Modelling Effectiveness Of Lockdown Measures During The COVID-19 Pandemic – Europe and Asia
Final Report

Word Count: 8656

Marc Xu

Candidate Number: 220533

BSc Computer Science – School of Engineering and Informatics

Supervised by Dr. Adam Barrett

10/05/2022

Statement of Originality

This report is submitted as part requirement for the degree of ... at the University of Sussex. It is the product of my own labour except where indicated in the text. The report may be freely copied and distributed provided the source is acknowledged. I hereby give / withhold permission for a copy of this report to be loaned out to students in future years

Candidate Number: 220533

Signed

Date: 10/05/2022

Acknowledgements

A big thank you to Dr. Barrett for providing
all resources facilitating the process of writing this paper

Another big thank you to all health service members
working in the height of the COVID-19 pandemic risking their lives

Summary

This paper presents an introduction to the process of how modelling the effectiveness of lockdown measures during the COVID-19 pandemic will be achieved. It will look over different works related to my topic and more importantly look into a research paper conducted by Vishaal R and Laura P, *A Modified Age-Structured SIR Model for COVID-19 Type Viruses*, which take a very interesting age-scaling approach to modelling the COVID pandemic. In this research paper they take a matrix-based approach to the SIR model which gives it an age-scaling factor, which from an outsider's point of view seems to be a very plausible approach, as the symptoms of COVID are crucial to the upper aged group whilst the lower aged group spread it easily. SARS-CoV-2 more notably recognized as COVID-19, an ongoing contagious, fast spreading disease impacting how the world would live. After failing to quarantine the disease when it was first discovered in Wuhan, China, December 2019, COVID-19 spread the world amassing havoc [1]. Governing powers tried to shut down the disease by implementing lockdown measures, hence why this report will aim to model the effectiveness of lockdown measures implemented by governing powers in Europe and Asia to draw a comparison between them. The process of evaluating the effectiveness of lockdown measures can be achieved by using the SIR (susceptible, infected and removed) model. The SIR model is considered to be a relatively simple model due to the number and nature of its components, **S**usceptible, **I**nfected and **R**emoved.

Contents

Abstract

This paper presents an introduction to the process of how modelling the effectiveness of lockdown measures during the COVID-19 pandemic will be achieved. This paper will first briefly introduce the two main concepts of this paper, COVID-19 and the SIR model. This paper will then outline the aims and objectives of this project. Further on, this paper will then describe possible professional and ethical issues. In addition this paper will create an analysis plan which will cement the requirements needed for the final paper, a project plan which will set deadlines in which achievements are to be achieved. Furthermore, we then move into the literature review and background research area, this will give the reader a better idea of important concepts that are required to understand the paper as a whole. This section will introduce the SIR model and its component that partake the concept. Moreover, it will look over different works related to my topic and more importantly look into a research paper conducted by Vishaal R and Laura P, *A Modified Age-Structured SIR Model for COVID-19 Type Viruses*, which take a very interesting age-scaling approach to modelling the COVID pandemic. In this research paper they take a matrix-based approach to the SIR model which gives it an age-scaling factor, which from an outsider's point of view seems to be a very plausible approach, as the symptoms of COVID are crucial to the upper aged group whilst the lower aged group spread it easily. Once the literature for the paper has been introduced to the reader, the process behind the methodology will be presented and the reader will be aware of how the final results are achieved. Finally, the results will be presented along important remarks and a conclusion regarding the effectiveness of lockdown measures during the COVID-19 pandemic will be achieved.

Introduction

SARS-CoV-2 more notably recognized as COVID-19, an ongoing contagious, fast spreading disease impacting how the world would live. After failing to quarantine the disease when it was first discovered in Wuhan, China, December 2019, COVID-19 spread the world amassing havoc [1]. Governing powers tried to shut down the disease by implementing lockdown measures, hence why this report will aim to model the effectiveness of lockdown measures implemented by governing powers in Europe and Asia to draw a comparison between them.

The process of evaluating the effectiveness of lockdown measures can be achieved by using the SIR (susceptible, infected and removed) model. The SIR model is considered to be a relatively simple model due to the number and nature of its components, **S**usceptible, **I**nfected and **R**emoved. In the model, the susceptible group is defined as the group of people who are vulnerable to the disease, and hence is the default group for individuals in the population who aren't infected yet, haven't recovered or haven't died. On the other hand, the infected group is defined as the group of people within the population who are currently carrying the pathogen and will spread and infect it upon contact with the susceptible group. Lastly, the removed group is defined by the individuals who have either been recovered from the disease or have died from the disease, effectively removing them from the interests of the model.

Some researchers claim that the SIR model is too overly simplified to model such complex diseases, whilst some state the SIR model to be a very effective efficient model to model a disease, putting this dilemma aside, the paper will attempt to take an abbreviated approach to the model making changes where necessary to best suit the evaluation of the topic, modelling effectiveness of lockdown measures during the COVID-19 pandemic.

Aims, Objectives and Relevance

Aims and Objectives

This project mainly aims to explore and research lockdown measures implemented by countries in Europe and Asia. This will require myself to gather data from Worldometer [2] at three different stages of the COVID pandemic to be used in a modified SIR model. Worldometer is a source that manually validates data by cross-referencing primary sources made publicly available from governing bodies, and hence is trusted by many sources such as the UK Government, the Government of Thailand, Government of Pakistan, and many others [3]. The first-time era required to be researched are COVID figures before lockdown measures were implemented to have a base comparison. Second, it is required to find the era in which COVID figures were at its peak to have them compared to the era in which lockdown measures weren't implemented yet, this will allow evaluation to whether peak COVID figures occurred during lockdown measures. As a result, this will allow us to compare to the values created in the SIR model simulation giving knowledge and an outline to whether lockdown measures were significant or not.

Furthermore, it is important to analyse the possible differences in culture which may or may not cause outliers in results. In a research paper by authors, Naoki Y and George B, *Apparent difference in fatalities between Central Europe and East Asia due to SARS-COV-2 and COVID-19: Four hypothesis for possible explanation*, the authors outline 4 hypotheses, 2 of which could cause the greatest potential to cause an outlier in the results that are to be found [4]. In hypothesis 1, the authors discuss differences in *socio-behavioural aspects determine the observed differences*. The authors explain the difference in greeting between individuals which likely cause a higher probability of spreading COVID in the west. The authors claim that in Asia, bowing is the mainstream form of greetings, where as in the West individuals tend to shake hands, kiss and hug instead of bowing creating physical contact between two individuals leading to an increase in the probability of which COVID can be transmitted. Furthermore, the authors also claim some cultural habits that cause an increase in the probability in which COVID is spread. The main cultural habit outlined by the authors are the use of masks. The authors claim that the use of face-covering in case of the influenza or fear of diseases is a common feature in Asian culture and not common in Western culture. And hence, the authors believe this social factor play an important role in which the spread of infection [5].

Moreover, hypothesis 3 the authors claim that in East Asia, specifically China, agriculture developed much earlier compared to the West, and with this abundance of food, this led to an *explosive increase in population density*, and hence, under this *over-crowded and chaotic conditions*, individuals in East Asia may have possibly experienced more plagues including several zoonoses, *a disease that can be transmitted between animals and humans* [6] [7]. Hence it is natural to believe that East Asians *may have evolved to become more resistant against infectious agents* [8].

In addition, it is important to synthesize the data collected mentioned beforehand, this will be able achieved once the collected data is organized and sorted. By synthesizing the data collected through explanation and evaluation, this will allow me to first:

1. Make quantitative estimations about the effectiveness of lockdown measures through analysis of deaths and hospitalizations during lockdown
2. How Europe or Asia could have done an objectively better job in implementing lockdown measures to best interest the health of the population
3. And mentioned beforehand, how cultural differences are able to impact a disease such as COVID-19

Lastly, if time permits it would be ideal to use Python to create an interactive figure to show how the infected group in the SIR model is able to infect the susceptible group. This will require knowledge the acquired in the module Natural Language Engineering which gave a good outlook of the Python language.

Relevance

Over and above, as this is project is heavily reliant upon researching figures and facts related to COVID, I am able to apply essential research skills developed throughout the Computer Science degree starting with the Professional Skills module. I am confident with the research skills developed such that appropriate sources and the judgement to whether a source is reliable or not can be determined. Furthermore, given that this project requires a good grasp of mathematics, more specifically modelling, graphing and calculus, I will be able to apply some of the knowledge learnt in the Mathematical Concepts module to good use. Lastly, as I intend to create interactive figures and diagrams, I can apply my Python skills to achieve my primary objective.

By the time the reader has gone through the final paper, it is expected that the reader will have a deeper understanding of the fundamental possibilities of whether the lockdown measures were effective or not and the improvements that could be made to them. Furthermore, it is also expected that the reader is able to grasp the foundations of the SIR model and the possible modifications that can be made to it to best suit the needs of the disease in question.

Requirement Analysis

A further goal of this project is to make the concept of the SIR model and how it was used to discuss the effectiveness of lockdown measures during COVID-19 understandable such that it can cater to all target audiences. The younger audiences may not be able to understand the analysis and evaluation of the topic through the figures in the SIR model, but it is hoped to communicate with the younger audience through the conclusion, the section in which this paper summarizes the findings and more. Whereas, for audiences that are able to understand the SIR model and the figures behind it, it is hoped to communicate cemented evidence supporting this paper's arguments communicating the importance of lockdown measures.

Requirement	Mandatory/Desirable?	Description
Gather data from Worldometer for relevant countries and have them cross-refernced	Mandatory	As mentioned beforehand, Worldometer reported that governing bodies had issues in reporting consistent figures, resulting in possible skewed data. By cross-referencing figures the most accurate figures will be able to be provided.
Research and explore different cultures throughout Europe and Asia regarding social behaviours that may involve physical contact of some sort	Mandatory	Given the greeting example in the Aims, Objectives and Relevance section, it is rather crucial to look for other possible social behaviours expressed by nations throughout Europe and Asia.
Synthesize data by looking at possible outliers and anomalies	Mandatory	By reviewing the data to look out for possible outliers and anomalies will allow a decision to be make to whether the anomalous data set should be included in the analysis or not, as possible outliers and anomalies could skew the results.
Read through first, Chikina M and Pegden W, second Prem K and Cook A.R's work on how an age-contact matrix can be produced for the relevant nations in question	Mandatory	The example matrix provided was in a case study conducted in the US, as this nation is not within the interests of this paper. In addition, for the interests of this paper the process in which a social age contact matrix is constructed still needs to be clarified and further studied.
The age-scaling factor proposed must be thoroughly researched and well explained and detailed	Mandatory	This is one of the main aspects of the paper and will require the most time.
Once the age-scaling factor has been studied extracting one in order to meet the needs of this paper is required	Mandatory	The paper presenting the age scale factor matrix only gave the matrix table for a state in the United States of America, hence as this paper is wider reaching creating or

		extracting this data is crucial to this paper
Parameters of the SIR model must be well studied to allow accurate and just simulations	Mandatory	Parameters of the SIR model make or break the accuracy of the generated simulations and adjustments will be need to be make to represent correct changes in the simulation
Graphs must be well labelled and explained	Desirable	In order to meet my objective of making this paper being able to cater all target audiences, graphs must be labelled well in order to assist in the understanding of the graphs
Create interactive figures with Python	Desirable	If time permits, this will aid the reader by giving a better visual representation of findings which achieve the goal of making the paper cater to all target audiences.

Project Plan

Extensive research has already been achieved through the process of reading other researcher's work. By reading and noting the work of other researcher's work, decent knowledge has been grasped with a good understanding of:

1. Possible cultural factors that may explain differences in effectiveness of lockdown measures
2. What partakes the SIR model and it's relevant formulae
3. Understood the age-scaling modification applied to the SIR model to circumvent a fundamental flaw of the SIR model

However, it is important that more is looked into the production of a social age contact matrix explained in two separate research papers by author's first, Chikina M and Pegden W, second Prem K and Cook A.R.

