The Day The Doors Were Open: The Reopening Of Schools In Jamaica During The Covid 19 Pandemic

E Calvert[2], S Dias[3], P Surujpaul[1]

ABSTRACT

Introduction: This paper seeks to study the effectiveness of modelling COVID-19 pandemic by developing an adapted susceptible-infected-removed (SIR) model that provides a theoretical framework to investigate its spread within Jamaica, and how this can address the policy decision of when schools can be reopened for face-to-face classes, without full depletion of hospital capacity. **Methods:** The adapted model incorporates differences in disease transmission between children (less than 18 years old), vaccination and death due to infection. Parameters specific to transmission between adults and students were developed. Data for infected, hospitalized as a subset of infected, dead, vaccinated and recovered populations over weekly periods from September 2021 to November 2021were collected from the Ministry of Health and Wellness of Jamaica and Johns Hopkins University COVID Map. A system of five(5) equations was developed, and Matlab 2019b was utilized as the solver for the differential equations. **Results:** Graphs of population as a function of time were generated for two events: 65% of students becoming vaccinated; and 50% of students being integrated into face-to-face school; with the hospitalized population as the projected outcome. **Conclusion:** The results indicated that once 65% of vaccination is achieved, schools can return to full reopening as the projected hospitalized population is unlikely to exceed the threshold.

Index Terms – SARS CoV 2**,** Paediatric, School Opening, COVID, Pandemic

INTRODUCTION

SARS-CoV-2, a novel coronavirus, was discovered following an outbreak of unexplained pneumonia cases in the Wuhan region of mainland China during December 2019. Over the next 20 months, COVID-19, the name designated by the World Health Organization (WHO) to the infection caused by SARS-CoV-2, has infected over 200 million individuals and has caused almost 5 million deaths globally(1). On March 10, 2020, the Jamaican Ministry of Health reported the first case of COVID-19. SARS-CoV-2 has infected about 87 thousand Jamaicans since then, resulting in 2,153 deaths(2). To slow the spread of COVID-19 and flatten the epidemic curve, the government has enacted a series of strict laws and measures aimed at preventing an increase in positive cases and critically ill COVID-19 patients, which would put a strain on hospital resources and healthcare workers(3, 4).

School Closure

The wearing of masks in public, lockdowns, no movement days, extended curfew hours and the suspension of face-to-face learning for all schools, are some of policies implemented by the Jamaican government. Closure of schools worldwide, not limited to Jamaica, have led to the adoption of online platforms to deliver school curriculums(5, 6). However, the technological requirements for this mode of learning have left many students offline and many online classrooms empty. Considering the benefits of face-to-face schools many efforts have been put in place to re-institute usual school with CARICOM and other regional and international bodies proposing robust plans for return to normalcy (7).

Vaccination

Regionally, these efforts aimed at reopening schools have been strengthened by national vaccination drives. Jamaica received its first shipment of 50, 000 coronavirus vaccines on March 8, 2021; thus far, 356, 000 Jamaicans have been fully vaccinated which represents 12 percent of the population(2). With on-going vaccination drives and tours, the conversation has now been opened to entertain the resumption of face-to-face learning within schools. Issues such as this and many others have led to mathematical models being adopted and developed to capture the effects of the

From: [1]Department of Physics, The University of the West Indies, Mona Campus, Jamaica, [2]Department of Computing, The University of the West Indies, Mona Campus, Jamaica, [3]Department of Biomedical Engineering, The University of the West Indies, Mona Campus, Jamaica

Correspondence: Dr S Dias, Department of Biomedical Engineering, The University of the West Indies, Mona Campus, Jamaica

pandemic on health and mitigation strategies at large(8, 9).

Mathematical Models of Disease

Many models have been in place since the COVID 19 pandemic based on the SIR model introduced in the early 20^{th} century(10). This model is based on several assumptions which limits the model's ability to accurately predict the spread of this pandemic. SARS-Cov-2 has demonstrated unique qualities which are not accounted for in the SIRS model. One such phenomenon is the disparity in disease severity and infectivity among the paediatric population. Additionally, there is no account for the effect of vaccination in the originally proposed model(10, 11). To correct these deficiencies, the model has been altered over the years to consider additional variables relevant to subsequent pandemics and new interventions(11).

It was evident at the onset of the COVID pandemic that prevalence among children was less than that for adults(12). Additionally, within any population children are less likely to be symptomatic and unlikely to be tested and diagnosed; thus data for the infected student population will be underestimated(12). It was initially proposed that this finding could be the result of confounders due to local interventions shielding them from disease(5). As a result, studies were done in communities and households across North America, Europe, and Asia(5, 13, 14).

