How wearing a mask and practicing physical (social) distancing is changing the shape of Covid-19 pandemics spread curve in Serbia?

System Dynamics analysis

By

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Contents

Abstract

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), a novel coronavirus, emerged in the city of Wuhan, Hubei, China, in early December 2019. During the time of writing these lines, numbers of infected people reached over 18 million and close to 700,000 deaths all over the globe.

On Feb 26, 2020, the rate of increase in cases became greater in the rest of the world than inside China. When it is about official response of the global community, March of 11th, 2020, World Health Organization declared a global pandemic that would rapidly spread to create the worst global public health crisis in the modern history. Two most important elements of the global society were put under the question: public health and resilience of the health systems around the globe. Efficient and effective response of the policy maker, next to early detection of the virus, presented itself as causal necessity in preserving public health in the scenario of pandemics.

Expression "flattening the curve" became main buzz all over the globe. Two scenarios came to the light – slowing down the disease via lockdown measures and more relax, as referred to "Swedish scenario" - Sweden decided not to impose a full lockdown on a public life or businesses to "flatten the curve" of the coronavirus epidemics, counting on developing "herd immunity" in shortest period possible, as an assumption.

Serbia was among those countries that introduced severe lock down measures, some even addressing them as "draconian". On 15th of the March, at 20:15 CET, the President of Serbia declared a nationwide state of emergency. Due to effects that pandemics imposed immediately on the global society, about 317,000 Serbian expats headed back to Serbia from all around the globe due to loss of an employment, crossing the border during the first two weeks of the lockdown. This have significantly increased the risk of an infection transmission as most of them came from the regions that have been seriously under the infection already. During May, in the wake of presidential election, measures have been loosened dramatically which resulted in actual peak of infection starting end of June. Agitated by feeling manipulated to believe that pandemics are over, Serbs went demonstrating on the streets breaking the rule of social distancing even more.

Policy of wearing masks and practicing social distancing is grounded as the main social strategy tool in dealing with infection spread through "Hammer and the dance" approach in managing the policy.

To study the problem through the effects of the measures imposed, the Autor considered epidemiological SEIR model (Susceptible-Exposed-Infected-Recovered), adding the stock of Deaths and inflow of expats using the system dynamics modelling

methodology. The model parameter values have been chosen to be within the range of plausible values for COVID-19, based on the information available throughout the pandemics. Beyond that, estimated parameters were fine-tuned to roughly match the stock of Infected and Death. For the purpose of model calibration in this case-study-research-analysis we used data series from first 137 days of pandemics scenario in Serbia.

Conclusion:

The results of this study indicate an inextricable link between implementation of combined policy of masks and social (physical) distancing and control of infection transmission, thus – total deaths caused by the infection. We compared and validated our policy scenarios results by the model developed at the Institute for Health Metrics and Evaluation at the University of Washington (IHME) by following their estimates for 1st of November and 1st of December. The result of our research implies that before the immunization is ready, the most effective way of protecting public health by slowing down the infection with respect to the ongoing SARS-CoV-2 is having in place the policy of masks and social distancing.

KEYWORDS: COVID-19, System Dynamics, SEIR, Serbia, social (physical) distance, mask, policy, infection transmission.

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This thesis was written under the emergency state in Serbia and the lock-down scenario. In extremely stressful times and under the challenging circumstances. But that was just peanuts.

I dedicate my thesis to true heroes of our time – to the health workers of the planet. Bow to the ground.

Thank you all for being the part of my journey.

Chapter 1 – Introduction

1.1. Background

1.1.1 Global pandemics of Coronavirus disease 2019, Covid-19, caused by virus SARS-CoV-2

A virus is a small parasite that cannot reproduce by itself. Once it infects a susceptible cell, however, a virus can direct the cell machinery to produce more viruses. Most viruses have either RNA or DNA as their genetic material. (Lodish H, 2000)

Intermittent outbreaks of infectious diseases have had profound and lasting effects on societies throughout history. Those events have powerfully shaped the economic, political, and social aspects of human civilization, with their effects often lasting for centuries. Epidemic outbreaks have defined some of the basic tenets of modern medicine, pushing the scientific community to develop principles of epidemiology, prevention, immunization, and antimicrobial treatments.(D, 2019)

Coronaviruses are enveloped RNA viruses that are distributed broadly among humans, other mammals, and birds and that cause respiratory, enteric, hepatic, and neurologic diseases.(L.Leibowitz†, 2011). Different from both MERS-CoV and SARS-CoV, 2019-nCoV is the seventh member of the family of coronaviruses that infect humans.(Na Zhu, 2020) Most people infected with the coronavirus 2 (SARS-CoV-2), will experience mild to moderate respiratory illness and recover without requiring special treatment. Older people, and those with underlying medical problems like cardiovascular disease, diabetes, chronic respiratory disease, and cancer are more likely to develop serious illness.("WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020," 2020)

Medical science is still coming with new and more specific findings about the virus and its general impact on human health; its future course is still highly unpredictable.

