIRD model is used to simulate the peak infection using the similar values of parameters and initial conditions, as the said literature shows. Then, the absolute percentage error (APE) between simulated peak infected cases by literature and simulated peak infected cases by this study's model is calculated, as seen in Table 6. Mean Absolute Error (MAE) is calculated to be 7.49% while the accuracy of the classical SEIRD model performance, regarded as the benchmark before proposing this new modified model, is 92.51%. This study will only simulate the model without performing any parameter fitting; thus, this kind of validation method helps in determining if either the existing classical SEIRD model, that acts as a benchmark, or the proposed modified model are sufficiently reliable to proceed.

Table 5: Comparison of the simulated peak infection by using different settings of epidemiological parameters for classical SEIR and SEIRD model by published literature in Malaysia

Author	Country	Model	Period of simulation (Days)	Simulated peak infection date (From t_0)	Simulated peak number of infected cases	Peak infection (%)
Aidalina & Lim [29]	Malaysia	Basic SEIR *Not consider Infected becoming dead and not consider Death cases (no D compartment)*	100	t_0 = 18/3/2020. 5/4/2020 (18 days)	13.76×10^6	43
Labadin & Hong [30]	Malaysia	Basic SEIR *Consider Infected becoming dead but not consider Death cases (no D compartment)*	150	t_0 = 27/2/2020. 15/5//2020 (78 days)	4×10^6	12.27
Alsayed et al. [31]	Malaysia	Basic SEIRD *same with classical SEIRD model in this study but a bit different in its equations (dE/dt and dS/dt)*	365	t_0 = 24/1/2020. 26/7/2020 (184 days)	2.5×10^6	7.668

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Table 6: Comparison of the simulated peak infection between published literature and the simulated peak infection by our classical SEIRD model

Author	Peak infection simulated by published literature (%)	Peak infection simulated by the classical SEIRD model (%)	Absolute percentage error (%)
Aidalina & Lim [29]	43	43.75	1.74
Labadin & Hong [30]	12.27	12.27	0
Alsayed et al. [31]	7.67	9.26	20.73

Table 7: Mean absolute percentage error (MAPE) (%) and accuracy (%)

Mean Absolute Percentage Error (MAPE) (%)	Accuracy (%)
7.49	92.51

4.4 Modified SEIRD Model Simulation

In this study, we propose a new SEIRD model that has been constructed in terms of systems of non-linear ordinary differential equations (ODEs) as in Eq. (20) to Eq. (24). This proposed model has been considered novel for four basic factors in modelling the behavior of COVID-19 spread in Malaysia, which are consideration of 1) sporadic cases, 2) reinfection cases, 3) government interventions of movement control order, and 4) population behavior. It is believed that this new model would provide a better understanding of the complex structures and behaviors of COVID-19, and finally assist decision makers in planning a strategy for ending the pandemic. Using the variables and parameters as detailed in Table 3 and Table 4, the modified SEIRD model simulation based on Eq. (20) to Eq. (24) was produced. This figure portrays the simulation of modified SEIRD model when the above factors are considered. These factors highlight the complexity of virus behavior and human behavior as discussed in section 2. This modified SEIRD model uses time-varying value of infection rate as per Eq. (25) to Eq. (26) because the model assumes that the dynamics of COVID-19 spread, which is represented by epidemiological parameters, are changing over time. This assumption was made because the government interventions of movement control order were considered. Thus, the value of infection rate varied over time. That was the reason for the implementation of time-varying parameters as a recent simulation of modified SEIRD model should use parameters that are dependent on time.