Activity	Start Date	Duration (estimation in days)	End Date
Selection of project	26/08/2021	25	20/09/2021
Background research for project proposal	26/08/2021	51	17/10/2021
Project proposal	20/09/2021	27	17/10/2021
Further background reading	08/10/2021	34	05/11/2021
Interim Report	17/10/2021	25	11/11/2021
Gathering and cross-referencing data from Worldometer	12/11/2021	6	18/11/2021
Synthesisation of data	18/11/2021	21	09/12/2021
Look for possible outliers in data	09/12/2021	3	12/12/2021
Analysis of data	10/01/2022	14	24/01/2022
Application of age-scaling factor in the SIR model and production of age-contact	24/01/2022	24	17/02/2022

matrix for relevant nations in question			
Draft report	17/02/2022	61	19/04/2022
Feedback evaluation	TBA	N/A	TBA
Poster preparation and presentation	TBA	N/A	TBA
Final report	-	-	10/05/2022

Professional and Ethical Considerations

Professional Considerations

This project involves the collection of data already surveyed and made public from official governing powers, hence not breaking any BCS Code of Conduct by *The Chartered Institute For IT* [9]. However, it is to this paper's concern that governing powers are also in line with the BCS Code of Conduct. The following section will discuss how this project is in line with the BCS Code of Conduct:

1. Public Interest
You shall:

a) *have due regard for public health, privacy, security and wellbeing of others and the environment.*
b) *have due regard for the legitimate rights of Third Parties*.*
c) *conduct your professional activities without discrimination on the grounds of sex, sexual orientation, marital status, nationality, colour, race, ethnic origin, religion, age or disability, or of any other condition or requirement*
d) *promote equal access to the benefits of IT and seek to promote the inclusion of all sectors in society wherever opportunities arise.* [10]

As the nature of this project requires the use of data that is made publicly available by governing bodies in an anonymous fashion, any analysis done on this data set does not impact public health, privacy security and wellbeing of others and the environment, nor does this break any legal laws as this dataset is made public. Furthermore, as the sex, sexual orientation, marital status, nationality, colour, race, ethnic origin, religion, age or disability does not impact the data set it is not within the interests of governing bodies to discriminate against them, hence in line with clauses 1.a, 1.b, 1.c and 1.d.

2. Professional Competence and Integrity
You shall:

a) *only undertake to do work or provide a service that is within your professional competence.*
b) *NOT claim any level of competence that you do not possess.*
c) *develop your professional knowledge, skills and competence on a continuing basis, maintaining awareness of technological developments, procedures, and standards that are relevant to your field.*
d) *ensure that you have the knowledge and understanding of Legislation* and that you comply with such Legislation, in carrying out your professional responsibilities.*
e) *respect and value alternative viewpoints and, seek, accept and offer honest criticisms of work.*

f) *avoid injuring others, their property, reputation, or employment by false or malicious or negligent action or inaction.*
g) *reject and will not make any offer of bribery or unethical inducement.* [11]

It is only within this paper's interest to further develop his knowledge within the field, specifically due to the fact how this is the first interaction with the SIR model and does not claim any knowledge that is out of reach, whilst, at the same time keeping an open mind to criticism. Lastly, as this is paper is written under a scholarly environment, clauses 2.a, 2.b, 2.c, 2.d, 2.e, 2.f and 2.g are in accordance.

3. Duty to Relevant Authority
You shall:

a) *carry out your professional responsibilities with due care and diligence in accordance with the Relevant Authority's requirements whilst exercising your professional judgement at all times.*
b) *seek to avoid any situation that may give rise to a conflict of interest between you and your Relevant Authority.*
c) *accept professional responsibility for your work and for the work of colleagues who are defined in a given context as working under your supervision.*
d) *NOT disclose or authorise to be disclosed, or use for personal gain or to benefit a third party, confidential information except with the permission of your Relevant Authority, or as required by Legislation. Authority, or as required by Legislation.*
e) *NOT misrepresent or withhold information on the performance of products, systems or services (unless lawfully bound by a duty of confidentiality not to disclose such information), or take advantage of the lack of relevant knowledge or inexperience of others.* [12]

As this paper is conducted under a scholarly environment it is within the paper's interests to claim full professional responsibilities of this paper whilst being line with the Relevant Authority's, in this case, the University of Sussex, interests. Given that this data set is made public by governing bodies, this paper will be in line with clauses 3.a, 3.b, 3.c, 3.d and 3.e.

4. Duty to the Profession
You shall:

a) *accept your personal duty to uphold the reputation of the profession and not take any action which could bring the profession into disrepute.*
b) *seek to improve professional standards through participation in their development, use and enforcement.*
c) *uphold the reputation and good standing of BCS, the Chartered Institute for IT.*
d) *act with integrity and respect in your professional relationships with all members of BCS and with members of other professions with whom you work in a professional capacity.*
e) *encourage and support fellow members in their professional development.* [13]

Given that I am currently partaking in a university course accredited by the BCS, The Chartered Institute of IT, it is within my interests to follow, and will follow, clauses 4.a, 4.b, 4.c, 4.d and 4.e.

Ethical Considerations

Lastly it is important for the reader to understand that anomalies may arise in this paper on a natural basis due to uncertainties of the data, with myself being unable to impact the anomaly. Worldometer claims they encounter reporting issues from governing powers on a daily basis, which will impact the results of my findings [14]. On the 29th of April Worldometer claimed that the French Government reported a decrease of 1417 confirmed cases compared to the 28th of April, this was a different figure that appeared in a city-wide report released by the French Ministry of Health. As a result of these reporting issues, analysis on this paper can possibly be skewed and biased towards certain countries [15]. However it is believed that the results are confident and that the impact will be minimized as Worldometer cross-references nation-wide reports released by Governing Powers to its state/city reports counterpart.

Literature Review and Background Research

The SIR Model

The SIR model is a model created by William O.K and Anderson G.M in 1972, that consists of three groups, the Susceptible, the Infected and the Removed [16].

According to Tolles J and Luong T, authors of *Modelling Epidemics With Compartmental Models*, during a pandemic it is assumed that a population is to be placed in one of the three components of the SIR model, susceptible, infected and removed [17]. Firstly, it is assumed that the entire population starts off as susceptible and are expected to be infected through contact with another infected individual [18]. This suggests that no herd immunity, defined as *when a large portion of the population becomes immune to a disease*, is developed yet, hence causing many deaths in the upper age brackets [19]. Secondly, after a period of time in which the individual is considered to be infectious, the infected individual passes on the removed stage, either through recovery or death [20]. The period of time mentioned beforehand will depend on the nature of the pandemic, for example, in the context of COVID, the British government recommends self-isolating for 10 days, meaning that under normal circumstances it will take 10 days for an individual to move from the infected stage to the recovered stage through recovery [21].

Further on, a function can be given to define the number of Susceptible (S) at any given time t, S(t). The same can be done for the Infected(I) and Removed(R) group, I(t), R(t). Whilst the change of susceptible, infected and removed with respect to time can be given by the following set of differential equations [22].

$$\frac{dS}{dt} = -\beta \times I \times \frac{S}{N}$$

$$\frac{dI}{dt} = \beta \times I \times \frac{S}{N} - \gamma \times I$$

$$\frac{dR}{dt} = \gamma \times I$$

Through differentiation and integration, we can also follow that:

$$S(t) = S(0)e^{\frac{-R_0(R(t)-R(0))}{N}}$$

Where:

β defined as the transmission rate

γ defined as the removal rate

N defined as the total population

R_0defined as the reproduction number $= \frac{\beta}{\gamma}$

Furthermore, it is important to note that a value of $R_0 > 1$ suggests that the disease will begin to spread if no form of quarantining the infected group is introduced to the formula, hence meaning that the bigger the R_0 value is, the faster the disease will exponentially grow [23]. For example, measles is a relatively fast spreading disease with $12 \leq R_0 \leq 18$, meaning that a measles infected individual may spread the disease to 12-18 individuals in the susceptible group under vacuum circumstances [24]. This also means that due to the nature of which COVID spreads, the rate of susceptible individuals moving into the infected group is highly dependent on the number of infected people. As diseases spread exponentially, it can be determined that the more infected individuals there are, the faster it is expected for the disease to spread.

Assumptions of the SIR Model and It's Flaws

In order for the SIR model to be considered as a very simple model, the SIR model makes a number of assumptions.

1. First, the SIR model assumes that in a population of size N, each individual of the population N, has an equal chance of getting into contact with an infected individual [25]. This has been criticized by many researchers as this is not a realistic view of the probabilities of how diseases spread. Consider the fictional example between person A and B. The new outlet has just released a statement introducing COVID into the daily lives of A and B. Person A takes precaution by starting social distancing measures, whilst person B discards the news and continues to live its daily life. It is a fundamental flaw to say that person A and B have the same probability of getting into contact with an infected individual. Furthermore, this is made under the assumption that person A and B are of the same age. This assumption becomes even more flawed when the question of age is input into the question, individuals of higher age tend to have weaker immune systems, hence it is safe to claim that individuals of older age are more susceptible to diseases effecting immune systems. Thus, this generalization questions the reliability of this model as it is unrealistic.
2. Second, it is assumed that the individuals from the Removed group of the SIR model are unable to become infected again bringing them back into the Infected group. In the context of COVID, this proven false as on the 13th of October 2020, BBC reported that an individual that was able to get re-infected by COVID a second time [26].
3. Lastly, the SIR model assumes a constant population of size N. In a world where travelling has never been cheaper than before, it is also a mistake to assume that a population will remain constant. However, this can be considered negligible in the case of COVID as governing bodies imposed travelling restrictions relatively fast.

However, one must take a step back to consider that the SIR model is a simulation of what is expected to happen and not a specific case by case scenario, hence why researchers consider the SIR model to be effective.

Solving the Age Flaw of the SIR Model

As mentioned in the abstract a research paper conducted by authors Vishaal R and Laura P, *A Modified Age-Structured SIR Model for COVID-19 Type Viruses*, takes a very intelligent method to bring the variable age into the formula.

First, the authors claim that for diseases such as COVID-19, the variable age, plays a big part in the components of the SIR model, this could possibly be due to how individuals of higher age tend to have weaker immune systems, suggesting that individuals of older age are more vulnerable to diseases such as COVID-19, as mentioned before [27].

Age	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
0-9	19.2	4.8	3.0	7.1	3.7	3.1	2.3	1.4	1.4
10-19	4.8	42.4	6.4	5.4	7.5	5.0	1.8	1.7	1.7
20-29	3.0	6.4	20.7	9.2	7.1	6.3	2.0	0.9	0.9
30-39	7.1	5.4	9.2	16.9	10.1	6.8	3.4	1.5	1.5
40-49	3.7	7.5	7.1	10.1	13.1	7.4	2.6	2.1	2.1
50-59	3.1	5.0	6.3	6.8	7.4	10.4	3.5	1.8	1.8
60-69	2.3	1.8	2.0	3.4	2.6	3.5	7.5	3.2	3.2
70-79	1.4	1.7	0.9	1.5	2.1	1.8	3.2	7.2	7.2
80+	1.4	1.7	0.9	1.5	2.1	1.8	3.2	7.2	7.2

Figure 1. Age-Contact Matrix Implementation by Vishaal R and Laura P [28]

Second, the authors decide to separate age groups into 9 intervals, 0-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80+ to impose a matrix, M, which describes the rates of contact between each age bracket. The values of which describe the rates of contact between different age groups is based upon two different research papers conducted by first, Chikina M and Pegden W, second Prem K and Cook A.R [29] [30] [31]. The values that take place in the cells within the matrix are *proportional to the total number of contacts per time between age groups, divided by the product of their population size* [32]. The authors then further elaborate how if individuals from different age brackets had equal total number of contacts, then this would be a constant matrix, which is one of the assumptions the SIR model assumes.

Following the age-contact matrix, the differential equations now become:

[33]

$$\frac{dS_i}{dt} = -\beta \times \frac{S_i}{N} \times \sum_{j=1}^{n} M_{ij} \times I_j$$

$$\frac{dI_i}{dt} = \beta \times \frac{S_i}{N} \times \sum_{j=1}^{n} M_{ij} \times I_j - \gamma \times I_j$$

$$\frac{dR_i}{dt} = \gamma \times I_j$$

By implementing Vishaal R and Laura P approach to the SIR model, this partially solves assumption number 1 above as this now factors in the variable, age. It is believed believes that if this approach is taken to the SIR model, the social behaviour of individuals becomes negligible, this is because with a disease such as COVID-19, age is one of the main factors effecting the three components of the SIR model, susceptible, infected and removed.

Methodology

Construction of the Matrix

As this paper mainly revolves around the use of a social age contact matrices, it is crucial to create the different matrices for the required countries used in this study, as the paper by Vishaal R and Laura P only provides the social contact matrix for Washington, United States of America, heavily limiting the scope of this paper. Later it was found that another study, *Projecting Contact Matrices in 177 Geographical Regions: An Update and Comparison with Empirical Data for the COVID-19 Era,* by authors Kiesha P, Kevin Z, Petra K, Rosalind E, Nicholas D, CMMID COVID-19 Working Group, Alex C and Mark J, extrapolated data from the European Commission's POLYMOD study to create social contact matrices for 177 geographical regions [34].

First and foremost, it is important to inform that the POLYMOD study conducted by the European Commission aimed to strengthen public health decision making in Europe through the study of diary-like social surveys [35]. The POLYMOD study had a wide scope aiming to achieve 5 goals with their study.