On 31st of the December 2019, the Wuhan Municipal Health Commission in Wuhan City, Hubei province, China, reported a cluster of 27 pneumonia cases (including seven severe cases) of unknown aetiology, with a common reported link to Wuhan's Huanan Seafood Wholesale Market, a wholesale fish and live animal market.(ECDC, 2020)

On 30th of the January 2020, the World Health Organization (WHO) declared this first outbreak of novel coronavirus a 'public health emergency of international concern.(ECDC, 2020)

It wasn't until March 11th, 2020, that the World Health Organization declared a global pandemic. (Organization, 2020) It seems that even the most experienced international public health experts did not anticipate that it would rapidly spread to create the worst global public health crisis "in the modern history". On the other hand, the question of global preparedness has been raised and it is speculated that there has been present a reluctance to make a decision like that. (Mackenzie, 2020)

Concluded with 1st of Jun 2020, 215 Countries and Territories around the world have reported a total of 6,162,516 confirmed cases of the coronavirus COVID- and a death toll of 371,037deaths. (wordlometers.info, 2020)

Two most important elements of the global society were put under the question: public health and resilience of the health systems around the globe. Efficient and effective response of the health system, next to early detection of the virus, present causal necessity in preserving public health in the scenario of pandemics. Following the development of the virus spread and the impact that made on the health system in Italy foremost, question that came to the light was 'how resilient and ready to act" health systems around the globe are? Are we capable as a global society of managing the crisis such as global pandemics in 21st century? Are we equipped and trained? What is our crisis response? Do we have a strategy in place? Following the spring of 2020 we have learned about how ready we have been in facing the pandemics. Expression "flattening the curve" became main buzz all over the globe. Two scenarios came to the light – slowing down the disease via lockdown measures and more relax, so called "Swedish scenario" as Sweden decided to not impose a full lockdown on public life or businesses to "flatten the curve" of the coronavirus epidemic.

Pharmaceutical interventions such as vaccination and anti-viral drugs are currently under development. In the short run, addressing the COVID-19 outbreak was critically dependable on the successful implementation of public health measures including social distancing, workplace modifications, disease surveillance, contact tracing, isolation, and quarantine.

Global health experts have been saying for years that another pandemic whose speed and severity rivalled those of the 1918 influenza epidemic was a matter not of "if" but of "when".(Gates, April 30, 2020)

1.1.2. Covid-19 in Serbia and nationwide state of emergency

In Serbia is a current outbreak of Coronavirus disease 2019 caused by SARS-CoV-2. On 6th of the March (10:00h), the first case was confirmed when a man who had been travelling in Hungary came back to the city of Subotica in Serbia and tested positive for the virus.(T. g. o. t. r. o. Serbia, 2020b)

On 15th of the March (18:00h), two more cases were confirmed. At 20:15 CET, the President of Serbia declared a nationwide state of emergency.("State of emergency declared throughout Serbia," 2020) Serbia closed its borders to all foreigners not living in Serbia, while Serbian citizens entering the country were required to self-quarantine for up to 28 days, or face criminal charges of three years in prison. All schools, faculties and kindergartens were also closed.(T. G. o. t. R. o. Serbia, 2020a)

Serbia's coronavirus state of emergency measures drew eyes of human rights groups. In Serbia – arguably the frontrunner among candidate countries to join the European Union – the necessity and the extent of the measures adopted remain rather debatable. What is perhaps more intriguing are not the measures themselves, but the way they were introduced.(Group, 2020)

General public was split between the necessity that rise out of the acknowledgment regarding the development of the devastation situation in Italy and the resistance toward the oppressing manner of using the presidential power as well as the way of introducing the measures to fight "the war against the virus" as it was very often referred to in public announcements. The Steering Committee of the Serbian Bar Association (AKS) considers that the state of emergency was introduced in the Republic of Serbia in an unconstitutional manner. They did not "contest the need to restrict the rights of individual citizens in order to effectively prevent the spread of the epidemic and protect the health and life of citizens, but at the same time, insists on the continued adherence to the Constitution by the executive authorities in deciding which, to what extent and how much the rights of each individual may be restricted."(Bjelotomic, 2020)

Because of the effects that pandemics imposed immediately on the global society, about 317,000 Serbian expats(Stojanovic, 2020) headed back to Serbia from all around the globe due to loss of an employment, crossing the border during the first two weeks of the lockdown. This have significantly increased the risk of an infection transmission as most of them came from the regions that have already been seriously under the infection and potentially presented itself as a serious strain on the health system of the developing country.

Trust that nation puts in the policy maker, next to the quality of the health care system and overall character of the risk response in the pandemics scenario, showed as a vital condition in effective implementation of the Covid-19 policies all around the world, not leaving Serbia behind.

Resilient and agile health systems showed as next crucial factor to sustain the strains that pandemics scenario can bring.

After the split of former Yugoslavia, Republic of Serbia, as well as other ex-Yugoslav countries, inherited Bismarck healthcare system model.(Roman Mužik, 2014) Health care system in Serbia is based on universal health coverage. Bismarck healthcare system model reflects publicly provided healthcare system financed through social healthcare insurance. National Health Insurance Fund (RZZO) of Serbia covers recurrent expenditure through input-based provider payments.(Roman Mužik, 2014)

In the last decade, healthcare in Serbia has been operated in the environment characteristic for the transition countries with limited financial resources and efforts have been made to create a healthcare system in line with European standards. (Vlahovic Z, 2010) Current funding based on the number of staff and beds does not motivate providers to improve efficacy, quality of care and health outcomes.(Stosić S, 2014) In its "Country Procurement Assessment Report on Serbia", the World Bank declared that the health sector is the epicentre of corruption in Serbia financing. The International Federation for Human Rights reports on several causes of corruption in health care.(Dickov, 2012)

Trend of the "brain outflow" is highly present in Serbian health sector. It is estimated that over 10,000 doctors left Serbia in the past 20 years.(BETA, 2018) This creates a vicious circle in a response to a trend. Medical personnel move abroad or switch to the private sector, where the pay and working conditions are far superior. Public health care systems, in turn, are struggling with less and less money and employees, but with longer and longer waiting lists. Lack of trained physicians, the quality of services rendered in medical sector and corruption present some out of many challenges that Serbian health care system is facing.