Based on the forecasted data in Fig. 9, the peak infection of COVID-19 is estimated to reach 8 million infected cases, which is about 24.5% of the Malaysian population, on 6 days of simulation from 27th February 2020 which is 3rd March 2020. The proposed SEIRD model forecast the peak infection earlier than the classical model as it also considers the sporadic cases, which is the spread of COVID-19 by asymptomatic patients, which now involves two types of infection rate β_I and β_E in the modelling. This early prediction of peak infection is consistent with the understanding of the effects of sporadic cases which may contribute to higher infected daily cases. Simply, it is due to the implementation of time-varying parameters of infection rates and modification on the modified mathematical model. Besides that, according to the Fig. 9, the number of infected (I) cases would gradually subside and becomes plateaued on 5th June 2020. Meanwhile, the total active recovered cases and the number of death cases of Malaysian was forecasted to reach 8 million and 13 million

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respectively by 13th September 2020. In this modified SEIRD model, the total active recovered cases, represented by recovered (*R*), must be determined when simulation of modelling with parameter fitting has been done. It is in contrast with the classical SEIRD model, as it will take the daily cumulative number of recovered (*R*) cases. Table 8 shows the summary of peak infection, the plateau, and the subsiding date from both epidemic models.

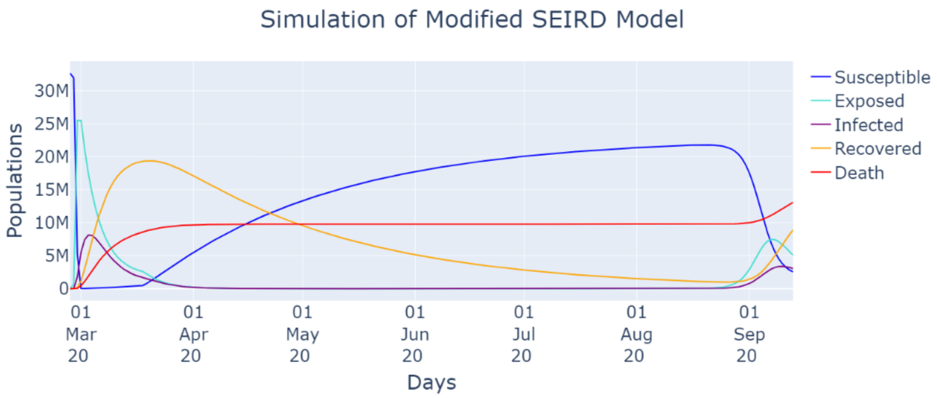

Fig. 9: Forecast of COVID-19 pandemic in Malaysia for 200 days during pre-vaccination period using modified SEIRD model with time-varying parameters of β_I and β_E .

Table 8: Comparison of predicted date of infected cases between classical and modified SEIRD model

Infected cases (*I*)	Actual data	Classical SEIRD model	Modified SEIRD model
Peak infection	5th April 2020	23rd April 2020	3rd March 2020
Subside	21th June 2020	24th May 2020	1st May 2020
Plateau	8th July 2020	23rd August 2020	5th June 2020

4.5 Effects of Considered Factors to Modified SEIRD Model

The four factors that have been considered in this study bring effects to the simulation of SEIRD model: either changing the number of cases, the pattern of the simulation, or the date of peak infection. The effects of these factors are crucial to highlight in this study as the simulation of modified SEIRD model will forecast the future COVID-19 cases and mimic the real phenomenon when the effects have been taken into consideration. The effects of each factor can be seen in Fig. 10 – Fig. 13. From these simulations, we may observe how the factors may have influenced the number of infected (*I*), recovered (*R*) and death (*D*) cases of COVID-19 pandemic in Malaysia. Figure 10 depicts the simulation of modified SEIRD when considering the factor of sporadic cases. This factor considers the transmission of COVID-19 when *S* having contact with *E* which completely introduce new type of infection rate β_E. Thus, in simulating the modified SEIRD model, there are two types of infection rate, which are infection rate β_I (*S* contact with *I* becoming *E*) and infection rate β_E (*S* contact with *E* becoming *E*). When simulating the modified SEIRD model, only changes of β_E are taken. Meanwhile, other parameters and variables remain the same. This is similar to the other factors when simulation has been done. Based on Fig. 10, it clearly shows that as β_E increases, the peak infected, peak recovered, and peak death increase. The