The current COVID-19 pandemic has compelled regional and international governments to enact strict containment policies to stem the spread of the extremely infectious SARS-CoV-2 virus, one of which is the closure of schools. This lack of student access to education(13) has necessitated the development of methods for estimating the influence that resuming face-to-face learning would have on the pandemic's trajectory; is it safe? or will the number of index cases and deaths rise? At present, models of the SARS-CoV-2 model do not consider a difference in disease spreading among and to the paediatric population(8, 9, 11, 15). This difference in disease spread may impact the spread of disease in paediatric versus adult gatherings. Thus, this research promises to produce a mathematical model adopted from the SIR model for epidemics, that can capture the effect that reopening of schools would have on the pandemic in Jamaica, which will help to guide public policies that govern school reopening.

METHODOLOGY

According to Kermack and McKendrick (10), the variables established from the original SIR model include the following populations: susceptible(S), infectious(I) and recovered/removed(R). These populations are always equal to the total population, (N), which obviates the assumptions of no consideration of deaths and births. Additionally, the model assumes no zoonotic spread, no consideration of changes in virus characteristics, homogenous exposure and transmissibility or re-introduction of removed to the susceptible population. These variables are related to each other by parameters: a, relating transmission of disease from infectious population to susceptible population; b, constant relating infectious population to either becoming recovered or removed.

A new model has been proposed which includes the following considerations: differences in disease transmission between children (less than 18 years old), vaccination and death due to infection. These are incorporated under the following assumptions:

1. Single variant of SARS CoV 2 is responsible for all infections during the period being modelled.
2. Vaccination confirms life-long immunity
3. Vaccination rate reduces with susceptible population
4. No concurrent change in government policy
5. Dichotomous division of population into adult and student, with 18 years as cut-off
6. Transmission between infected and susceptible divisions of each population occurs at different rates.

The proposed populations and associated parameters have been summarized in table 1 below.

Table 1 List of variables and parameters utilized in proposed model

Components	Symbol	Description
Variables		
Susceptible adults	S_A	Population of adults who are susceptible to COVID virus
Susceptible students	S_s	Population of students who are susceptible to COVID virus
Infected students	I_s	Population of students who have been infected with COVID-19 virus
Infected adults	I_A	Population of adults who have been infected with COVID-19 virus
Hospitalized infected	I_H	Population of adults who have been infected with COVID-19 virus
Removed population	R	Population removed from being Susceptible either by vaccination or recovery
Dead	D	Population removed from being infected by death
Parameters		
Student-student transmission	$\alpha_{is\text{-}s}$	Rate of transmission from infected student to susceptible student
Adult-student transmission	$\alpha_{ia\text{-}s}$	Rate of transmission from infected adults to susceptible student
Student-adult transmission	$\alpha_{is\text{-}a}$	Rate of transmission from infected student to susceptible adult
Adult-adult transmission	$\alpha_{ia\text{-}a}$	Rate of transmission from infected adults to susceptible adult
Hospital transmission proportion	β	Rate of infected population becoming hospitalized due to infection
Student vaccination	μ_S	Rate of vaccination of student population
Adult vaccination	μ_A	Rate of vaccination of adult population
Recovery rate	ε	Rate of recovery from infection
Adult death rate	Ω_A	Death rate of infected adults

Student death rate	Ω_S	Death rate of infected students

This adopted model has been pictorially represented in figure 1 to show the interaction between each population and the associated parameters.