1. POLYMOD intended to assist governing powers to correctly model and analyse a public health concern, incorporating policy makers, public health specialists, mathematicians and health economists interact such that the best decision in response to a matter regarding the public health is reached [36].
2. The study claims that mathematical models for simulation's accuracy is heavily dependent on the assumptions and parameters input to the model. An important parameter in which the ways different members of a society interact are hence crucial to a mathematical model's accuracy. Given how this social study of community interaction was not too well documented, the POLYMOD study had a goal of documenting the ways in which a community interacts. In order to overcome this obstacle, the POLYMOD study estimated relevant modern community interactions in different European Countries by extrapolating and refining existing data sets [37].
3. Predicting the effects of quarantining infectious diseases such as COVID 19, require the use of sophisticated and dynamic parameters in which POLYMOD aims to smoothen the process.

It is perhaps to be said that predicting the outcomes of an action accurately from governing powers is a top tier goal as this may keep the population satisfied and understand the decision behind the process in quarantining infectious diseases [38].

4. The POLYMOD study also aimed to adapt and expand well defined models to address public health issues and to create new techniques for minimizing the spread of microbial diseases [39].
5. To view solutions of minimizing the spread of microbial diseases from an economic perspective to best determine the cost effectiveness of different solutions that best suit a nation's goal [40].

Given the 5 goals from the POLYMOD, it can be said that the study's scope was significantly greater than this paper's scope in simply aiding in modelling a pandemic. Furthermore, as the POLYMOD study is only limited to the European economic region, methods of community contact in regions outside of Europe were mandatory as well, this led to the paper, *Projecting Contact Matrices in 177 Geographical Regions: An Update and Comparison with Empirical Data for the COVID-19 Era*, in which the methods of which a community contacts are well documented for 177 geographical regions. This paper not only bases its methodology off the POLYMOD study, but also updates the data set to accurately represent the methods in which a community contacts in the year 2020 [41].

Age Groups	0,5	5,10	10,15	15,20	20,25	25,30	30,35	35,40	40,45	45,50	50,55	55,60	60,65	65,70	70,75	75,80
0,5	3.31171	0.82603	0.31879	0.21676	0.28189	0.55289	0.87161	0.83755	0.53075	0.32094	0.29262	0.25154	0.16500	0.12489	0.07818	0.04493
5,10	1.47170	8.63014	1.03089	0.24912	0.24112	0.56917	0.84707	0.95016	0.97951	0.50389	0.37297	0.24089	0.19673	0.12722	0.06283	0.04759
10,15	0.23273	2.39356	11.79705	0.82849	0.32913	0.43174	0.53856	0.87708	1.13579	0.72266	0.47222	0.26309	0.14259	0.10725	0.08141	0.07488
15,20	0.17566	0.36893	3.45370	10.93923	1.14050	0.63181	0.52546	0.75908	0.90143	1.03269	0.59054	0.27689	0.12654	0.07822	0.04280	0.03396
20,25	0.23251	0.21467	0.25483	2.14764	3.76565	1.57720	1.05958	0.95685	0.82922	1.06210	0.78578	0.45120	0.17350	0.06879	0.07067	0.06041
25,30	0.39200	0.19886	0.11789	0.42029	1.57128	3.09918	1.82830	1.48478	1.28456	1.07059	1.08984	0.66138	0.29823	0.08508	0.03878	0.03143
30,35	0.56299	0.57498	0.38582	0.22295	0.83471	1.74532	2.77498	1.93094	1.52887	1.21708	0.93160	0.73140	0.38644	0.13135	0.06337	0.05910
35,40	0.73342	0.93973	0.68794	0.37645	0.63585	1.47489	1.87215	3.02789	2.23222	1.45976	1.08804	0.63070	0.40908	0.21765	0.12551	0.05375
40,45	0.53707	0.93067	1.05128	0.74567	0.88154	1.41995	1.89629	2.15476	3.09635	1.93878	1.38710	0.58955	0.39968	0.20172	0.14248	0.07364
45,50	0.30888	0.56468	0.68921	1.05724	0.97898	1.20720	1.47788	1.70297	1.83468	2.36826	1.41800	0.72769	0.33631	0.15663	0.14010	0.13698
50,55	0.42500	0.47350	0.66951	0.85896	1.13088	1.57924	1.47055	1.42843	1.90705	2.06507	2.09816	1.14149	0.46286	0.17221	0.12559	0.12240
55,60	0.73844	0.73897	0.49413	0.64435	0.87925	1.56994	1.73768	1.33173	1.50998	1.30367	1.55896	1.73742	0.75137	0.30340	0.15332	0.12138
60,65	0.92354	0.82330	0.50343	0.52843	0.65600	1.13375	1.39214	1.37927	1.16201	0.99952	0.94322	1.15979	1.28184	0.54433	0.33853	0.14606
65,70	0.72865	1.00134	0.75817	0.41864	0.49739	0.71986	1.11773	1.03789	0.94324	0.54378	0.61484	0.72619	0.75139	1.07194	0.36903	0.18722
70,75	0.44012	1.14628	0.93030	0.82307	0.31800	0.61451	0.60397	1.00578	1.09963	0.82462	0.64525	0.52448	0.98723	0.86508	1.17246	0.42141
75,80	0.44572	0.56527	0.77686	0.62090	0.26619	0.27644	0.46725	0.59720	0.62437	0.67815	0.65572	0.42767	0.34715	0.47726	0.43906	0.39661

Figure 2: Social Age Contact Matrix for the Country Portugal

The data is accessed through the language R, I then decided to extract the social age contact matrices for all required country's into excel to better help structure and view the data. As shown above the social age contact matrix for Portugal is represented with 16 different age groups. Upon further inspection, this matrix is rather inconsistent, in theory two different age groups should report the same number of contacts on a daily basis, however in this case, 2 different values are reported for the corresponding same value, in other words this matrix is not symmetric when in theory symmetry should be present. For example, cell B3 shows the number of contacts with people aged 10-15 reported by people aged 0-5, the same value should be present in cell C2 which shows the number of contacts with people aged 0-5 reported by people aged 10-15.

Transposed Data

Age Groups	0,5	5,10	10,15	15,20	20,25	25,30	30,35	35,40	40,45	45,50	50,55	55,60	60,65	65,70	70,75	75,80
0,5	3.31171	1.47170	0.23273	0.17566	0.23251	0.39200	0.56299	0.73342	0.53707	0.30888	0.42500	0.73844	0.92354	0.72865	0.44012	0.44572
5,10	0.82603	8.63014	2.39356	0.36893	0.21467	0.19886	0.57498	0.93973	0.93067	0.56468	0.47350	0.73897	0.82330	1.00134	1.14628	0.56527
10,15	0.31879	1.03089	11.79705	3.45370	0.25483	0.11789	0.38582	0.68794	1.05128	0.68921	0.66951	0.49413	0.50343	0.75817	0.93030	0.77686
15,20	0.21676	0.24912	0.82849	10.93923	2.14764	0.42029	0.22295	0.37645	0.74567	1.05724	0.85896	0.64435	0.52843	0.41864	0.82307	0.62090
20,25	0.28189	0.24112	0.32913	1.14050	3.76565	1.57128	0.83471	0.63585	0.88154	0.97898	1.13088	0.87925	0.65600	0.49739	0.31800	0.26619
25,30	0.55289	0.56917	0.43174	0.63181	1.57720	3.09918	1.74532	1.47489	1.41995	1.20720	1.57924	1.56994	1.13375	0.71986	0.61451	0.27644
30,35	0.87161	0.84707	0.53856	0.52546	1.05958	1.82830	2.77498	1.87215	1.89629	1.47788	1.47055	1.73768	1.39214	1.11773	0.60397	0.46725
35,40	0.83755	0.95016	0.87708	0.75908	0.95685	1.48478	1.93094	3.02789	2.15476	1.70297	1.42843	1.33173	1.37927	1.03789	1.00578	0.59720
40,45	0.53075	0.97951	1.13579	0.90143	0.82922	1.28456	1.52887	2.23222	3.09635	1.83468	1.90705	1.50998	1.16201	0.94324	1.09963	0.62437
45,50	0.32094	0.50389	0.72266	1.03269	1.06210	1.07059	1.21708	1.45976	1.93878	2.36826	2.06507	1.30367	0.99952	0.54378	0.82462	0.67815
50,55	0.29262	0.37297	0.47222	0.59054	0.78578	1.08984	0.93160	1.08804	1.38710	1.41800	2.09816	1.55896	0.94322	0.61484	0.64525	0.65572
55,60	0.25154	0.24089	0.26309	0.27689	0.45120	0.66138	0.73140	0.63070	0.58955	0.72769	1.14149	1.73742	1.15979	0.72619	0.52448	0.42767
60,65	0.16500	0.19673	0.14259	0.12654	0.17350	0.29823	0.38644	0.40908	0.39968	0.33631	0.46286	0.75137	1.28184	0.75139	0.98723	0.34715
65,70	0.12489	0.12722	0.10725	0.07822	0.06879	0.08508	0.13135	0.21765	0.20172	0.15663	0.17221	0.30340	0.54433	1.07194	0.86508	0.47726
70,75	0.07818	0.06283	0.08141	0.04280	0.07067	0.03878	0.06337	0.12551	0.14248	0.14010	0.12559	0.15332	0.33853	0.36903	1.17246	0.43906
75,80	0.04493	0.04759	0.07488	0.03396	0.06041	0.03143	0.0591	0.05375	0.07364	0.13698	0.1224	0.12138	0.14606	0.18722	0.42141	0.39661

MMULT Data

Age Groups	0,5	5,10	10,15	15,20	20,25	25,30	30,35	35,40	40,45	45,50	50,55	55,60	60,65	65,70	70,75	75,80
0,5	14.22925	15.20874	9.30951	7.21109	6.32242	8.15964	9.49337	10.90570	10.46066	8.02008	8.55750	9.39127	9.01174	7.28722	6.22816	4.47810
5,10	15.20874	81.24402	36.74831	13.25838	8.40428	10.05856	14.35794	19.04634	19.55209	13.89085	13.48320	15.31470	15.03090	14.98101	15.85567	9.15096
10,15	9.30951	36.74831	149.14265	54.48166	10.92521	9.42676	13.78699	19.72343	25.01048	18.30574	17.99432	15.38646	14.29952	16.05598	18.72832	13.90571
15,20	7.21109	13.25838	54.48166	136.64354	33.53367	14.12231	12.51260	16.32155	22.61078	23.36065	21.59088	17.31490	14.41029	12.26983	17.17487	12.82145
20,25	6.32242	8.40428	10.92521	33.53367	26.16356	18.64865	15.22195	15.59657	17.90459	16.99170	17.93687	15.55767	12.29010	9.07444	8.99259	6.35559
25,30	8.15964	10.05856	9.42676	14.12231	18.64865	22.52494	20.03205	20.38257	21.38401	18.31132	20.04508	18.61001	14.74889	10.62685	9.63003	6.35483
30,35	9.49337	14.35794	13.78699	12.51260	15.22195	20.03205	21.41370	22.31148	23.05763	19.02183	19.93573	19.00783	15.67512	11.82262	10.66924	7.12026
35,40	10.90570	19.04634	19.72343	16.32155	15.59657	20.38257	22.31148	26.21732	26.85390	21.70642	22.19055	20.44343	17.37198	13.39108	13.08763	8.57543
40,45	10.46066	19.55209	25.01048	22.61078	17.90459	21.38401	23.05763	26.85390	29.69211	24.11780	24.85772	22.03528	18.19461	14.08780	14.33534	9.58172
45,50	8.02008	13.89085	18.30574	23.36065	16.99170	18.31132	19.02183	21.70642	24.11780	21.19800	21.79994	18.93013	15.33724	11.44754	11.90965	8.25052
50,55	8.55750	13.48320	17.99432	21.59088	17.93687	20.04508	19.93573	22.19055	24.85772	21.79994	23.44798	20.73941	16.45346	12.11893	12.27181	8.58997
55,60	9.39127	15.31470	15.38646	17.31490	15.55767	18.61001	19.00783	20.44343	22.03528	18.93013	20.73941	19.90498	16.23330	12.13682	11.68315	7.91933
60,65	9.01174	15.03090	14.29952	14.41029	12.29010	14.74889	15.67512	17.37198	18.19461	15.33724	16.45346	16.23330	14.27902	10.99090	10.90057	6.98762
65,70	7.28722	14.98101	16.05598	12.26983	9.07444	10.62685	11.82262	13.39108	14.08780	11.44754	12.11893	12.13682	10.99090	9.35148	9.28180	5.89336
70,75	6.22816	15.85567	18.72832	17.17487	8.99259	9.63003	10.66924	13.08763	14.33534	11.90965	12.27181	11.68315	10.90057	9.28180	10.76153	6.54597
75,80	4.47810	9.15096	13.90571	12.82145	6.35559	6.35483	7.12026	8.57543	9.58172	8.25052	8.58997	7.91933	6.98762	5.89336	6.54597	4.39043

Figure 3: Shows the post data processing of the data. Upper matrix shows the original matrix but transposed, lower matrix shows the matrix but symmetric.