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peak infected will become higher and faster when there are sporadic cases reported in Malaysia, as indicated by Fig. 10. These results highlight the crucial impact that this factor brings to the output of the SEIRD model simulation. In the real scenario of the COVID-19 pandemic, when sporadic cases started to be reported in Malaysia and when there was no quick government intervention implemented, a higher than usual daily total active cases were reported, which also causes the time of peak infection to be reached earlier. This modified SEIRD model simulation brings important insights to the government authorities and other decision makers to take action earlier if such cases happen, either to implement a movement control order or introduce a vaccination program to the community in order to ensure that the Malaysian healthcare system will not collapse. The simulated number of peak infected, peak recovered, and peak death are the crucial indications for the government to decide which intervention should be implemented and when to implement it.

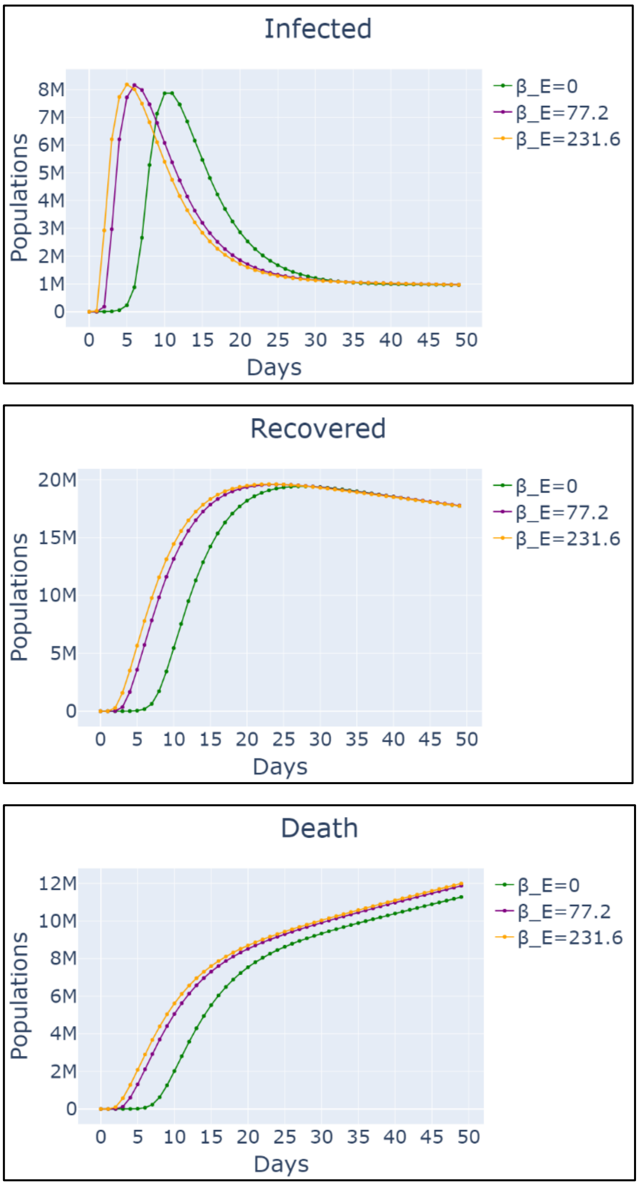

Fig. 10: Forecast of COVID-19 pandemic in Malaysia for 50 days during pre-vaccination period as β_E increases (β_E refers to factor 1: sporadic cases).

Furthermore, Fig. 11 depicts the simulations when considering the factor of reinfection cases, Fig. 12 depicts consideration of the factor of government interventions of movement control order, and Fig. 13 depicts consideration of population behavior. When the factor of reinfection cases has been considered, δR is a part of the mathematical model. Meanwhile, when the factor of government interventions of movement control order has been considered, decay exponential function of infection rate β_I and β_E need to be implemented in the simulation of the SEIRD model. r in the function of time-varying parameters of infection rate represents the Malaysian population behavior in abiding standard operating procedures (SOP) while $(1-r)$ refers to the population who neglect the rules.