What has not been analysed yet officially, but is circulating in the society coming out as the experience from people that due to infection had an opportunity to experience the system, everybody agree about following: unsecure and afraid personnel, lack of systematic approach to the patients, late response, big gap between what has been communicated day in and out on the medias by the state officials when it is about preparedness and what people met on the ground. And one more thing – immense sacrifice of some of those on the front line.

Serbia has fewer doctors and technicians than the European average. EU countries have 333 doctors per 100,000 people, and Serbia 285, according to the latest comparable data from the BATUT Institute. Serbia has 554 nurses and technicians per 100,000 people, while there are 825 in the EU.(SERBIA & 2018), (WHO, 2020)

Conclusion is that pandemic of Covid-19 imposed significant and obvious risk on already strained Serbian health care system. Lack of the capacities, lack of the human resources and trained human resources, unpreparedness for the scenario of pandemics are just some of the problems.

How to get more time while preparing strategy to confront the biggest public health treat in the last 100 years? By every and only mean available immediately – maximizing social distancing and regular use of the masks as proposed by epidemiologist where governing apparatus went step further and declared a nationwide state of emergency.

1.2. Problem definition and research challenges

1.2.1. Problem definition

After the 51 days of the lock-down, Serbian government denounced the emergency state 6th of May and in the wake of the upcoming parliament elections loosened up social's measures introduced, one could say dramatically. During June big social public and private gatherings has been allowed, such as football match with over 25,000 supporters, tennis tournament and many graduation and wedding parties. General public understood loosening measures as the pandemic is over.

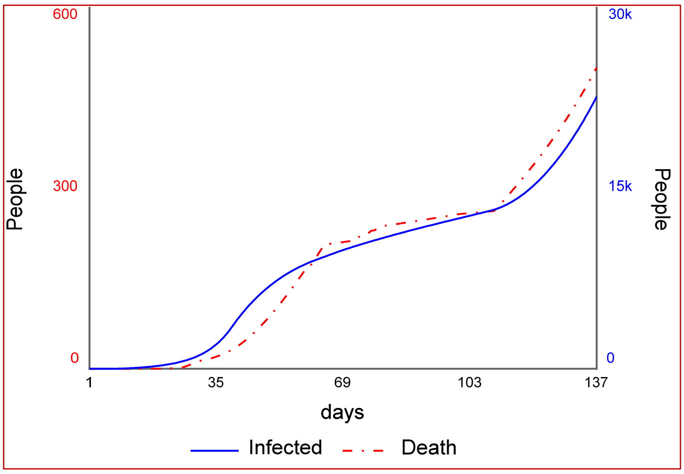


Figure 1: Effect of pandemics in Serbia in first 137 days, data series of the time horizon of the research

That resulted in significant increase of the contacts and obvious peak in infection. This time the one that have been prevented during a lock-down and one that possibly could have been prevented by managing loosening policy more carefully. During July Serbia experienced it first actual pandemic wave that draw attention of the overall public back to the pandemics. The government started preparing public for possible second lock-down, but this time the response of general public, agitated as a consequence of losing trust in a policy maker and the medical risk team, resulted in local demonstrations in Belgrade that very fast spread all over the Serbia. Instead of the social distance the opposite happened.

Time horizon of data series used to build a model and validate the structure is 137 days since the patient "zero" (6th of March trough 20th of July 2020).

Following the development of the situation in Serbia, more questions have been raised about the strategy of the policy management and if the collateral in the cases that resulted in deaths as well in people getting infected and carrying plausibly permanent long term damages to their health could have been avoided and how can be avoided by more responsible and careful policy management. The concern that follows is what is the best approach that general public can use to maximize prevention against the infection.

Concluded with 2nd of August 2020, Serbia have total of 25,882 cases of Corona virus and 582 confirmed deaths from Covid-19 and mortality ratio 2,25% based on the official sources available.

1.2.2. Research challenges

Prevailing data issues in the time of COVID-19 followed the Autor during the research. Relevant, and accurate data about COVID-19 and the resources the country has in the fight is important. The speed and timeliness of how such is released is equally critical. And not to forget the general principle of transparency.(Team, 2020)

Data availability and transparency for Serbia:

- *Data availability*. The number of the expats that came back to Serbia due to outbreak of SARS-CoV-2 is rather vague. This information is still available only to the highest officials and when communicated to general public it was in the range of "40,000" in first couple of days to "approx. 317,000"(Stojanovic, 2020) people following the first two weeks of emergency state.

- *Data transparency*. Number of diseased due to infection of SARS-CoV-2 is rather under the question, compared to the official data. In the certain part of Serbia people raised issue regarding their relatives being buried in tin and sealed coffins, after getting admitted to the hospital due to symptoms that could have been symptoms of Covid - 19, but their names never officially found its place on the Covid diseased lists, thus not in the official counts. These cases are allegedly under the investigation.

<u>*Assessment of the epidemiological parameters of SARS-CoV-2*</u>

- The Autor elaborated this in the part about the choice of the parameters introduced in the model.