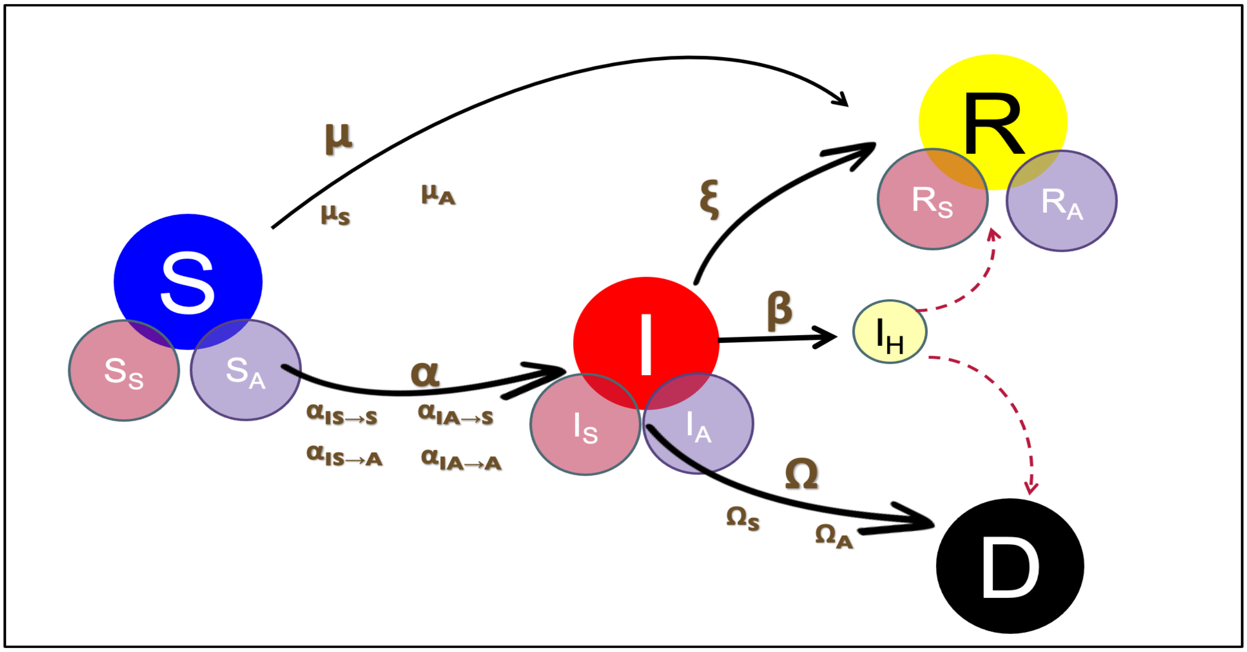

Figure 1 Age-dependent modified SIR Model for SARS-CoV 2 Pandemic. Individuals can move from the susceptible to the recovered population at a rate, similarly a fraction of those persons who have been infected, I, will also go to the removed group having acquired natural immunity. The remainder of the infected population will die and enter population D. A constant fraction of those who are infected will be hospitalized and form a subset of the infected population. Individuals will become infected and leave the susceptible population by interacting with previously infected populations.

These interactions have been represented as a series of differential equations which have been illustrated below

$$\frac{dS}{dt} = -\left(\underbrace{\alpha_{Is\rightarrow s} S_s I_s + \alpha_{IA\rightarrow s} S_s I_A}_{\text{Transmission to students}} + \underbrace{\alpha_{Is\rightarrow A} S_A I_s + \alpha_{iA\rightarrow A} S_A I_A}_{\text{Transmission to adults}}\right) - \mu_A \frac{S_A}{S_{A_{initial}}} - \underbrace{\mu_S \frac{S_S}{S_{S_{initial}}}}_{\text{vaccinated}} \tag{1}$$

$$\frac{dI}{dt} = \left(\alpha_{Is\rightarrow s} S_s I_s + \alpha_{IA\rightarrow s} S_s I_A + \alpha_{Is\rightarrow A} S_A I_s + \alpha_{iA\rightarrow A} S_A I_A\right) - \varepsilon\underbrace{\left(I_A + I_S\right)}_{\text{recovered}} - \underbrace{\left(\Omega_A I_A + \Omega_S I_S\right)}_{\text{deaths}} \tag{2}$$

$$\frac{dR}{dt} = \underbrace{\varepsilon\left(I_A + I_S\right)}_{\text{recovered}} + \mu_A \frac{S_A}{S_{A_{initial}}} - \mu_S \frac{S_S}{S_{S_{initial}}} \tag{3}$$

$$\frac{dD}{dt} = \Omega_A I_A + \Omega_S I_S \tag{4}$$

$$I_H = \beta I(t) + c \tag{5}$$

Where c is zero since a person will not be infected and not have COVID at the same time.

Data Acquisition

Data was collected from the epidemiology desk of the Ministry of Health and Wellness of Jamaica and Johns Hopkins University COVID Map to reflect weekly collected information for the following populations: infected, hospitalized as a subset of infected, dead, vaccinated and recovered. The susceptible population is calculated as the difference of the sum of the previously listed populations and the total population. Raw data collected was dichotomized into adults and student data then rates for mortality and vaccination for each population. Rates were calculated over a period to reflect reports of a stable variant of SARS CoV 2 as opposed to using data which spanned discovery (and assumed introduction) of new variants. All data obtained was blinded and included no identifiers of individual results. Data was available for onset of pandemic to the acquisition date of November 30, 2021. However, data for testing of the model and determination of parameters spanned September 1 - November 30, 2021. This time period was included for the following reasons:

1. Limit effect of multiple variants on calculated parameters
2. Allows for limited testing of the model against actual partial school opening which began on October 1, 2021.