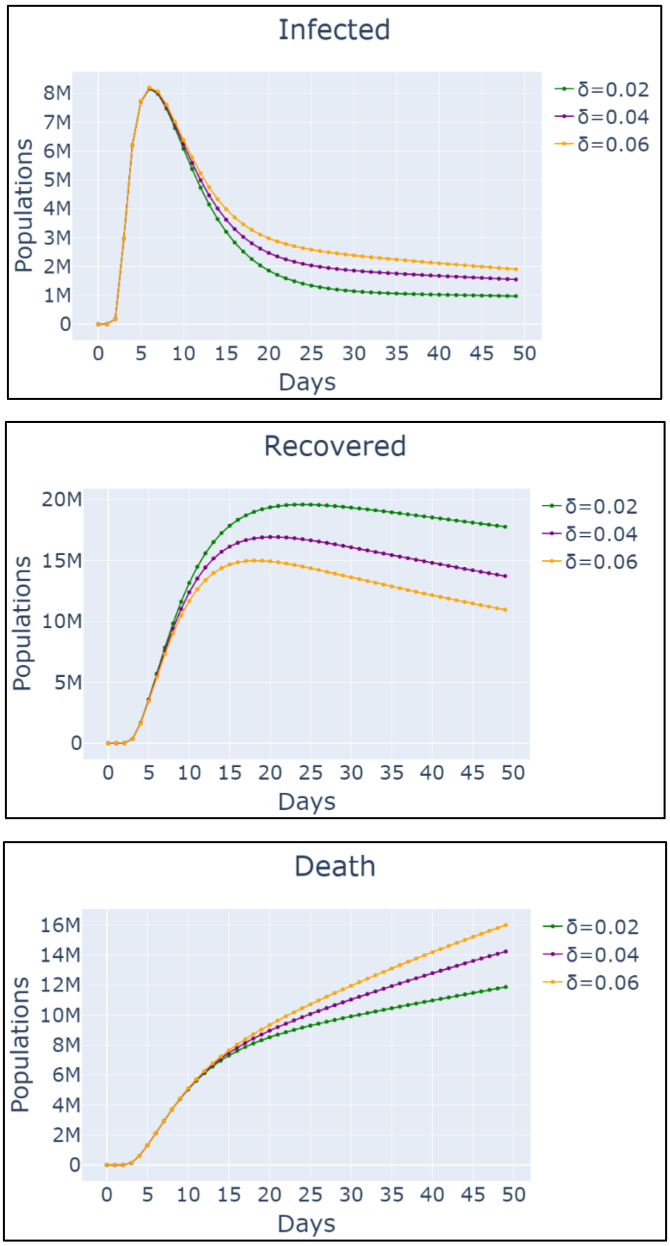

Fig. 11: Forecast of COVID-19 pandemic in Malaysia for 50 days during pre-vaccination period as δ increases (δ refers to factor 2: reinfection cases).

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Based on Fig. 11, it clearly portrays the effects of reinfection cases as the value of δ increases. When δ increases, the duration of infected cases subsides and reaches a plateau. This means that the pandemic of COVID-19 in Malaysia will require a longer time to resolve when there are reinfection cases reported in Malaysia and will cause new higher peak infected if there is no government intervention taken. Figures 12 and 13 depict the effects of human behaviors towards COVID-19 cases, which are the action taken by government in implementing MCO and action taken by population in abiding by the rules and regulations or Standard Operating Procedures (SOP). Figure 12 shows significant effects on the reduction of the number of peak infected cases, peak recovered cases, and peak death cases when there is implementation of Movement Control Order (MCO) by government.