In regards of the general data validation regarding Covid-19 it is important to include the discussion about data accuracy. Taking in consideration that the number of real infected people globally is much higher than reported due to testing limitation (Holland, 2020, JUNE 25) and that is plausible assumption that Covid-19 related deaths can be questionable (Jovanovic, 2020, 22nd June) and not just in Serbia (News, 2020, 3rd August) it is important to keep in mind that for the purpose of this study was necessary estimating values as well as assuming certain elements.

Regarding the data accuracy, CDC states:

> *"CDC tracks COVID-19 illnesses, hospitalizations, and deaths to monitor trends, detect where outbreaks are occurring, and determine whether public health measures are working. However, counting exact numbers of COVID-19 cases is not possible because COVID-19 can cause mild illness, symptoms might not appear immediately, there are delays in reporting and testing, not everyone who is infected gets tested or seeks medical care, and there are differences in how completely states and territories report their cases."(CDC, 2020, 13th July)*

1.3. Research Objectives and Research Question

In accordance with the problem definition in the previous section there are two objectives of this case study research that the Autor is interested in exploring by using System Dynamics methodology:

1st Explore and understand the dynamics of the Covid-19 spread in Serbia following available data series in the first 137 days since the patient "zero";

2nd Scenario analysis of "hammer and a dance" policy strategy focused on "flattening the curve" as a proposition for future policy management by keeping in mind masks and physical distancing measures.

To fulfil the stated research objectives, the following research question were formulated for the project to answer:

> *1. How wearing a mask and practicing physical (social) distancing is changing the shape of Covid-19 pandemics spread curve in Serbia?*

1.4. Methodology Choice and Research Strategy

The method employed in this study is quantitative system dynamics modelling and simulation-based analysis. Mathematical models of infectious diseases have a long history of aiding decision makers from the first Kermack-McKendrick model in the 1920’s which serves as the building block for modelling epidemics.(Kermack & McKendrick, 1991)

The systems modelling methodology of system dynamics is well suited to address the dynamic complexity that characterizes many public health issues and it is argued that challenges of dynamic complexity in public health may be effectively addressed with the systems modelling methodology of system dynamics.(Homer & Hirsch, 2006) The methodology involves development of causal diagrams and policy-oriented computer simulation models, (Homer & Hirsch, 2006) by using the necessary structure of stocks and flows as fundaments to mapping the dynamics of complex systems. (Sterman, 2000)

Further, System Dynamics has been defined as “the use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behaviour”. (Richardson, 2011) As a dynamic tool for scenario analysis, System Dynamics models allow epidemiologists to do a set of what-if analyses, with the purpose of assessing the system's behaviour under various conditions, and afterwards, to compare and evaluate the results of alternative sanitary policies. (Bagni, Berchi, & Cariello, 2002) The ability to predict future epidemic threats, both in real as well as digital worlds, and to develop effective containment strategies heavily leans on the availability of reliable infection spreading models.(Dadlani, Muthukrishnan, Murugan, & Kim, 2014)

Research strategy used to achieve the objectives of this research was using the generalized epidemiological SEIR (Susceptible-Exposed-Infected-Recovered) model inspired foremost by work of Tom Fiddaman (Tom Fiddaman, 2020), Kim Warren (Kim Warren, 2020) and Bob Eberlein (iseesystems, 2020b) during the outbreak of Covid -19 pandemics in spring of 2020. Further, inflow of expats (317,000 of them) has been added as well as the stock of Death and additional structure.

Following the guidance of modelling principles such as iteration of data collection trough continuous literature review, model building, simulation, analysis, validation and documentation (Sterman, 2000) were undertaken throughout the project. The SD model was built and used in the Stella Architect software. (iseesystems, 2020a)

1.5. Data Collection and Data Analysis

The background of the quantitative and qualitative data for the constructed system dynamics model was obtained from the extensive analysis mostly of the documents, literature and online sources related to the defined problem and iteratively as we are in the midst of the global pandemics and we are in the middle of the learning loop.

Data sources often used in SD studies include documented numerical data, documented written data and mental data present in the minds of people operating within the system being studied (Forrester, 1992*)*.

> *"System dynamics depends heavily upon quantitative data to generate feedback models. Qualitative data and their analysis also have a central role to play at all levels of the modelling process. Although the classic literature on system dynamics strongly supports this argument, the protocols to incorporate this information during the modelling process are not detailed by the most influential authors. Data-gathering techniques such as interviews and focus groups, and qualitative data analysis techniques such as grounded theory methodology and ethnographic decision models could have a strong, critical role in rigorous system dynamics efforts*"(Luis Felipe Luna-Reyes, 2004)

The model parameter values have been chosen to be within the range of plausible values for COVID-19, based on the information available throughout the pandemics. The data series of the new cases and mortality are found from the daily official reports of Serbian government (T. g. o. t. r. o. Serbia, 2020b). Beyond that, estimated parameters were fine-tuned to give simulated Infected and Death counts that roughly match (within the margin of uncertainty) the number of Serbian deaths through July 20, 2020 (as reported by (T. g. o. t. r. o. Serbia, 2020b) and to roughly match the infected in the same period. In addition, the projected deaths you see from this model until November 1st with the trajectories from middle of July, 2020 are with the range predicted by the model developed at the Institute for Health Metrics and Evaluation at the University of Washington, (Washington., 2020)

Overall literature review and data collection had focuses on:

- Epidemiological data and information about SARS-CoV-2 and the development of the pandemics through medical research papers and literature;

- Application of the System Dynamics methodology for the purpose of studying the dynamics of outbreak of the epidemics, as well as application in the case of SARS-CoV-2 through the literature, scientific papers and existing epidemiological models;

- Serbian data series, statistics and policy responses through official data sources and statistic books, media;

- Cross-checking and following the policy response all around the world via media, scientific papers and online “meet-ups” that gathered people from all meridians;

It has been (and still is!) rather encouraging to witness the global cooperation of the scientists from all around the world. The outbreak has prompted an explosion of research on the coronavirus. One can conclude that what shines through as a beacon of hope in ongoing fights against the corona virus is an act of humanity that we witness as sharing knowledge and joint efforts in science and in help and assistance that have been activated cross borders around the globe.