In order to tackle this issue, it was decided that the matrices needed to undergo a smoothing process. To smooth the matrices out in order to make it symmetrical, we first have to define what it means for a matrix to be symmetric. A matrix is symmetric if it meets both conditions, first the matrix must be in form of a square matrix, meaning that the matrix has the same number of rows and columns, second if the matrix is transposed each value in each cell is equal. As shown in figure 2, the matrix is partially symmetric as it is defined as a square matrix, however to have the matrix such that when transposed each value in each cell is equal, the matrix would first have to be transposed. Once transposed the matrix would then have to undergo the MMULT function from excel, returning the product of the two arrays, in this case the original matrix and the transposed version of the original matrix. It was decided to use the MMULT function because by using the MMULT function it would consider the reports from both age groups maintain its high accuracy at the cost of losing some of its precision. Finding the mean of the arrays was not considered as results were found to have a large range compromising the accuracy of the matrix.

Python Code

```python
europeSocialContact = {
    9:"Albania",
    10:"Austria",
    11:"Belarus",
    12:"Belgium",
    13:"Bosnia and Herzegovina",
    14:"Bulgaria",
    15:"Croatia",
    16:"Czechia",
    17:"Denmark",
    18:"Estonia",
    19:"Finland",
    20:"France",
    21:"Germany",
    22:"Greece",
    23:"Hungry",
    24:"Iceland",
    25:"Ireland",
    26:"Italy",
    27:"Latvia",
    28:"Lithuania",
    29:"Luxembourg",
    30:"Malta",
    31:"Moldova",
    32:"Montenegro",
    33:"Netherlands",
    34:"North Macedonia",
    35:"Norway",
    36:"Poland",
    37:"Portugal",
    38:"Romania",
    39:"Russia",
    40:"Serbia",
    41:"Slovakia",
    42:"Slovenia",
    43:"Spain",
    44:"Sweden",
    45:"Switzerland",
    46:"Ukraine",
    47:"United Kingdom",
  }
```

```python
asiaSocialContact = {
    2:"Afghanistan",
    3:"Armenia",
    4:"Azerbaijan",
    5:"Bahrain",
    6:"Bangladesh",
    7:"Bhutan",
    8:"Brunei",
    9:"Cambodia",
    10:"China",
    11:"Cyprus",
    12:"Georgia",
    13:"Hong Kong",
    14:"India",
    15:"Indonesia",
    16:"Iran",
    17:"Iraq",
    18:"Israel",
    19:"Japan",
    20:"Jordan",
    21:"Kazakhstan",
    22:"Kuwait",
    23:"Kyrgyzstan",
    24:"Laos",
    25:"Macao",
    26:"Malaysia",
    27:"Maldives",
    28:"Mongolia",
    29:"Myanmar",
    30:"Nepal",
    31:"Oman",
    32:"Pakistan",
    33:"Palestine",
    34:"Philippines",
    35:"Qatar",
    36:"Saudi Arabia",
    37:"Singapore",
    38:"South Korea",
    39:"Sri Lanka",
    40:"Syria",
    41:"Tajikistan",
    42:"Thailand",
    43:"Timor-Leste",
    44:"Turkey",
    45:"United Arab Emirates",
    46:"Uzbekistan",
    47:"Vietnam",
    48:"Yemen",
  }
```

```python
countryPopulation = {
    "Albania":2871997,
    "Austria":9101265,
    "Belarus":9443585,
    "Belgium":11682736,
    "Bosnia and Herzegovina":3243156,
    "Bulgaria":6851913,
    "Croatia":4058543,
    "Czechia":10745656,
    "Denmark":5829856,
    "Estonia":1328182,
    "Finland":5556609,
    "France":65540141,
    "Germany":84278500,
    "Greece":10329086,
    "Hungry":9615074,
    "Iceland":345331,
    "Ireland":5039605,
    "Italy":60297717,
    "Latvia":1847717,
    "Lithuania":2652206,
    "Luxembourg":644775,
    "Malta":443714,
    "Moldova":4016657,
    "Montenegro":628213,
    "Netherlands":17204861,
    "North Macedonia":2083216,
    "Norway":5499497,
    "Poland":37770097,
    "Portugal":10141831,
    "Romania":19000844,
    "Russia":146049974,
    "Serbia":8672412,
    "Slovakia":5464524,
    "Slovenia":2079465,
    "Spain":46788207,
    "Sweden":10215519,
    "Switzerland":8771464,
    "Ukraine":43248837,
    "United Kingdom":68544332,
    "Afghanistan":40546229,
    "Armenia":2973467,
    "Azerbaijan":10307886,
    "Bahrain":1810684
```

Figure 4: Two dictionaries are created to call the social age contact matrices from the excel file, as the original excel files were created separately to divide Europe and Asia europeSocialContact{} and

asiaSocialContact{} were created respectively. The last dictionary countryPopulation{} contains the population for all countries included in the comparison.

```
for x in range(9,48):
  europeSocialContact[x] = pd.read_excel('EU Contact Matrix MMULT.xlsx', sheet_name = x)

for y in range(2,49):
  asiaSocialContact[y] = pd.read_excel('Asia Contact Matrix - MMULT.xlsx', sheet_name = y)
```

Figure 5: For loops reading the required excel files for this paper

```
def covidSIR(y, t, N, beta, gamma, matrix):
  S, I, R = y
  dSdt = -beta * S * I * matrix / N
  dIdt = beta * S * I * matrix / N - gamma * I
  dRdt = gamma * I
  return dSdt, dIdt, dRdt

def covidSIRAsiaSimluations(country, countrycode, agegroup):
  N = countryPopulation[country]
  beta = 1
  matrix = asiaSocialContact[countrycode].sum(numeric_only=True).values[agegroup]
  D = 18
  gamma = beta / D

  S0, I0, R0 = N-1, 1, 0

  t = np.linspace(0,0.1, num=50)
  y0 = S0, I0, R0

  simulate = odeint(covidSIR, y0, t, args=(N, beta, gamma, matrix))
  S, I, R = simulate.T

  f, ax = plt.subplots(1,1,figsize=(10,4))
  ax.plot(t, S, 'b', alpha=0.7, linewidth=2, label='Susceptible')
  ax.plot(t, I, 'y', alpha=0.7, linewidth=2, label='Infected')
  ax.plot(t, R, 'g', alpha=0.7, linewidth=2, label='Recovered')

  ax.set_xlabel('Time (Entire duration of pandemic)')
  ax.set_ylabel('Population')

  ax.yaxis.set_tick_params(length=0)
  ax.xaxis.set_tick_params(length=0)
  ax.grid(b=True, which='major', c='w', lw=2, ls='-')
  legend = ax.legend()
  legend.get_frame().set_alpha(0.5)
  for spine in ('top', 'right', 'bottom', 'left'):
      ax.spines[spine].set_visible(False)
  plt.show();
```

Figure 6: Function covidSIR represents the systems of ODEs used to simulate the COVID-19 pandemic. Function covidSIRAsiaSimulations takes the initial parameters set (more to be discussed in later sections of this paper)

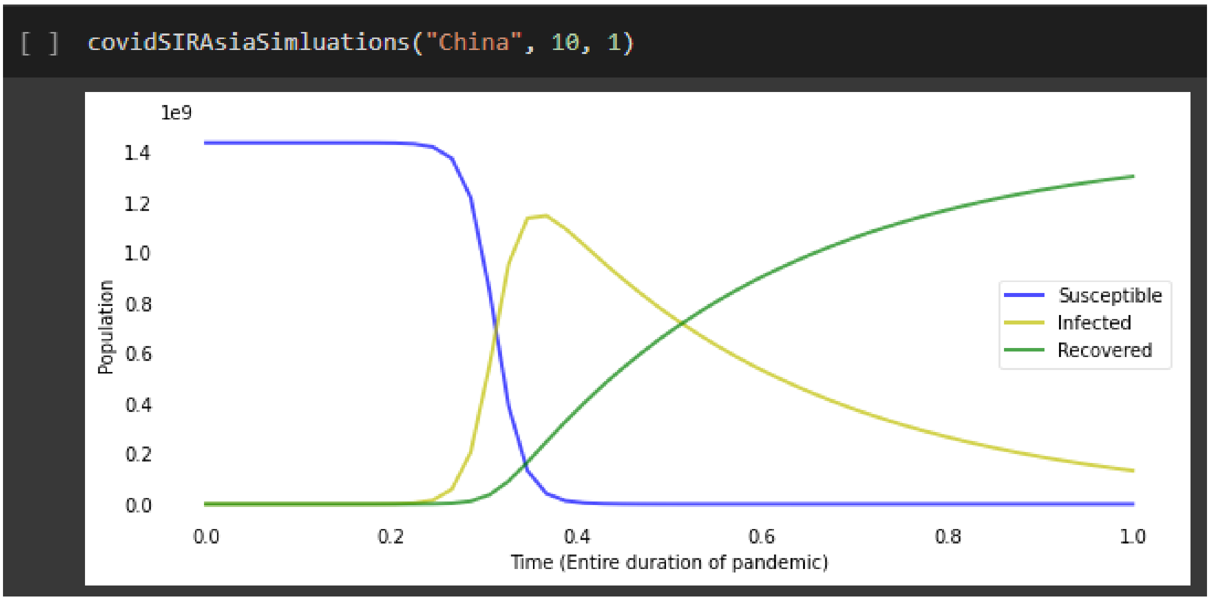

Figure 7: Example simulation of the SIR model for China age group 0-5, beta=5, initially only 1 infected

Results and Findings

To further expand on Figure 6, as aforementioned the function, covidSIR, represents the systems of ODEs used to simulate the COVID-19 pandemic with respect to the social age contact matrix as mentioned in the literature review. In addition, the function, covidSIRAsiaSimulations set the initial parameters for the simulation and take 3 parameters, country, countrycode and agegroup. The parameter country is of type string and represents the country in which the simulation is occurring, if the country in question is situated in Europe then an equal covidSIREuropeSimulations function is present a swell to suit the need. Secondly, the parameter countrycode represents the sheet number of the country in question in which the dictionary containing the corresponding key values should be consulted, for example, China is noted as sheet number 10, hence if simulations of COVID-19 were to be simulated then countrycode = 10 for China. Lastly, the last parameter required as an input is agegroup. The parameter agegroup is of type integer and represents the different age groups in the social age contact matrix study, where 1 is equal to age groups 0-5, 2 is equal to age groups 5-10, 3 is equal to age groups 10-15 and so on.

The next parameter beta is rather interesting. Beta represents the transmission rate of the disease COVID-19. For the purpose of the simulation lets assume that the initial infected pool of people are only able to infect 1 other person. This is without the influence of any form of government intervention in order to seize the disease. This will be the value we will be working with to understand the effects of lockdown measures, for example if social distancing rules were to be set, it can be expected that the parameter beta is to decrease as the probability of transmitting the disease is now smaller. Additionally, D represents the period in which an infected individual remains infected, hence gamma represents the removal rate also defined as 1/D. Lastly for the initial conditions we only assumed that 1 person was infected.

With regards to evaluating the effects of lockdown measures I have selected 4 countries from each continent to manipulate parameters in order to find out if lockdown measures are effective or not. For Asia, the countries China, Japan, United Arab Emirates and Saudi Arabia have been selected. As mentioned before, it is hypothesized that culture may have a large impact on the effectiveness of lockdown measures hence China and Japan were chosen as they share some similar aspects in terms of culture and United Arab Emirates and Saudi Arabia were chosen as they share similar aspects in terms of culture as well. These 2 sets of countries are also localized in a close geographical location. On the other hand, for Europe, the countries, Portugal, Spain, Albania and Bulgaria were chosen. I will first present a simulation of if government intervention was not present and compare them to simulations of if government intervention became present. By having the factor of if government intervention is present or not will have a large impact on the value of beta, meaning that if government intervention is present then beta is expected to be a smaller value as the rate at which the disease spreads is slower, and if government intervention is not present then beta is expected to be a bigger value as the rate at which the disease spreads is faster. Lastly, we will work the initial number of infected individuals as a way to show the importance of setting in lockdown measures fast. For the sake of comparison, I have chosen the age group 25-30 as my samples as the age 25-30 incorporates a wide range of members from the community, this includes students, employees, parents, etc.