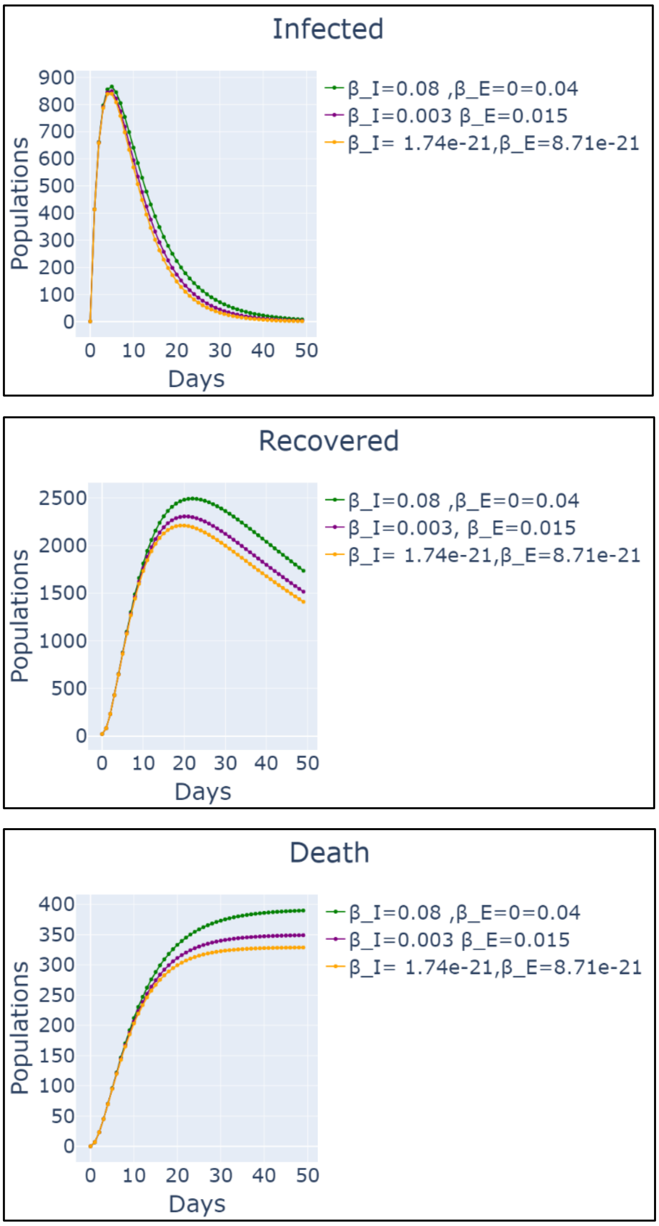

Fig. 12: Forecast of COVID-19 pandemic in Malaysia for 50 days during pre-vaccination period as β_I and β_E decrease (β_I and β_E decrease refer to factor 3: government intervention of MCO).

Figure 13 shows the effects of population behavior towards the COVID-19 reported cases which are infected (*I*), recovered (*R*), and death (*D*), as the value of *r* decreases. The figure highlights that the higher the percentage of population who abide by the rules (higher *r*), the lesser the number of peak infected, peak recovered, and peak death cases. This will surely bring a positive impact if compared with lower percentage of the population who abide by the rules. We set the value of r to be 99%, 60% and 20% just to show the percentage of their compliance. 99% means strong compliance, 60% means moderate compliance and 20% means weak compliance. The figure shows the importance of strong compliance by the Malaysian population after lifting the MCO, as it may delay the increase of infected and thereby decrease the peak case level. This will surely help Malaysia to recover slowly either in economical or health aspects.