Given the fact the health science is still learning about the virus, data validation through the model building and system analysis was a part of each iterative learning cycle.

Chapter 2 - Model Description and structure validation

2.1 Model overview, parameters and main feedback loops explained

As it was mentioned in the previous chapter the widely used epidemiological model is the SIR model developed by Kermack and McKendric at the beginning of the 20th century (Kermack & McKendrick, 1991).The model contains three stocks, Susceptible, Infected and Recovered, thus known as – SIR model.

The dynamics of infectious disease modelling is grounded in the idea that the rate of infections is affected by susceptible of the population and by the fraction of infected people. (Sterman, 2000) The higher the fraction of infected, the higher the likelihood is for a susceptible to meet an infected and thus get infected.

Characteristic for the virus SARS-CoV-2 is that before people get infected they are exposed and for the period of time either not infectious (Lai et al., 2020) (testing negative on Covid-19 before the onset of the symptoms) or they stay asymptomatic the whole time of infection, or - there is infectiousness before the onset of symptoms. All this stated increases the risk of transmission drastically and impose a big problem for allocating proper policies in prevention. This reinforcing loop of infection depletes the stock of susceptible. The exponential growth of infectious diseases will be decreased when there are only a little amount of susceptible left causing an S-shaped behaviour. The stock of infected decreases by recovery in S(E)IR model.

In the following page we will offer contextual explanation of the SIR model and then we will progress on the SEIR(D) model with additional structures that is used for achieving the objectives of this research.

For the purpose of this case study research analysis we used data series from first 137 days of pandemics scenario in Serbia. All model equations are listed in appendix A.

2.1.1. SIR model

SIR model (Susceptible-Infected-Recovered) means that the total population is divided in three stocks. This model assumes homogeneous population, indefinite acquired immunity as the population moves from infected to recovered, as well as that the rate under which individuals interact is the same. All of these assumptions can be relaxed(Sterman, 2000) for the purpose of modelling and studying different aspects of the phenomenon of virus infection and its outbreak among any population in general. The dynamics of this model are characterized by 3 main loops: one R reinforcing loop of *Contagion* and two B Balancing loops*, Depletion* and *Recovery.*

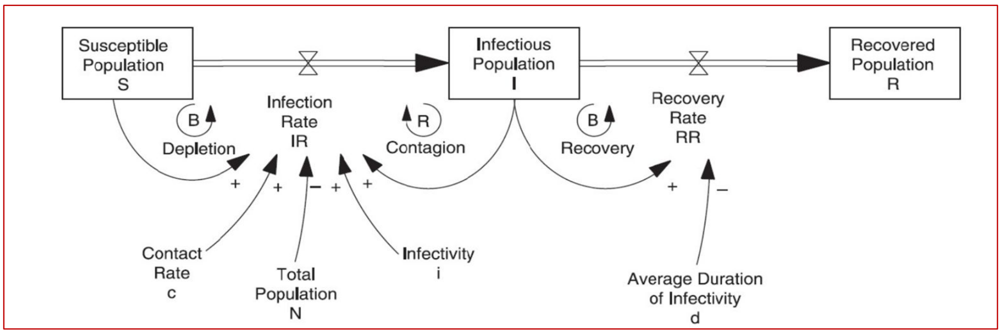


Figure 2: Structure of the SIR epidemic model, people remain infectious an sick for limited time, then recover and develop immunity (Sterman, 2000)

The positive*,*

R reinforcing feedback loop of Contagion

is driven by the contacts rate that susceptible have with infected people that is resulting in increasing the stock of *Infected* through the *infection rate.*

This loop is strong as long as there are susceptible to get infected. The *susceptible* population is reduced by the *infecting,* *by the loop of Depletion, which is B balancing loop*

that over time crates behaviour graphically presented as S-shaped. This means that infection is progressing as long as there are susceptible people to contract an infection. All mentioned under the certain conditions which is presented with the contact rate and infectivity. The assumption that rise out of the structure is that by influencing the contact rate as social category, we could change the infection rate over time, thus the dynamics of the disease spread, (Sterman, 2000) while infectivity is epidemiological category, therefore less agile.