Determination of Parameters

A. Transmission Rates

According to Smith and Moore (2004), when chain rule is applied to the simple SIR model, the contact ratio and eventually transmission rate using a time independent relationship between the infected and susceptible population. This is represented by the series of equation below:

Where contact ratio is represented by c, and

$$c = \frac{\alpha}{\varepsilon} \tag{6}$$

Following from the original SIR model

$$\frac{dS}{dt} = -\alpha SI$$

$$\frac{dI}{dt} = \alpha SI + \varepsilon I$$

Following application of chain rule:

$$\frac{dI}{dS} = -1 + \frac{1}{cS}$$

$$I = \; - S + \frac{\ln ln\, S}{c} + q$$

$$\therefore I + S - \frac{\ln ln\, S}{c} = q$$

At some time, t_1,

$$I_{t_1} + S_{t_1} - \frac{\ln ln\, S_{t_1}}{c} = q$$

And similarly, at a time t_2. Consequently

$$c = \frac{ln \frac{S_{t_1}}{S_{t_2}}}{I_{t_2} + S_{t_2} - I_{t_1} - S_{t_1}} \tag{7}$$

Following this concept, for the purpose of this calculation, our transmission calculations were carried out using data prior to the initiation of vaccinations. This was done to limit the populations in our model to ensure applicability of equations determined from the original SIR model. However, to continue with dichotomy in our model, appropriate susceptible and infected population data from students and/or adults to determine each parameter. For example, for the transmission parameter $\alpha_{\text{ia-s}}$, for infected adult to susceptible student transmission, raw data used for calculations utilized initial and final data for infected adults and susceptible data to determine the contact ratio. This contact ration was then multiplied by the recovery rate following from equation (7).

These values are calculated on the basis of the assumption of the original SIR model of equal transmissibility with each interaction. However, this has not been demonstrated to be so, but as follows:

Transmissibility		
Student→student	$\gamma_{\text{iA-S}}$	0.560
Adult→student	$\gamma_{\text{iA-S}}$	0.504
Student→adult	$\gamma_{\text{iS-A}}$	1.800
Adult→adult	$\gamma_{\text{iA-A}}$	1.800

Consequently, transmission values were calculated as:

$$\alpha = \gamma \varepsilon c \tag{8}$$

The transmission rates are dependent on the degree of interaction between the infected and susceptible populations. Consequently, by re-calculating using values during school opening at 10%, as was the case in Jamaica after October 2021, transmission rates under these conditions were determined. The transmission values for other degrees of school reopening were then extrapolated considering the relative degree of changes in each population interaction.

B. Hospital Admission Factor: the admission factor will be calculated using the dataset collected as: $\frac{I_H}{I} = \beta$

C. Vaccination Rate - μ: The vaccination rate can be set at the median vaccination rate per day over the period of the dataset collected. These may be skewed due to staggered availability of vaccines for the population based on age and occupation. As a result, only data reflecting the period over which vaccines were universally available will be used to calculate a vaccination rate. This will be backward propagated in the testing of the model and used for future modelling.
D. Recovery Rate - ε : For pandemic models, the recovery rate is the inverse of the total days during which a patient is infectious (which usually coincides with symptomatic illness). For the case of SARS-CoV, a median value of 14 days has been reported. However, this may vary based on severity of the illness(16) but not factored in this model.
E. Death Rate - Ω: The death rate for students and adults is determining the number of reported deaths per day for each population.

Model Solution and Representation

Matlab 2019b© was utilized to solve the differential equations given above to represent our model. With all final equations given as a function of time, with values corresponding with t = 0 being initial values for each variable.

These models were then plotted onto a cartesian grid with time of the x-axis and population of adults (or students) on the y-axis as an absolute number. Plots are given for each variable population, susceptible, infected, death and recovered population.

Plots for the infected population includes the total number of persons infected as a function of time and the number of persons hospitalized at the corresponding time. Also, the plot for the recovered (immunized) population included both patients recovering from the infection as well as the vaccinated population. The plot for the vaccinated population is seen as a straight line whose gradient is the population specific vaccination rate, that is, μ_A or μ_S.

Figure 3 on the overleaf has been included to reflect a potential layout of results for easier interpretation of the interaction between the individual solutions.

Our initial proposition in creating the model suggested two (2) key events and a single measure of success:

> **Event 1:** 65% of students becoming vaccinated
>
> **Event 2:** 50% of students will be integrated into face-to-face school
>
> **Outcome:** Hospitalized population

RESULTS

At the time of writing this a paper, November 30, 2021, Jamaica's cumulative vaccination for the entire population stood at approximately 17%, with vaccinations among students attending primary and high schools at 14%. This was on a background of 10% face to face reopening of primary and high schools, which commenced in late September 2021.

Transmission Rate	School Closed	School Open
$\alpha_{iS\text{-}S}$	3.979E-08	1.432E-07
$\alpha_{iA\text{-}S}$	6.065E-09	1.445E-08
$\alpha_{iS\text{-}A}$	6.330E-08	8.220E-08
$\alpha_{iA\text{-}A}$	4.939E-08	1.857E-07

First, the model was tested over September 1 to November 30, 2021, which yielded a mean error of 0.0646% of the population.