Tables of Results with Parameters Beta =1, Initial Infected = 1

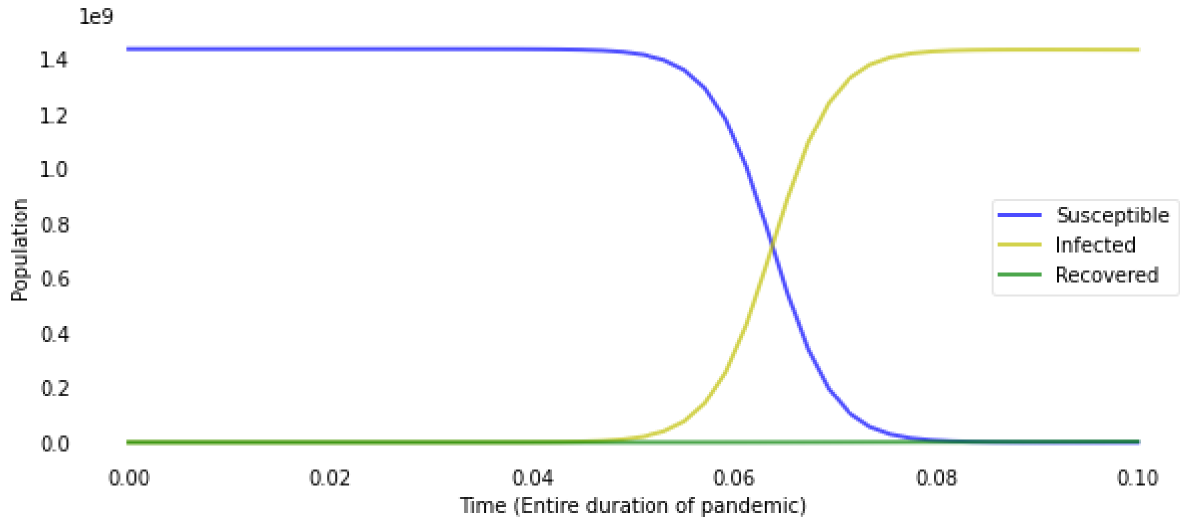

Figure 8: Simulations for China's COVID-19 Pandemic of age group 25-30

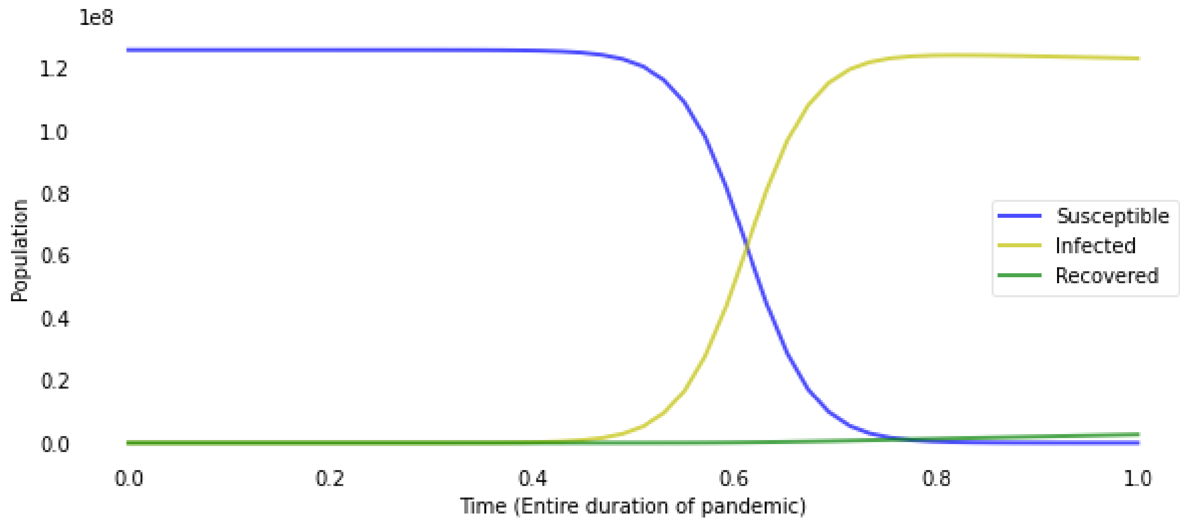

Figure 9: Simulations for Japan's COVID-19 Pandemic of age group 25-30

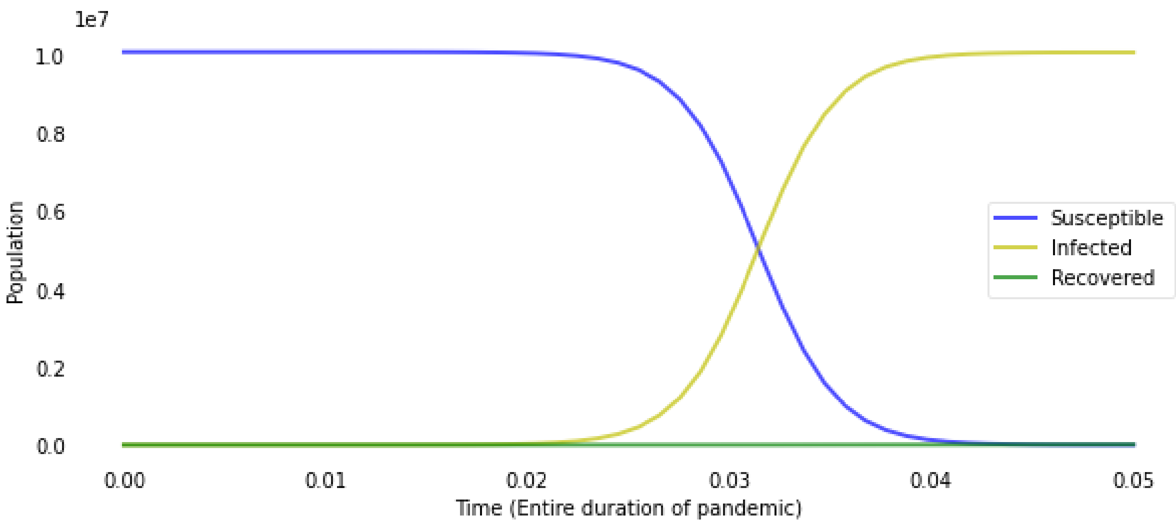

Figure 10: Simulations for United Arab Emirates' COVID-19 Pandemic of age group 25-30