The assumption that people recover and creates permanent immunity creates one more feedback, the negative,

B balancing, Recovery loop

that is defined by the stock of Infected individuals and the duration period of the infection. In the real life more realistic model includes the stock of Death and mortality rate over time as de facto we know that Covid-19 is affecting the population trough mortality rate as well. Therefore, our model took that in consideration. Thus, the total population N will be decreased by the number of those that have died under the exposure to the virus. On the other note, the stock of *Susceptible will increase* by *the inflow* of the *expats*,

*Susceptible(t - dt) + (expats - exposing) * dt*

INIT Susceptible = INIT_population-(Infected+Exposed+Recovered-Death)

UNIT: People

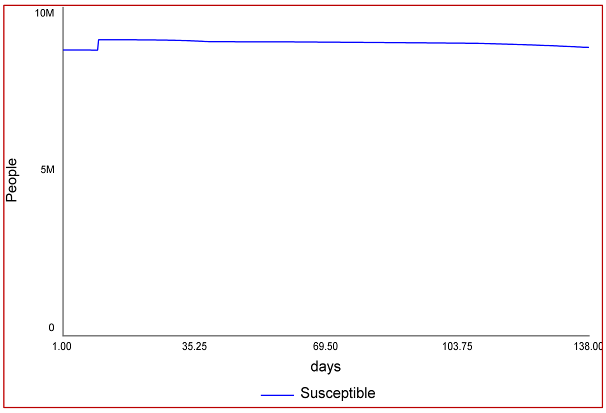


Figure 3: Stock of Susceptible

2.1.2. SEIR(D) model and Covid-19 parameters

The SEIR (Susceptible–Exposed–Infectious–Recovered) is extended SIR model, modified by adding the stock of Exposed and the flow of the rate of infecting. For the case of Covid-19 Exposed refers to those that are infected but asymptomatic, before the onset of the symptoms (Lai et al., 2020), as we explained earlier. The infecting moves people from susceptible category to those that have been exposed, but asymptomatic.

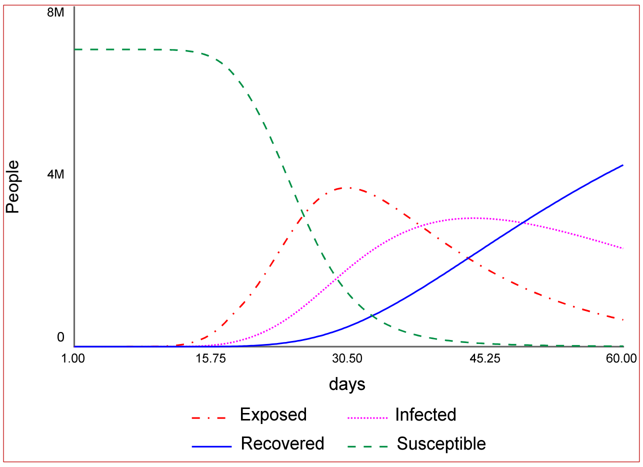


Figure 4: Conceptual behaviour of SEIR

For people to show symptoms the model is introducing incubation time, which is time taken for the symptoms to show, and then person is moving from Exposed to Infected trough the flow of *advancing*. For the purpose of our model we assumed, (Kolifarhood et al., 2020) and after thorough review of the numerous papers,

constant average incubation period of 10 days,

avg disease duration of 9 days (in the case of mortality)

and recovery period of 21 days

In order to try to simulate more realistic behaviour, as mentioned, we added the stock of Death. This brought a challenge. During an epidemic of a potentially fatal disease, it is important that the case fatality ratio be well estimated. The case fatality ratio (CFR) is a measure of the severity of a disease and is defined as the proportion of cases of a specified disease or condition which are fatal within a specified time.(G. H. O. G. WHO, 2020) Once an epidemic has ended, it is calculated with the formula:

CFR=Deaths/Totally infected

Coronavirus (COVID-19) CFR or *mortality rate* as it is often used in SD models is rather still under the estimation as in order to assess the global average of mortality rate scientist needs to know to total number of infected population and respectively *to leverage it against the mortality rate locally, nationally and then – globally.*

As of today, reported category regarding the people that dies is expressed as number of diseased relative to number of infected, which is respectively relative to the number of total tested people. Therefore, countries that have been effective with testing efficiently can have more accurate estimation of infected, those that have been infected (anti-body tests), estimating potentially total percentage of population that have been infected with SARS-CoV-2. Still, estimates of the severity of coronavirus disease, as well as any other novel disease(Ghani et al., 2005) are work in progress and throughout medical papers are advised to take with precaution epidemiological parameters (Battegay Manuela, 2020). Unreported cases would have the effect of decreasing the denominator and inflating the CFR above its real value. What we have learned as of now is that we need more robust effective tests both for testing infected, anti-bodies presence in the blood and efficient global testing in order to understand the severity of Covid-19 pandemics.

In our model, we used,

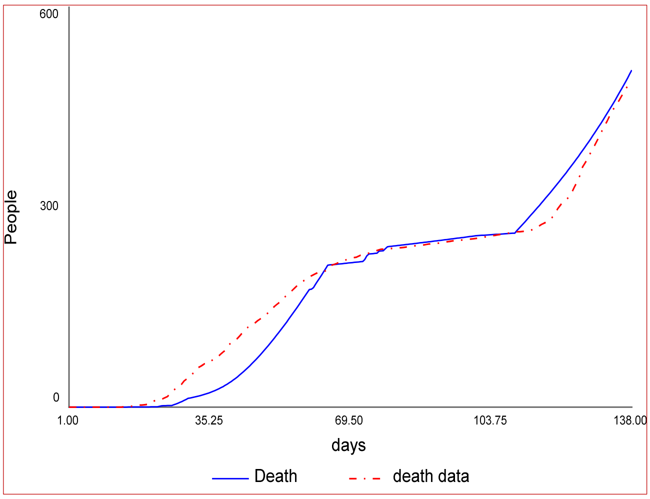


Figure 5: Comparative graph of the stock of Death with reference mode

avg mortality rate of 0.0128

relative to the number of serious cases of infected

UNIT: dmnl

*serious cases = Infected*fraction_serious_all_time*

UNIT: People

fine-tuned to give simulated death counts that roughly match (within the margin of uncertainty) the number of deaths through July 20, 2020 (137 days since patient zero which is the length of our data series).