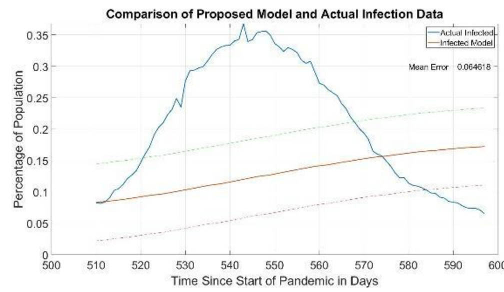

Figure 1 Comparison of COVID Model and Actual Data. Utilizing data from September 1 to November 30, 2021, parameters were determined and plots of both the modelled infection spread, and actual spread were plotted. The dotted lines indicate mean error of 95% confidence interval.

This was simulated using our modified SIR model, shown in figure 2 and the resulting impact on hospitalized COVID-19 cases shown in figure 3. In figure 2, it is observed quite clearly that with our current vaccination rate and schools reopening at 10% capacity face to face, that the number of susceptible individuals falls steadily over months, wirth a steady increase in the number of recoveries as both the number of infected and dead individuals remains low on a daily basis. This is directly reflected in figure 3 that shows that the number of hospitalized COVID-19 infected patients hovers between 50 and 250, not exceeding the 750 bed space capacity of Jamaica's hospitals.

This is also observed at 20% and 30% reopening of schools depicted by figures 4 and 5 respectively. So, reopening primary and high schools for face to face learning up to 30% given that 14% of the student population is vaccinated, will not cause the capacity of hospitals in Jamaica to be exceeded.

However, figure 6 depicts a different narrative, in which at 40% reopening of schools and 14% of students being vaccinated, the number of hospitalized COVID-19 patients is 750, meeting the hospitals' capacity. This worsens as shown by figure 9 in which 50% of students have returned to school, resulting in approximately 1,200 COVID-19 patients being hospitalized.

Investigating our specific research question of ascertaining whether Jamaica's hospital capacity of 750 would be exceeded if 65% of the student population is vaccinated to facilitate 50% of face-to-face learning was successful. The model showed that at 50% reopening with 65% of the student population vaccinated, the capacity of hospitals in Jamaica will not be exceeded, as the number of hospitalized COVID-19 patients would be approximately 420, as shown by figure 11. Thus, in order to reopen schools at target levels, the number of students vaccinated within the population needs to increase. However, as shown by figure 12, the time it would take to achieve 65% of students being vaccinated would be actually 342 days, starting from November 30, 2021.

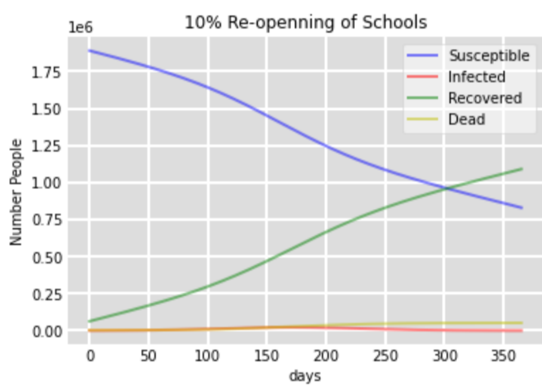

Figure 2 SIR Model populations at 10% school reopening. With 10% of students returning to school, the number of susceptible individuals falls steadily over months, with a steady increase in the number of recoveries as both the number of infected and dead individuals remains low on a daily basis.

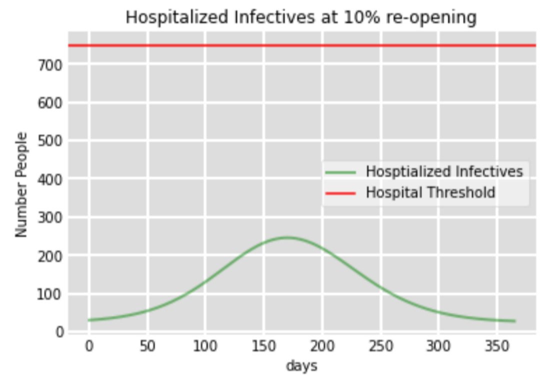

Figure 3 Hospital capacity at 10% school reopening. The number of hospitalized COVID-19 patients are approximately 250, not exceeding Jamaica's total hospital bed capacity of 750 to care for COVID-19 patients.