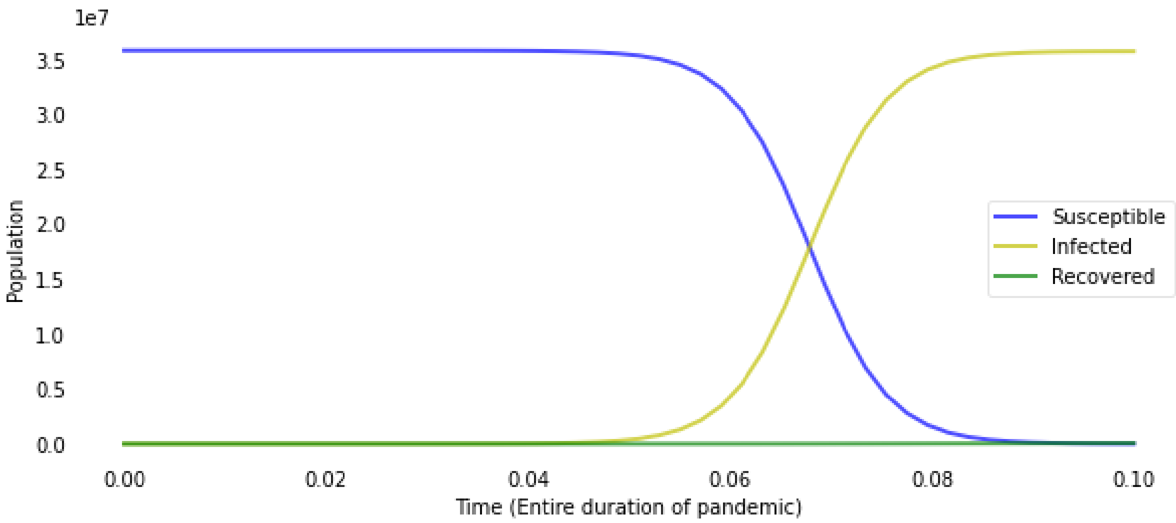

Figure 11: Simulations for Saudi Arabia's COVID-19 Pandemic of age group 25-30

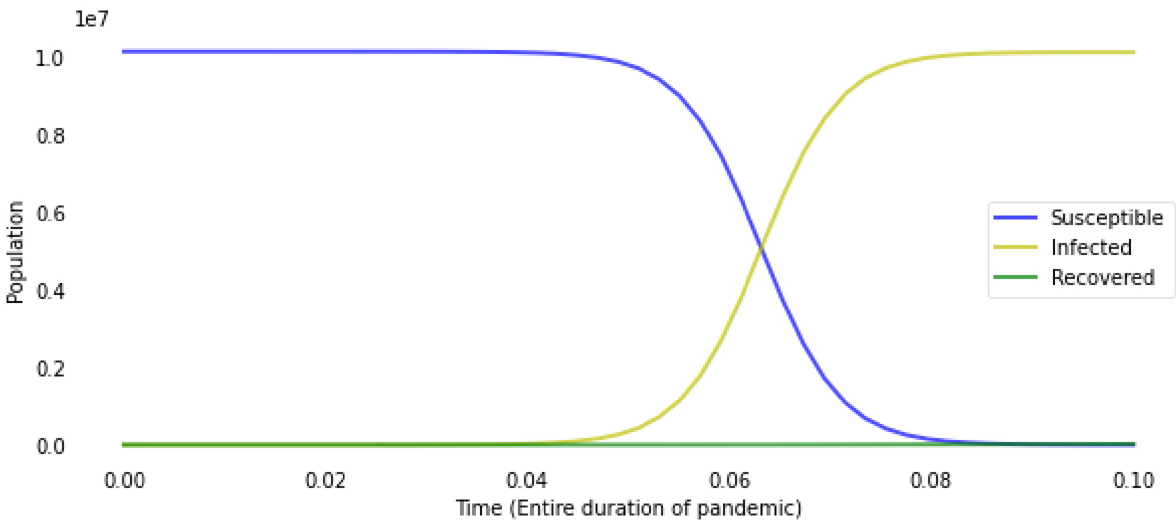

Figure 12: Simulations for Portugal's COVID-19 Pandemic of age group 25-30

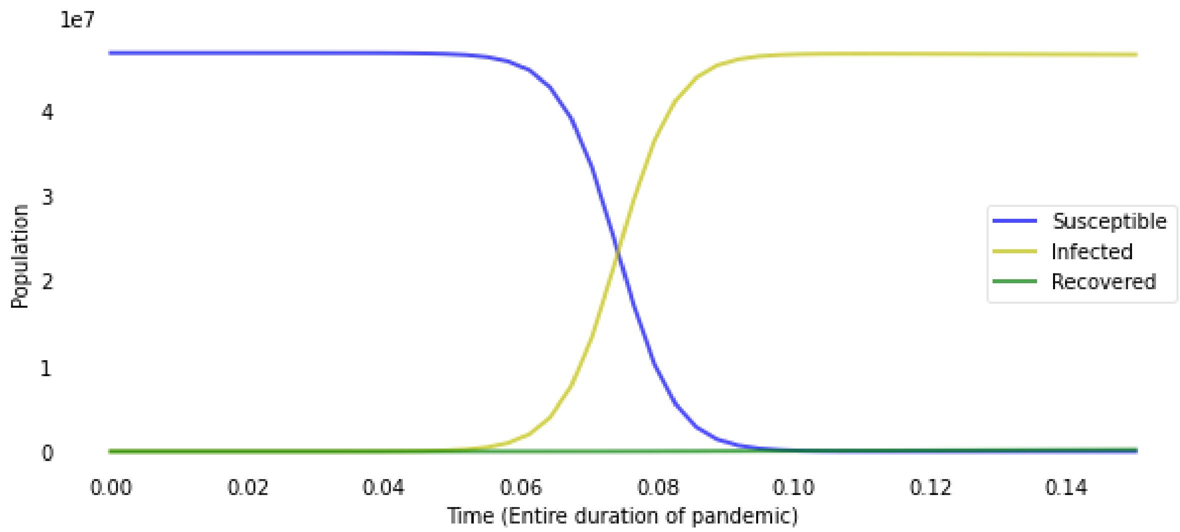

Figure 13: Simulations for Spain’s COVID-19 Pandemic of age group 25-30

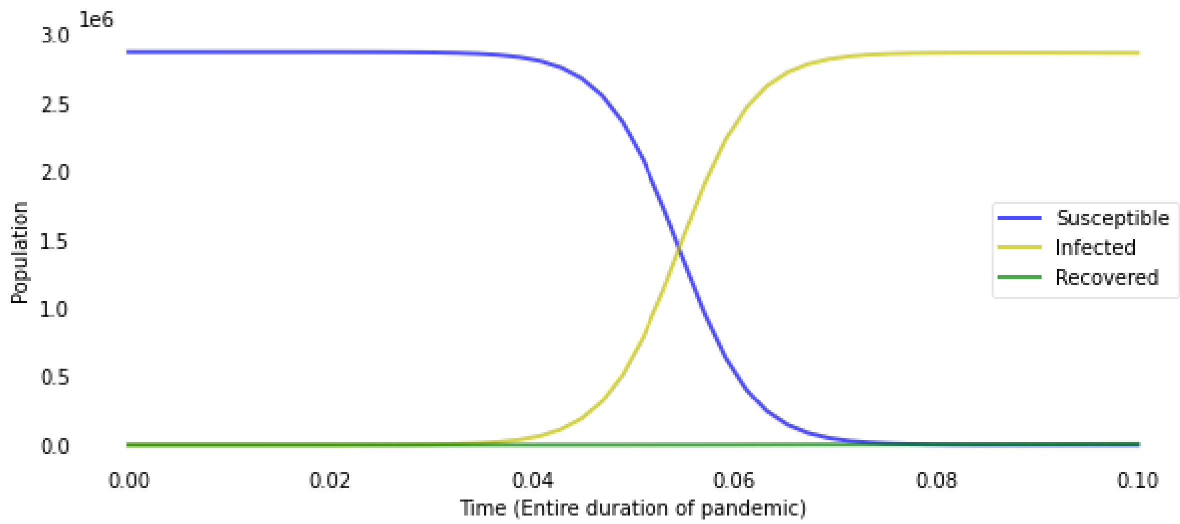

Figure 14: Simulations for Albania’s COVID-19 Pandemic of age group 25-30

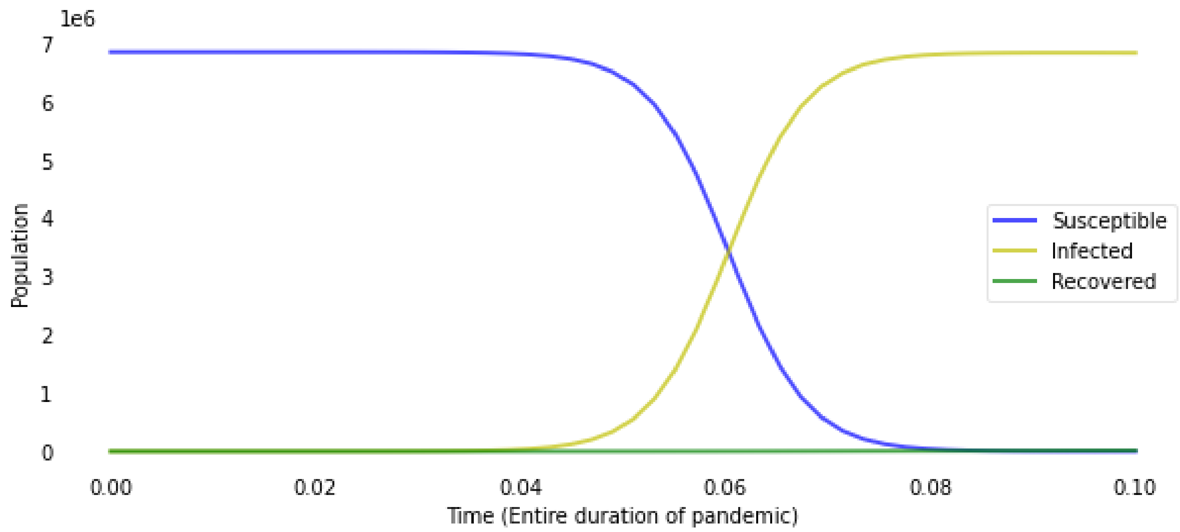

Figure 15: Simulations for Bulgaria’s COVID-19 Pandemic of age group 25-30

Now if we do: $\frac{Time\ at\ which\ Susceptible=Infected}{Time\ at\ which\ Susceptible=0} \times 100$ we can use this percentage as a metric to when the disease has become very serious without government intervention in the entire timeline at which the pandemic exists, in other words this can be considered as the critical period

$$S_{China}(0.07) \approx I_{China}(0.07);\ \ S_{China}(0.08) \approx 0;\ Metric_{China} = 87.5\%$$

$$S_{Japan}(0.6) \approx I_{Japan}(0.6);\ S_{Japan}(0.8) \approx 0;\ Metric_{Japan} = 75\%$$

$$S_{\mathrm{UAE}}(0.035) \approx I_{\mathrm{UAE}}(0.035)\ ;\ S_{\mathrm{UAE}}(0.04) \approx 0;\ Metric_{UAE} = 87.5\%$$

$$S_{\mathrm{Saudi\ Arabia}}(0.07) \approx I_{\mathrm{Saudi\ Arabia}}(0.07);\ S_{\mathrm{Saudi\ Arabia}}(0.08) \approx 0;\ Metric_{Saudia\ Arabia} = 87.5\%$$

$$S_{Portugal}(0.065) \approx I_{Portugal}(0.065);\ S_{\mathrm{Portugal}}(0.08) \approx 0;\ Metric_{Portugal} = 81.3\%$$

$$S_{Spain}(0.07) \approx I_{Spain}(0.07);\ S_{\mathrm{Spain}}(0.09) \approx 0;\ Metric_{Spain} = 77.8\%$$

$$S_{Albania}(0.055) \approx I_{Albania}(0.055);\ S_{\mathrm{Albania}}(0.07) \approx 0;\ Metric_{Albania} = 78.6\%$$

$$S_{Bulgaria}(0.06) \approx I_{Bulgarua}(0.06);\ S_{\mathrm{Bulgaria}}(0.08) \approx 0;\ Metric_{Bulgaria} = 75\%$$

As shown from the data, if there is no government intervention, in other words no lockdown measures have been implemented then the critical period arrives at roughly 75%-90% of the pandemic timeline.

Tables of Results with Parameters Beta = 0.05, Initial Infected = 1

We now assume the government has now intervened and has set a nation-wide lock down which suggests the extreme beta value of 0.05.

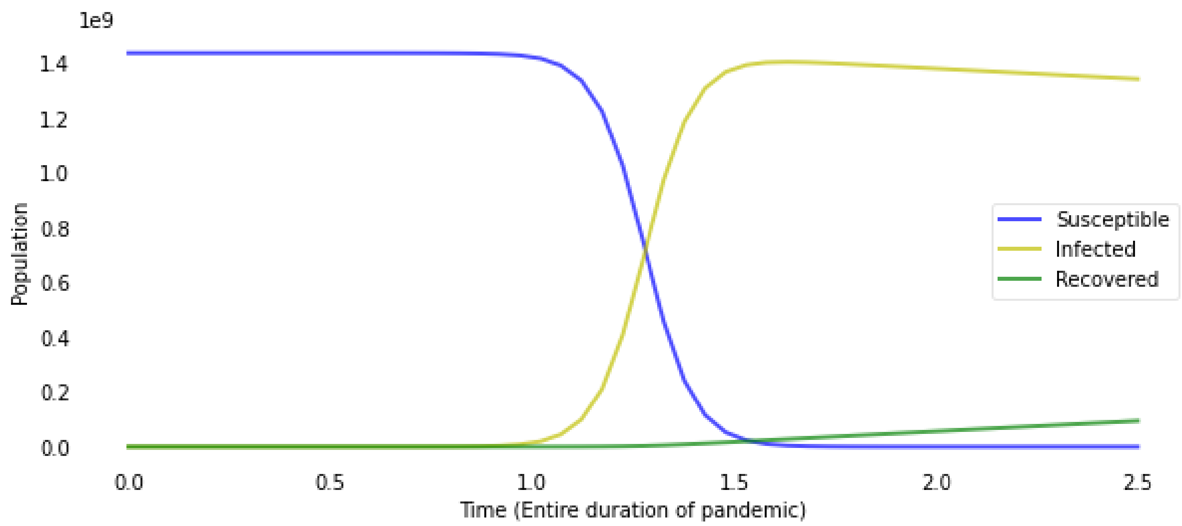

Figure 16: Simulations for China's COVID-19 Pandemic of age group 25-30

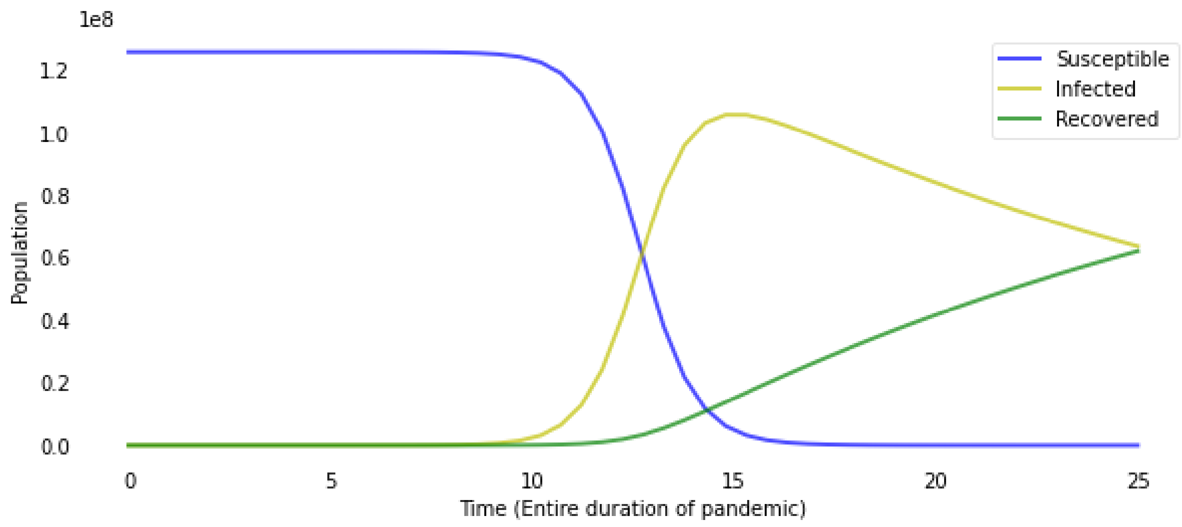

Figure 17: Simulations for Japan's COVID-19 Pandemic of age group 25-30

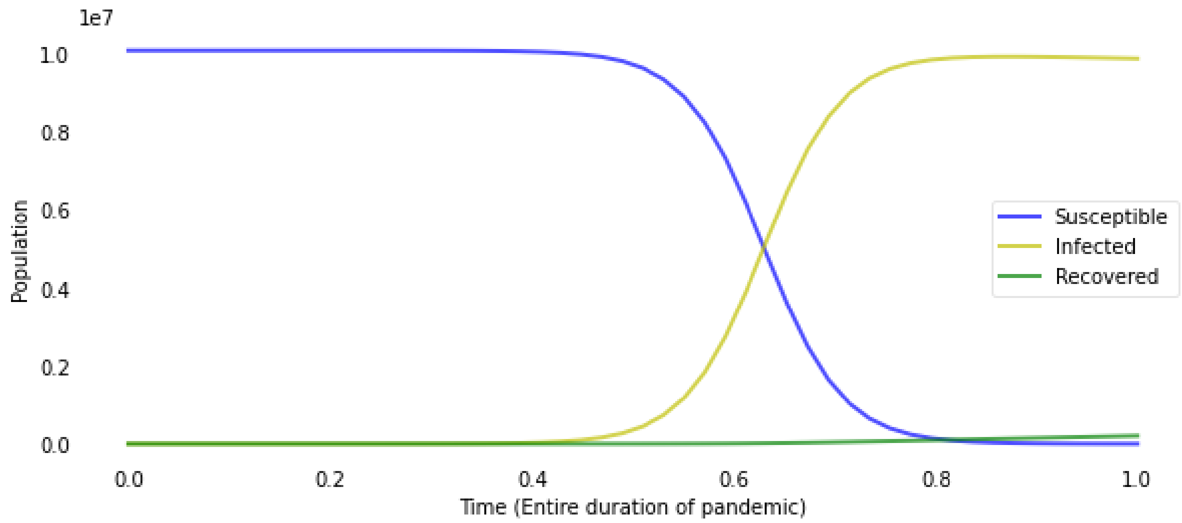

Figure 18: Simulations for United Arab Emirates' COVID-19 Pandemic of age group 25-30