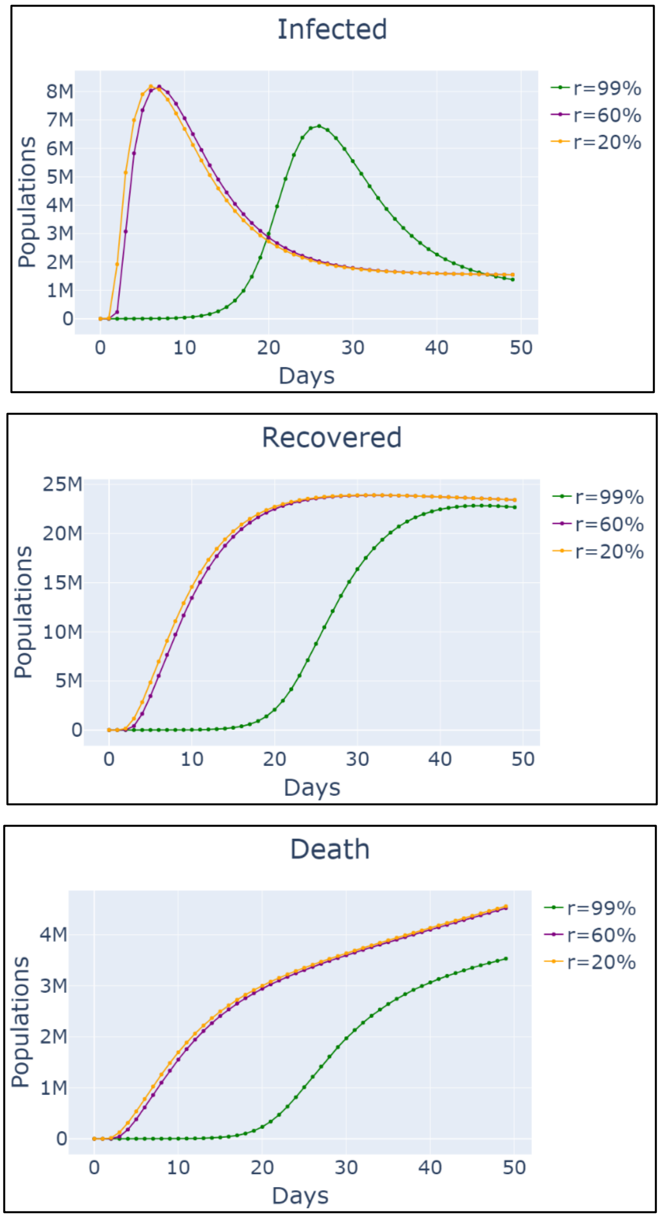

Fig. 13: Forecast of COVID-19 pandemic in Malaysia for 50 days during pre-vaccination period as r increases (r refers to factor 4: population behavior).

5. CONCLUSION

This study explained a system dynamics approach in modelling a modified SEIRD model considering sporadic cases, reinfection cases, government interventions of movement control order and population behavior in Malaysia, as these are found to be important to be studied on the effects of the factors towards the simulation of COVID-19 spread in Malaysia during pre-vaccination period. This study implemented the preliminary stage of forecasting the COVID-19 data as this study has only simulated the SEIRD model without parameter fitting (optimization) which needed for a reliable forecasting of future COVID-19 cases with a minimized error of simulation. Based on subsection 4.4 of this study, the number of infected cases at peak infection in our proposed modified SEIRD model are overestimated to the million cases as parameters optimization is not done in this study. This highlights the importance of parameter optimization of every model simulation done and included in our proposed SEIRD model. Despite the limitation of parameter optimization in this study, the findings of this study highlight the effects of the complexity of virus behavior and human behavior. This study suggests that the factors of sporadic cases, reinfection cases, government intervention of movement control order, and population behavior are important to consider in modelling the more complex behavior of COVID-19 transmission dynamics as it will helps mimic the real phenomenon and the simulation can give insights for government or researchers to take a decision in the best time to implement the rules and regulations effectively in curbing the COVID-19 spread in Malaysia. In combating the COVID-19 pandemic, two things that must be considered: virus behavior and human behavior. SARS-CoV-2 behavior is very complex as it mutates over time which creates new variants of SARS-CoV-2 that led to the emergence of new COVID-19 waves. Creating awareness among community, rules and regulations, movement control order (MCO), play a crucial role to curb the pandemic and reduce the transmission of COVID-19 since rules will be abided and interaction between humans will be limited.

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