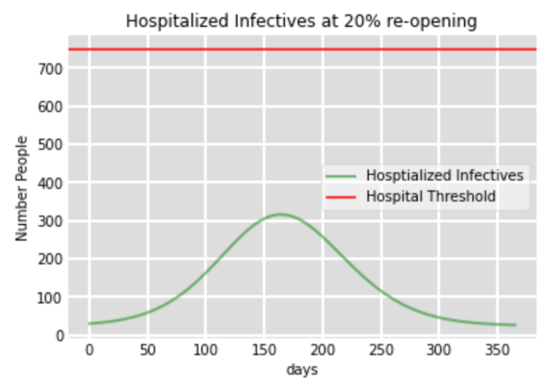

Figure 4 Hospital capacity at 20% school reopening. The number of hospitalized COVID-19 patients is approximately 300, not exceeding Jamaica's total hospital bed capacity of 750 to care for COVID-19 patients.

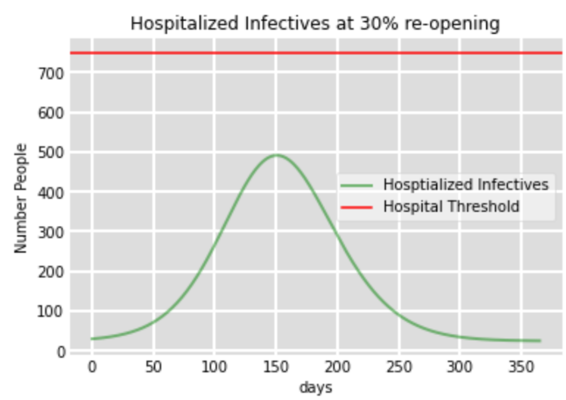

Figure 5 Hospital capacity at 30% school reopening. The number of hospitalized COVID-19 patients is approximately 500, not exceeding Jamaica's total hospital bed capacity of 750 to care for COVID-19 patients.

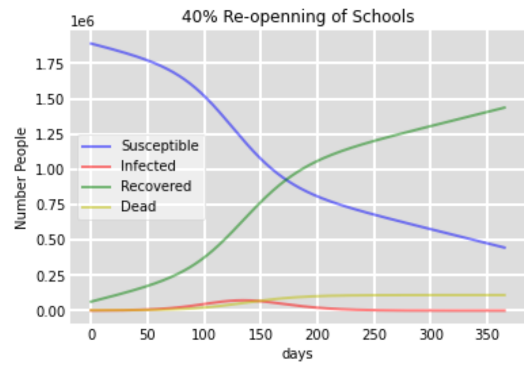

Figure 6 SIR Model populations at 40% school reopening. With 40% of students returning to school, the number of susceptible individuals falls steadily at a faster rate over months, with an uptrending increase in the number of recoveries as both the number of infected and dead individuals is higher at 40% but remains fairly low on a daily basis.

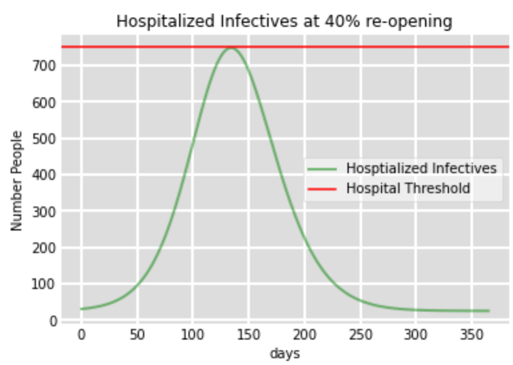

Figure 7 Hospital capacity at 40% school reopening. The number of hospitalized COVID-19 patients is approximately 750, now reaching Jamaica's total hospital bed space of 750 to care for COVID-19 patients.

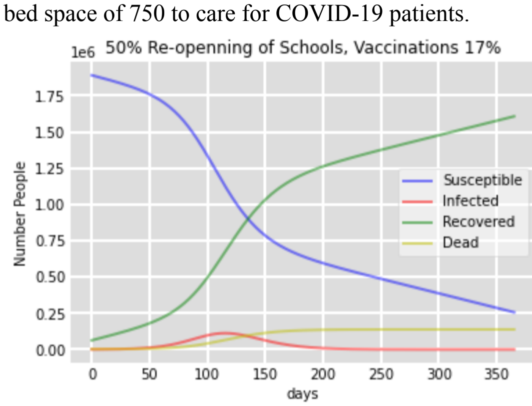

Figure 8 SIR Model populations at 40% school reopening. Having 50% of students returning to school, the number of susceptible individuals falls steadily to a low of 250,000 at a faster rate over months, with an uptrending increase in the number of recoveries. As of day 100, the number of deaths increases to a steady state and the number of infected persons increases briefly and plateau to a low.