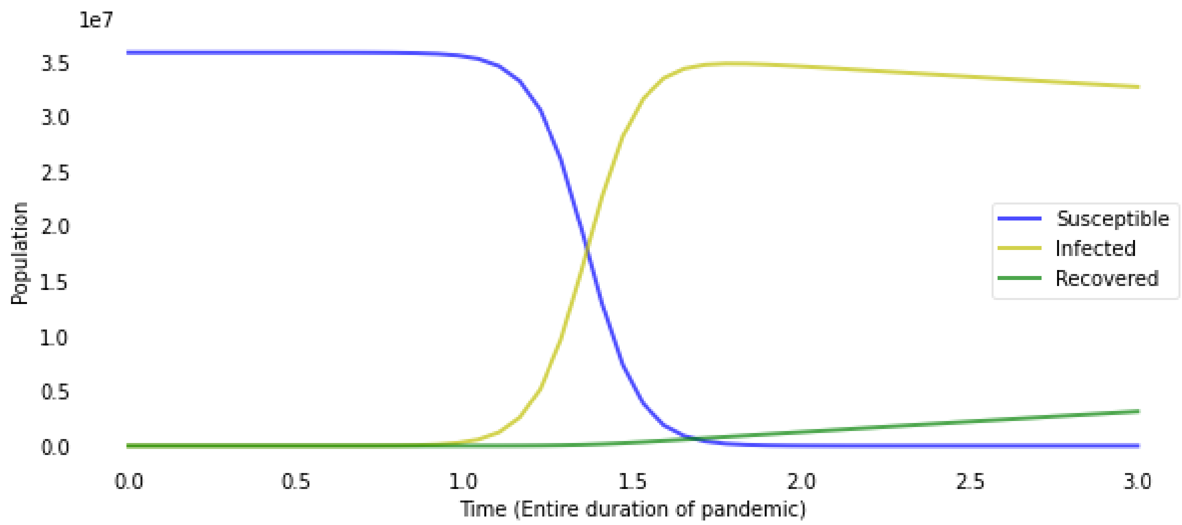

Figure 19: Simulations for Saudi Arabia's COVID-19 Pandemic of age group 25-30

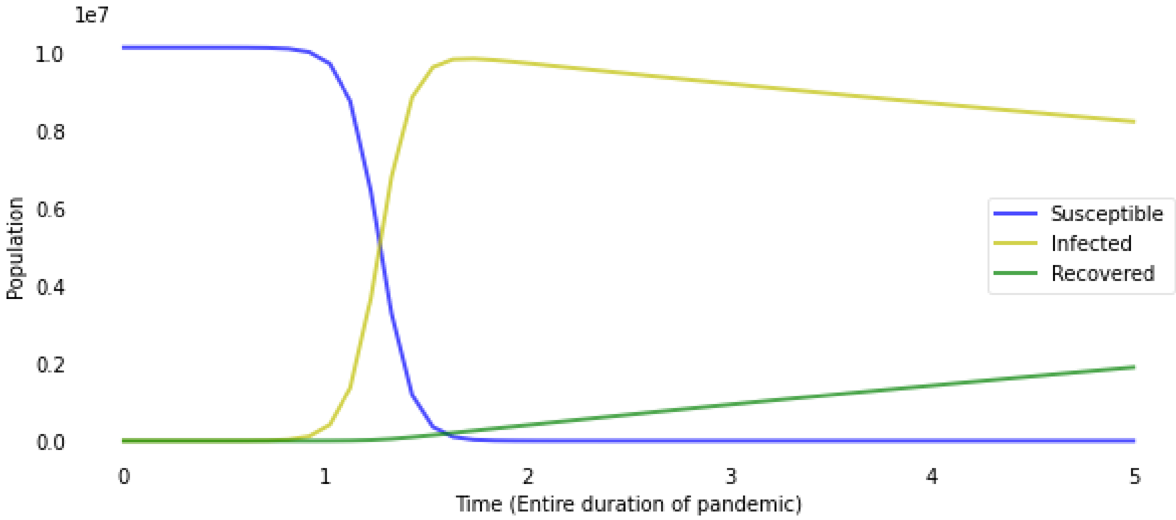

Figure 20: Simulations for Portugal's COVID-19 Pandemic of age group 25-30

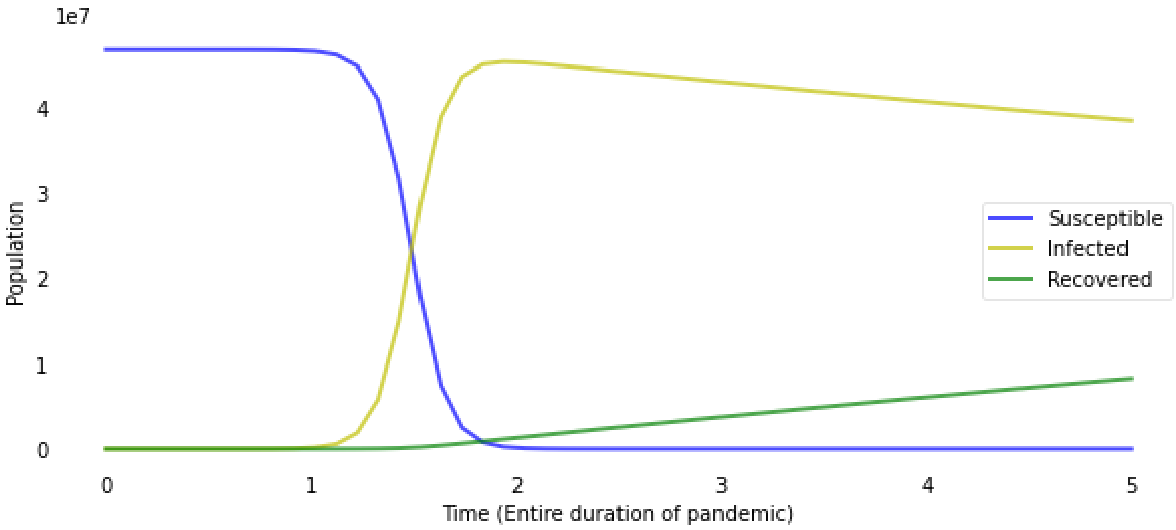

Figure 21: Simulations for Spain's COVID-19 Pandemic of age group 25-30

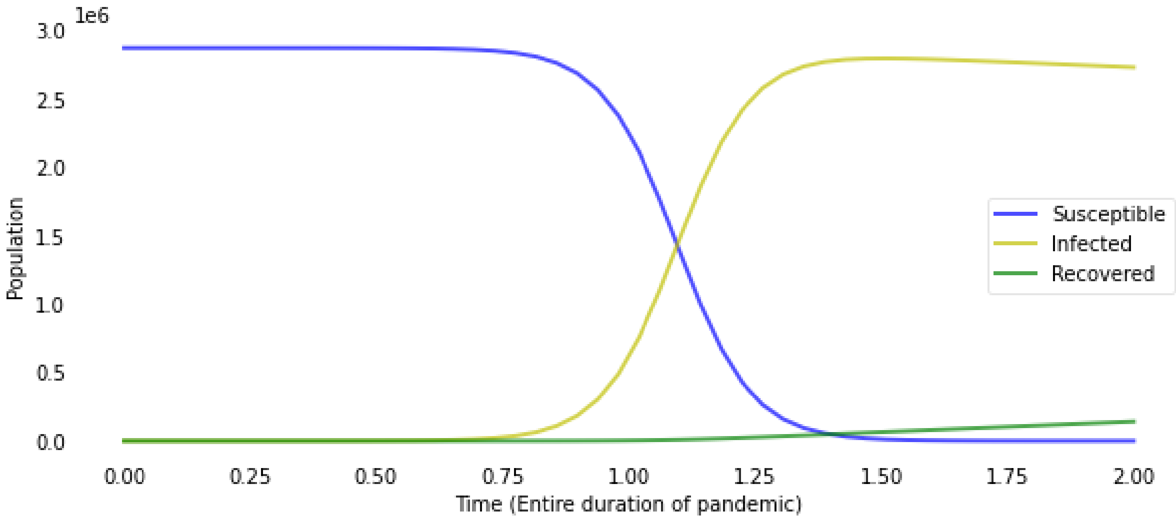

Figure 22: Simulations for Albania's COVID-19 Pandemic of age group 25-30

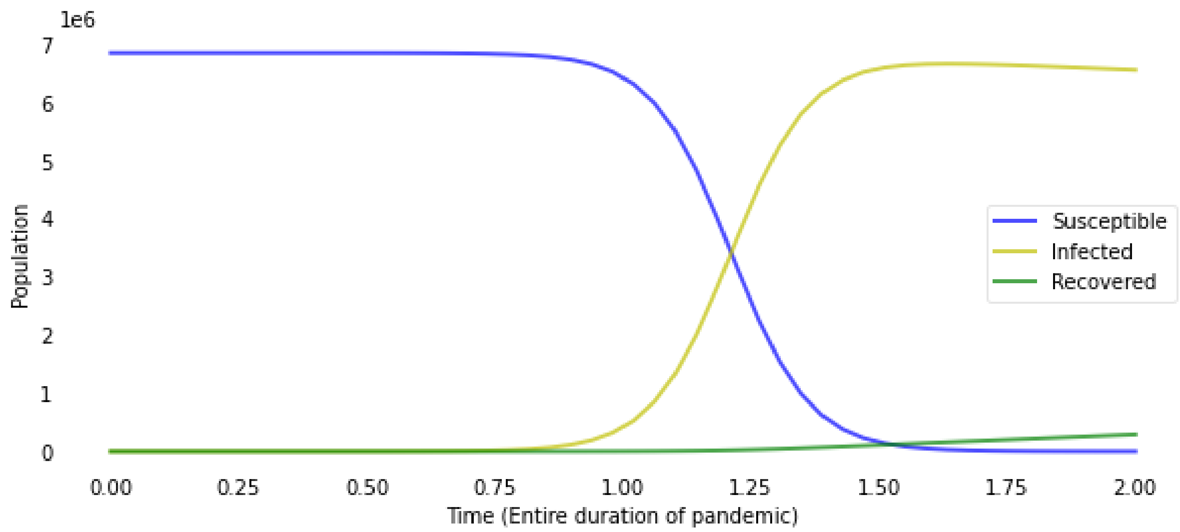

Figure 23: Simulations for Bulgaria's COVID-19 Pandemic of age group 25-30

Analysis

To determine whether lockdown measures were effective or not we must first revisit what it means for a nation to be under lockdown and what goals are often trying to be achieved as a result of being under lockdown. First and foremost, given the fact how a vaccine was not yet present in the uprise and growth of the pandemic, the most realistic way to stop the spread of a disease, is to remove all sorts of contact, a lockdown. This is because the less contacts there are the less likely someone else is forced to enter the Infected pool of the SIR model. Hence, it can be said that the purpose of a lockdown is to

1. Lower the transmission rate
2. Reduce the number of infections
3. Spreading the Infected community of the SIR model to a longer time frame in order to not overwhelm a nation's health services

Therefore, in accordance with the first point, when a lockdown is implemented the transmission rate in this case beta, is naturally expected to decrease which was reflected in our model as we changed beta from the value of 1 to 0.05. Secondly, our plotted graphs do not clearly indicate that the number of infections has been reduced, however we can deduce that the transmission rate is proportional to the number of infections, hence if the transmission rate decreases then so does the number of infections. Lastly, by looking at the graphs we may indeed determine that the infected community of the SIR model has elongated, this is evident by simply looking at the scales of the x axis of all graphs. For example, if we compare the two China simulations, figure 8 with beta equals to 1 and figure 16 with beta equals to 0.05, we can tell that the time scale went from originally ranging from 0 to 0.1 to now 0 to 2.5. Therefore, as there was increase in the scale of axis x representing time, we can say the 3 goals in which lockdowns try to achieve were met and hence we can say that lockdowns are effective.

Lastly, I would like to point the importance of constraining the disease from the initial point of time. To model this scenario, we increase the initial Infected population in the SIR model to 20% of the total population. This scenario assumes little to no government intervention hence taking a value of beta equals to 1.

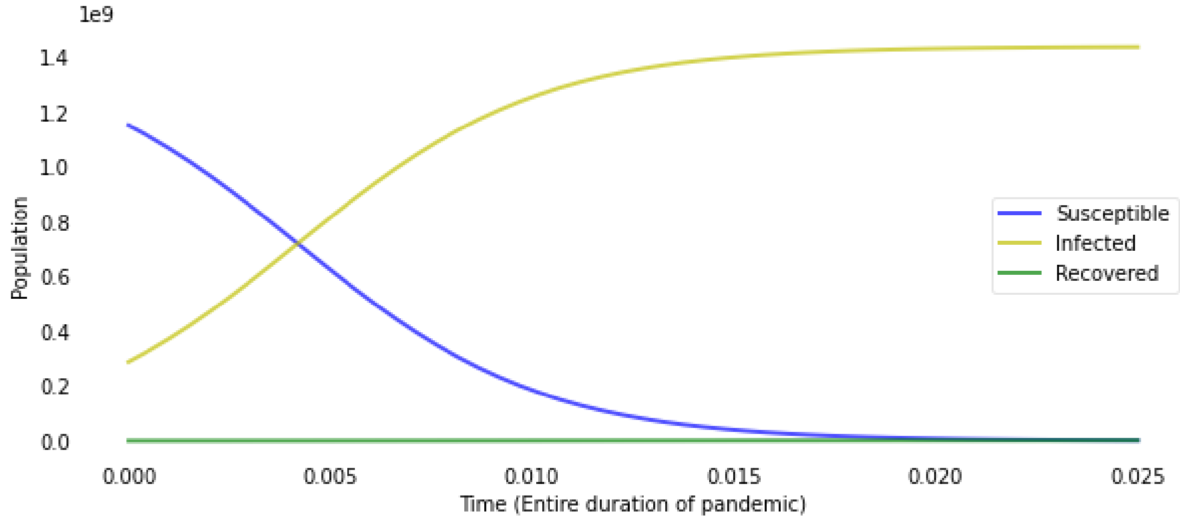

Figure 24: Simulation of China's COVID-19 pandemic if 20% of total population infected initially with beta equals to 1 of age-group 25-30

As shown from the graph above, in a very short time frame, the number of susceptible decreases largely and are transferred into the infected population. By having such a large population in the infected compartment of the SIR model in such a small period of time, would certainly overwhelm health services possibly resulting in large numbers of deaths. This also supports the fact that lockdown measures are indeed effective.