OUTFLOWS:

*(serious_cases*increased_effectiveness_of_medical_treatment_of_critically_ill_patients*mortality_rate)/"sickness_duration*"*

UNITS: People/Day

2.1.3. The notorious R0 and R

Infectivity is the ability of the virus to infect hosts given that the host is exposed to the source of the infection. The higher the contact rate or the greater the infectivity of the disease, the stronger the reinforcing positive loop of the infection will be.(Sterman, 2000).

The basic reproduction number (R0), is an epidemiologic metric used to describe the contagiousness or transmissibility of infectious agents. "R naught," is intended to be an indicator of the contagiousness or transmissibility of infectious and parasitic agents.(Delamater, Street, Leslie, Yang, & Jacobsen, 2019) R0 was originally called the basic case reproduction rate by George MacDonald in the epidemiology literature in the 1950s (Dietz, 1993; Fine, 1993; Macdonald, 1957)

> *"R_0 is affected by numerous biological, socio-behavioural, and environmental factors that govern pathogen transmission and, therefore, is usually estimated with various types of complex mathematical models, which make R_0 easily misrepresented, misinterpreted, and misapplied. R_0 is not a biological constant for a pathogen, a rate over time, or a measure of disease severity, and R_0 cannot be modified through vaccination campaigns. R_0 is rarely measured directly, and modelled R_0 values are dependent on model structures and assumptions. Some R_0 values reported in the scientific literature are likely obsolete. R_0 must be estimated, reported, and applied with great caution because this basic metric is far from simple."*(Delamater et al., 2019)

The R0 was first time introduced in the field of demography and in the hands of experts, R0 can be a valuable concept. However, the process of defining, calculating, interpreting, and applying R0 is far from straightforward and responding interpretation in relation to infectious disease dynamics masks the complicated nature of this metric.(Delamater et al., 2019)

> *"For any given infectious agent, the scientific literature might present numerous different R0 values. Estimations of the R0 value are often calculated as a function of 3 primary parameters—the duration of contagiousness after a person becomes infected, the likelihood of infection per contact between a susceptible person and an infectious person or vector, and the contact rate—along with additional parameters that can be added to describe more complex cycles of transmission."(Delamater et al., 2019)*

Therefore, the understanding of the terminology must be established: while the R0 present general and static metrics of the severity of the disease and it does not change over the course of the outbreak of the virus, but rather follow the virus as one of its main epidemiological characteristics and includes the assumption of a completely susceptible population(Delamater et al., 2019), R is, on the other hand, the metric that is dynamic and it is changing over time following the dynamics of the effect that the virus have on the population and it is more suitable for modelling purposes in order to present the changes in the infectivity and it does not assume complete susceptibility of the population therefore, can be estimated with populations having immune members.(Delamater et al., 2019)

Some of the existing data on R0 states that out of 21 estimates for the basic reproduction number ranging from 1.9 to 6.5, 13 were between 2.0 and 3.0 (Park, Cook, Lim, Sun, & Dickens, 2020), an Italian outbreak may range from 2.43 to 3.10 (MarcoD'Arienzoa, 2020) and of the most recent suggesting 5.7 regarding the situation in China (Steven Sanche1, 2020).

Trough studying the SD models of Covid-19 it was brought to the Author's knowledge how the colleagues modellers addressed the challenge of infectivity in conceptual models. Tom Fiddaman from Ventana Systems (Tom Fiddaman, 2020) in his model presented infectivity (R0:3.3) as constant by plugging the metrics into the transmission rate that further fed the inflow of *infection*. Bob Eberlein from Iseesystems (iseesystems, 2020b) used *infection rate* as a constant (0.025) that defined the inflow of *becoming exposed* with the *contact rate with infected* .

In our model we fine-tuned *Infectivity as constant* to give simulated counts that roughly match (within the margin of uncertainty) the value of the stock of Infected, by mostly calibrating the inflow of *exposed*:

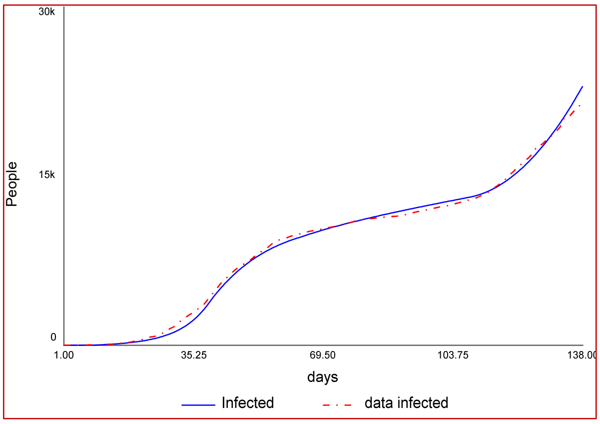


Figure 6: Comparative graph of the stock of Infected with reference mode

Infectivity = 0.045, UNIT: touch/person

INFLOW: infecting=

*(Exposed/incubation_time)**

testing_adjustment, UNITS: People/Day

INFLOW: exposed =

(IF TIME <39 THEN

*(IF TIME <10 THEN risky_contacts*infectivity*severity_spread_adjustment ELSE risky_contacts*infectivity*severity_spread_adjustment*"\"mask_on\"_policy_early_day_adjustment")*

ELSE

*(risky_contacts*infectivity*severity_spread_adjustment*"\"mask_on\"_policy_early_day_adjustment")*"cumulative_effect_of_the_lock-down_on_the_transmission")*

UNITS: People/Day

2.1.4. Introducing the inflow of expats

Due to effects that pandemics imposed immediately on the global society, about 317,000 (Stojanovic, 2020) Serbian expats headed back to Serbia from all around the globe due to loss of an employment, crossing the border during the first two weeks of the lockdown. This have significantly increased the risk of an infection transmission as most of them came from the regions that have been seriously under the infection already and potentially presented itself as a serious strain on the health system of the developing country.