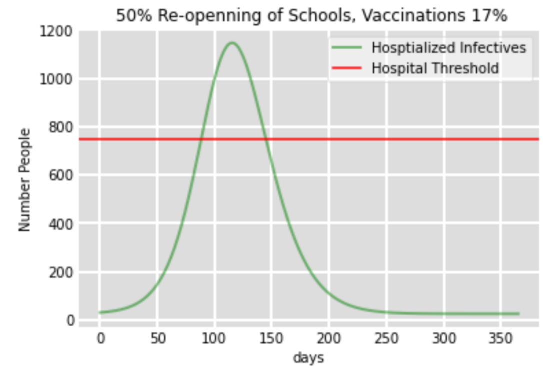

Figure 9 Hospital capacity at 50% school reopening. The number of hospitalized COVID-19 patients is approximately 1,200, exceeding Jamaica's total hospital bed space of 750 to care for COVID-19 patients.

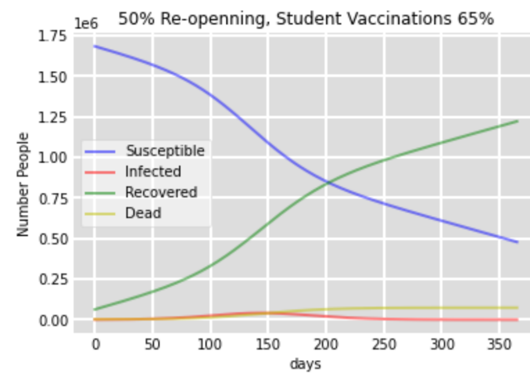

Figure 10 SIR Model populations at 50% school reopening and 65% student vaccination. Having 50% of students returning to school with 65% vaccinated, the number of susceptible individuals falls a lot more steadily over months, with a more gentle increase in the number of recoveries as both the number of infected and dead individuals remains low on a daily basis.

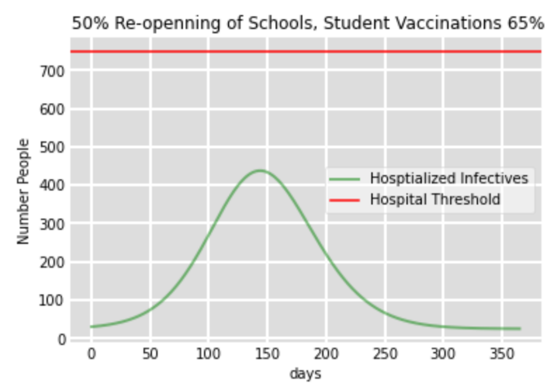

Figure 11 Hospital capacity at 50% school reopening and 65% student vaccinations. The number of hospitalized COVID-19 patients is approximately 420, not exceeding Jamaica's total hospital bed capacity of 750 to care for COVID-19 patients.

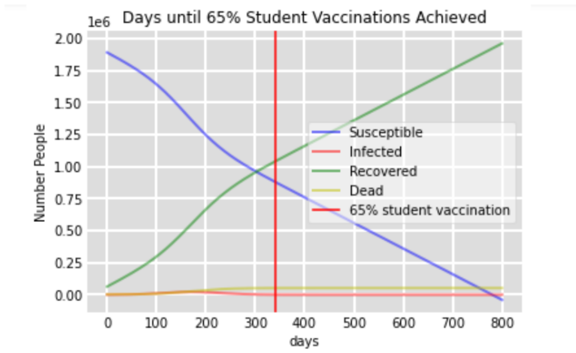

Figure 12 Time taken to achieve 65% student vaccination. At Jamaica's current vaccination rate, it would take 342 days to achieve 65% student vaccinations, starting from November 30, 2021.

Discussion

Our model was able to meet our set objective by demonstrating that once 65% of students have been vaccinated the peak of hospitalizations, at approximately 145 days, will be below the maximum capacity of hospitals for COVID patients. As a secondary objective, we were able to demonstrate what would happen at varying degrees of school opening if school was to be reopened at the current vaccination level. We demonstrated that hospital capacity will be reached if 40% of the school-aged population is allowed to return under present conditions. Also we were able to demonstrate that under the current vaccination rates that the publicized target of 6% vaccination of students will occur in approximately a year.

Though the assumptions made in creating the model may have been reasonable, they may critically affect the utility period of the model. Transmission rates were determined using data over time spans where there were changes in the mitigation measures such as curfews and changes in gather sizes. As these were not considered in the determining of parameters, and parameters given as constants as opposed to functions in effects of major mitigation factors. Consequently, this is a point of future consideration; that is, presenting a model where transmission parameters are functions of major events such as mitigation effects and variants' virulence.

At present the model underestimates the spread of the infection. This could partly be due raw data being used after the opening of schools being skewed positively due to the effect of vaccination. Consequently, this adds to the reasons for limiting the period over which the model is useful. It is noted based on runs of the model over the same period as school opening it became increasingly inaccurate after approximately 90 days.