Evaluation

Although this paper was able to show that lockdown measures were effective, it was clear that the model provided was not dynamic enough to be able to widen the scope of this paper to apply this model to different scenarios. For example, consider the scenario where a nation is currently under lockdown. It is clear that during lockdown the social contacts individuals of different age groups have between each other is minimal. However, for this paper, the study used to construct the social age contact matrix is a reflection of one's daily interaction, it does not consider the scenario where the individuals are under the effects of lockdown. Hence wise, this paper is only able to simulate the COVID-19 pandemic of a country for the specified age group if no lockdown measures have been set in place. If we were to simulate the pandemic with lockdown measures in place this would create a problem as there is no clear parameter in my solution to correctly and accurately tackle this issue. This problem was overcome with the best efforts in trying to remain correct and accurate in this paper by working with the transmission rate (beta) and creating estimations of the transmission rate replicating the behaviour during lockdown, such that a high transmission rate suggests no lockdown measures in place, whilst a low transmission rate suggests a possible lockdown measure are to be set in place. This estimation can be said to be very inaccurate as there is no clear upper bound for "maximum" government intervention nor "minimum" government intervention, which is why when comparing the SIR model for the two beta values, the values had such a large discrepancy.

Secondly as mentioned before the excel function MMULT was used to make the social age contact matrix symmetric. It was very important that the matrix was symmetric as individuals of corresponding age groups reporting different values would not allow results to be achieved. Hence It was determined to use the MMULT operate as a result of by utilizing the MMULT function it might take into account the reports from each age groups maintain its high accuracy at the price of losing its integrity in its precision. Finding the mean of the arrays was not deemed suitable as results were found to possess a substantial variety in values compromising the accuracy of the matrix. It is also important to claim that the cultural aspect to evaluating the effectiveness of lockdown measures cannot be correctly quantified nor estimated, hence unable to comment on the cultural aspect to determining the effectiveness of lockdown measures. Lastly, given the definition of a lockdown, it can be said that the transmission rate, beta, does not best reflect the scenario of a lockdown, as there are no lower nor upper bounds to the transmission rate providing a correct idea of balancing the transmission rate appropriately.

Conclusion

As shown in this paper government intervening to locking down nations are effective in achieving the goals desired by the purpose of a lockdown. By considering the 3 goals of a lockdown mentioned in the analysis, once a lockdown is enforced the transmission rate in this case beta, is of course expected to decrease. This was mirrored in our model as we correctly adjusted to modify beta from the value of 1 to 0.05. Secondly, our previously shown graphs don't clearly indicate that the amount of infections has been reduced, but we are able to deduce that the transmission rate is proportional to the number of infections, thus if the transmission rate decreases then so will the number of infections. Lastly, by inspecting the graphs we could verify that the infected community of the SIR model has elongated, this is often evident by merely viewing the scales of the x axis of all graphs. For example, if one were to compare the 2 China simulations, figure 8 with beta equals to 1 and figure 16 with beta equals to 0.05, we can tell that the time scale duration went from originally starting from 0 to 0.1 to currently 0 to 2.5. Therefore, as there was increase within the scale of axis x representing time, we can say the 3 goals during which lockdowns attempt to accomplish were met and thus we can say that lockdowns are effective. It was also noted that governing powers should act immediately when such outbreak of a disease occurs, as it was shown in the results that having a large initial population in the infection compartment of the SIR model would prove to be overwhelming for the health services industry.

I would also like to stress the importance of the social age contact matrix in this paper, this is because given the dynamics of a disease, in which social contacts between individuals are one of the main ways a disease spreads and infects, hence the use of the social age contact matrix made the results more relevant and specific to the different age groups.

It was initially mentioned that culture may have an impact on the spread of the disease as different cultures have different customs and traditions. For example, it was noted that it is very common in many countries in Asia such as Japan for people to wear face covering if the individual is under the influence of influenza. In addition, in Japanese culture it is a social norm for women to wear face masks if they are out in public without applying makeup. The habit and social norm of wearing face coverings should in theory lower the transmission rate, beta, however this paper was not explicitly able to prove that these cultural norms and traditions had a concrete impact on simulating the pandemic for such countries. The transmission rate, beta, was quite tough to calibrate and to be estimated into an appropriate value to accommodate for the correct scenario, hence it can be concluded that there is no concrete evidence that cultural traditions such wearing face coverings when the individual is under the influence of influenza has a direct effect in evaluating the effectiveness of lockdown measures. However, through manipulating the transmission rate, beta, this paper was able to show that lockdown measures are indeed effective.

Appendix

Interim Log

Email #1 – 02/09/2021

Emailed Dr. Adam Barrett regarding selection of project

Meeting #1 - 04/10/2021

Introductory meeting, discussed possibilities of project and useful resources

Meeting #2 - 18/10/2021

Discussed what should be included in a proposal and examples of good proposals for shown. Proposal had not been completed by then as the scope of the project was still being questioned.

Email #2 – 26/10/2021

Proposal submitted

Email #3 – 28/10/2021

Feedback for proposal received

Meeting #3 – 29/04/2022

After a long time of figuring out the age contact social matrix, the final solution was presented to Dr. Barrett. Dr. Barrett then informed me that the matrix should be symmetric and I left the meeting knowing what was needed to be done.

Works Cited List

[1]Henderson, Sarah MooreReviewed by Emily. "History of COVID-19." News, 28 Sept. 2021, https://www.news-medical.net/health/History-of-COVID-19.aspx.
[2] "Coronavirus Cases:" Worldometer, https://www.worldometers.info/coronavirus/.
[3] "Worldometer COVID-19 Data." *Worldometer*, https://www.worldometers.info/coronavirus/about/.
[4] Naoki Y and George B, "Apparent difference in fatalities between Central Europe and East Asia due to SARS-COV-2 and COVID-19: Four hypothesis for possible explanation" PMC US National Library of Medicine National Institute of Health, 05 August 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7403102/
[5] Naoki Y and George B, "Apparent difference in fatalities between Central Europe and East Asia due to SARS-COV-2 and COVID-19: Four hypothesis for possible explanation" PMC US National Library of Medicine National Institute of Health, 05 August 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7403102/
[6] "Zoonoses." *World Health Organization*, World Health Organization, https://www.who.int/news-room/fact-sheets/detail/zoonoses.
[7] Naoki Y and George B, "Apparent difference in fatalities between Central Europe and East Asia due to SARS-COV-2 and COVID-19: Four hypothesis for possible explanation" PMC US National Library of Medicine National Institute of Health, 05 August 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7403102/
[8] Naoki Y and George B, "Apparent difference in fatalities between Central Europe and East Asia due to SARS-COV-2 and COVID-19: Four hypothesis for possible explanation" PMC US National Library of Medicine National Institute of Health, 05 August 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7403102/
[9] The Chartered Institute For IT, "BCS, The Chartered Institute For IT, Code of Conduct for BCS Members", BCS The Chartered Institute for IT, 09 June 2021, https://www.bcs.org/media/2211/bcs-code-of-conduct.pdf
[10] The Chartered Institute For IT, "BCS, The Chartered Institute For IT, Code of Conduct for BCS Members", BCS The Chartered Institute for IT, 09 June 2021, https://www.bcs.org/media/2211/bcs-code-of-conduct.pdf
[11] The Chartered Institute For IT, "BCS, The Chartered Institute For IT, Code of Conduct for BCS Members", BCS The Chartered Institute for IT, 09 June 2021, https://www.bcs.org/media/2211/bcs-code-of-conduct.pdf
[12] The Chartered Institute For IT, "BCS, The Chartered Institute For IT, Code of Conduct for BCS Members", BCS The Chartered Institute for IT, 09 June 2021, https://www.bcs.org/media/2211/bcs-code-of-conduct.pdf
[13] The Chartered Institute For IT, "BCS, The Chartered Institute For IT, Code of Conduct for BCS Members", BCS The Chartered Institute for IT, 09 June 2021, https://www.bcs.org/media/2211/bcs-code-of-conduct.pdf
[14] "Worldometer COVID-19 Data." *Worldometer*, https://www.worldometers.info/coronavirus/about/.
[15] "Worldometer COVID-19 Data." *Worldometer*, https://www.worldometers.info/coronavirus/about/. [16] William Ogilvy Kermack and Anderson Gray McKendrick, "A contribution to the mathematical theory of epidemics", The Royal Society Publishing, 01 August 1927, https://royalsocietypublishing.org/doi/10.1098/rspa.1927.0118
[17]Tolles J, Luong T, "Modelling Epidemics With Compartmental Models", JAMA, 27 May 2020, https://jamanetwork.com/journals/jama/fullarticle/2766672
[18]Tolles J, Luong T, "Modelling Epidemics With Compartmental Models", JAMA, 27 May 2020, https://jamanetwork.com/journals/jama/fullarticle/2766672
[19] "Herd Immunity and Covid-19 (Coronavirus): What You Need to Know." *Mayo Clinic*, Mayo Foundation for Medical Education and Research, 28 Aug. 2021, https://www.mayoclinic.org/diseases-conditions/coronavirus/in-depth/herd-immunity-and-coronavirus/art-20486808.
[20] Tolles J, Luong T, "Modelling Epidemics With Compartmental Models", JAMA, 27 May 2020, https://jamanetwork.com/journals/jama/fullarticle/2766672
[21] "NHS Test and Trace: What to Do If You Are Contacted." *GOV.UK*, https://www.gov.uk/guidance/nhs-test-and-trace-how-it-works#part-1-people-who-develop-symptoms-of-covid-19.
[22] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[23] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[24] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[25] Tolles J, Luong T, "Modelling Epidemics With Compartmental Models", JAMA, 27 May 2020, https://jamanetwork.com/journals/jama/fullarticle/2766672
[26] https://www.bbc.co.uk/news/health-54512034
[27] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[28] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[29 Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[30] Chikina, M., & Pegden, W. "Modeling strict age-targeted mitigation strategies for covid-19", PLOS ONE, 24 July 2020, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0236237

[31] Prem, K. & Cook, A. R. "Projecting social contact matrices in 152 countries using contact surveys and demographic data", *PLOS ONE, 12 September* 2017, https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1005697
[32] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[33] Vishaal Ram and Laura P.Schaposnik, "A modified age-structured SIR model for COVID-19 type viruses", Scientific Reports, 26 July 2021, https://www.nature.com/articles/s41598-021-94609-3
[34] "Projecting Contact Matrices in 177 Geographical Regions: An Update and Comparison with Empirical Data for the COVID-19 ERA." *CMMID Repository*, 13 Aug. 2020, https://cmmid.github.io/topics/covid19/synthetic-contact-matrices.html.
[35] *Final Report Summary - POLYMOD (Improving Public Health Policy ... - Europa*. https://cordis.europa.eu/project/id/502084/reporting.
[36] *Final Report Summary - POLYMOD (Improving Public Health Policy ... - Europa*. https://cordis.europa.eu/project/id/502084/reporting.
[37] *Final Report Summary - POLYMOD (Improving Public Health Policy ... - Europa*. https://cordis.europa.eu/project/id/502084/reporting.
[38] *Final Report Summary - POLYMOD (Improving Public Health Policy ... - Europa*. https://cordis.europa.eu/project/id/502084/reporting.
[39] *Final Report Summary - POLYMOD (Improving Public Health Policy ... - Europa*. https://cordis.europa.eu/project/id/502084/reporting.
[40] *Final Report Summary - POLYMOD (Improving Public Health Policy ... - Europa*. https://cordis.europa.eu/project/id/502084/reporting.
[41] "Projecting Contact Matrices in 177 Geographical Regions: An Update and Comparison with Empirical Data for the COVID-19 ERA." *CMMID Repository*, 13 Aug. 2020, https://cmmid.github.io/topics/covid19/synthetic-contact-matrices.html.