It has been noted that the pandemic occurs in waves, which have onset the introduction of new variants. These waves have been documented to last for 3 to 6 months at time. However, not all variants have been demonstrated to cause significant waves in cases. Consequently, if the model is to be adjusted to represent limited susceptibility to match the periodicity of introduction of new variants this could more closely model the changes over an extended period of time.

Conclusion

From the results obtained through the modelling process, it can be concluded that our adopted SIR Model does have utility in achieving our stated objective of assessing the impact of primary and secondary schools reopening as well as vaccination, on Jamaica's in-patient capacity to manage infectious COVID-19 cases. However, it must be acknowledged that the decision to model for a single variant environment, assume school reopening was the only major change in mitigation policies, take the stance that vaccinations confer life-long immunity and surmise that infected individuals that recover can not be reinfected, may have influenced the model's results. With Jamaica currently at 14% vaccination for students and 10% reopening of schools, the hospital capacity of 750 has not been exceeded, but occurs at reopening 40% and above. At 50% school reopening of schools and 65% student vaccinations, the number of hospitalized COVID-19 patients is approximately 420, not exceeding Jamaica's total hospital bed capacity of 750. Thus, it can be recommended to the ministry of health and associated policy makers that the number of students that ought to be vaccinated must at least be 50% to consider reopening schools to half the capacity or more, which is expected to occur on days 320 to 342 starting from November 30, 2021.

REFERENCES

1. Zhu J, Gallego B. Evolution of disease transmission during the COVID-19 pandemic: patterns and determinants. Scientific reports. 2021;11(1):1-9.

2. Wellness MoHa. COVID-19 Resources and Protocols [Website]. Government of Jamaica; 2021 [updated November 27, 2021. Available from: https://www.moh.gov.jm/covid19/covid-19-resources-and-protocols/.

3. Control CfD, Prevention. SARS-CoV-2 variant classifications and definitions 2021 [Available from: https://www.cdc.gov/coronavirus/2019-ncov/variants/variant-info.html.

4. Center JHCR. COVID-19 map: Johns Hopkins University; 2021 [Available from: https://coronavirus.jhu.edu/map.html.

5. Hyde Z. COVID-19, children and schools: overlooked and at risk. Med J Aust. 2021;214(4):190-1 e1.

6. Im Kampe EO, Lehfeld A-S, Buda S, Buchholz U, Haas W. Surveillance of COVID-19 school outbreaks, Germany, March to August 2020. Eurosurveillance. 2020;25(38):2001645.

7. Martin Baptiste AG-G, Paul Murphy, Karen Ramsay, Joan Spencer-Ernandez, Laurette Bristol, Anton De Grauwe, . The Framework for the Reopening of Schools in the Caribbean. Caribbean Community; 2021.

8. Bjørnstad ON, Shea K, Krzywinski M, Altman N. The SEIRS model for infectious disease dynamics. Nature Methods. 2020;17(6):557-9.

9. Smith D, Moore L. The SIR model for spread of disease-the differential equation model. Convergence. 2004.

10. Kermack WO, McKendrick AG. Contributions to the mathematical theory of epidemics. II.—The problem of endemicity. Proceedings of the Royal Society of London Series A, containing papers of a mathematical and physical character. 1932;138(834):55-83.

11. Calafiore GC, Novara C, Possieri C, editors. A modified SIR model for the COVID-19 contagion in Italy. 2020 59th IEEE Conference on Decision and Control (CDC); 2020: IEEE.

12. Yonker LM, Neilan AM, Bartsch Y, Patel AB, Regan J, Arya P, et al. Pediatric severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): clinical presentation, infectivity, and immune responses. The Journal of pediatrics. 2020;227:45-52. e5.

13. Dattner I, Goldberg Y, Katriel G, Yaari R, Gal N, Miron Y, et al. The role of children in the spread of COVID-19: Using household data from Bnei Brak, Israel, to estimate the relative susceptibility and infectivity of children. PLoS computational biology. 2021;17(2):e1008559.

14. Viner RM, Mytton OT, Bonell C, Melendez-Torres G, Ward J, Hudson L, et al. Susceptibility to SARS-CoV-2 infection among children and adolescents compared with adults: a systematic review and meta-analysis. JAMA pediatrics. 2021;175(2):143-56.

15. Chen Y-C, Lu P-E, Chang C-S, Liu T-H. A time-dependent SIR model for COVID-19 with undetectable infected persons. IEEE Transactions on Network Science and Engineering. 2020;7(4):3279-94.

16. Prescott HC, Girard TD. Recovery from severe COVID-19: leveraging the lessons of survival from sepsis. Jama. 2020;324(8):739-40.