This event was simplified and presented in model as *inflow of expats,* following the example of other colleagues using the same method introducing imported (potential) infections.

PULSE(total_number_of_expats, 10, 0)

UNITS: People/Day

2.1.5. Social distancing measures under the emergency state, "the lock-down" scenario (day 9 – 60 since the patient "zero")

In the short run, addressing the COVID-19 outbreak was critically dependable on the successful implementation of public health measures including social distancing, workplace modifications, disease surveillance, contact tracing, isolation, and quarantine.

Serbian response to the pandemics regarding the reinforcing the policy of so called "social distancing", was proclamation of the Emergency state that lasted for 51 day. In its context the purpose of this measure was direct impact on the contact density among every and each individual aiming in efficient way to slow down the spread of a contagious disease such as Covid-19.

The category "65+" of the population as the most under the risk of contracting severe shape of the infection was under the lock down for 24h during those 51 day, with exceptions of getting allowed to visit food stores every second day in the period between 5 and 7 o'clock in the morning. Volunteering structure has been put in place to provide services to the most vulnerable members of the population, so they maximally decreased the risk of being exposed and potentially contracting an infection.

The curfew rule for the rest of the population applied from 16h, later 17h to 5 am in the morning next day, every day and not long time from the proclamation of the emergency state weekends have been under the curfew as well, Friday 16h (17h) – Monday 5am. Those that could, they have been working from home. Kindergartens, schools, restaurants, theatres and in general all public places have been closed for the period of 51 day.

We presented lock-down effect through the implications on the average contact rate as the social parameter of defining the course of disease dynamic, using as inspiration Bob Eberlein's (iseesystems, 2020b) solution for it.

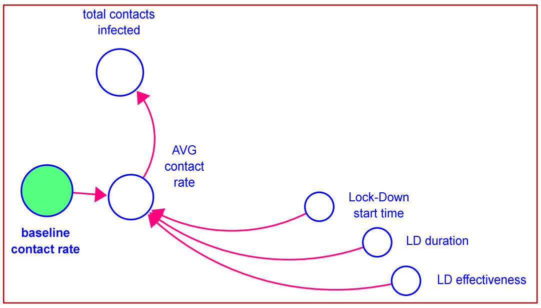


Figure 7: lock-down structure under the duration of the emergency state

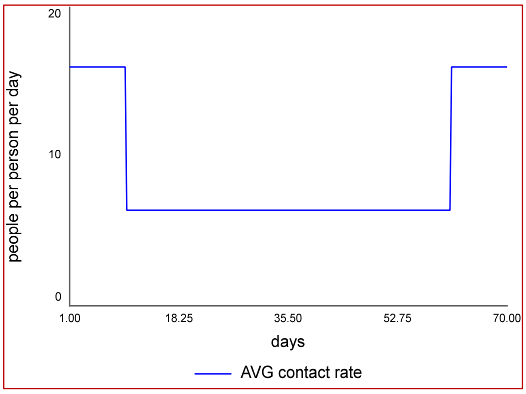


Figure 8: effect of the lock-down on contact rate

IF TIME <"Lock-Down_start_time" OR TIME >"Lock-Down_start_time"+LD_duration

THEN baseline_contact_rate

ELSE baseline_contact_rate(1-LD_effectiveness)*

UNITS: people per person per day

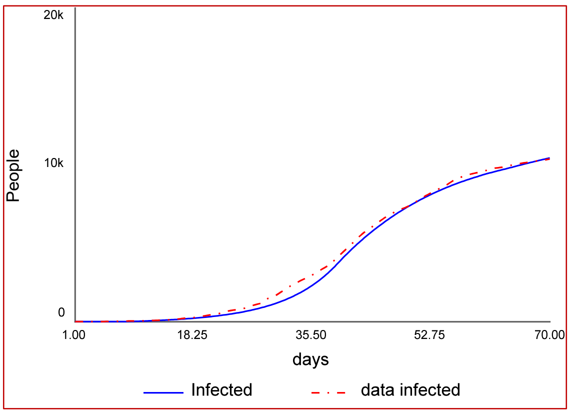


Figure 9: Infected - reference mode compared to simulation

By introducing the "lock-down" structure and fine-tuning the inflow of exposing our model succeed to produce the behaviour that replicates the reference mode in the stock of Infected under the emergency state scenario (day 9 through the day 60).

Introducing "social distancing" that resulted in the significant decrease of the contact density, which respectively made every potential contact less infective, for 60 days Covid-19, statistics in Serbia noted 9744 tested infected and 203 deaths with the mortality rate ratio among infected (tested) of 2,12%, which as long as the data is proven valid after the revision and with sudden import of the significant potential number of infections, can be refer to as - optimally successful.

The preliminary population statistics for the period January-April 2020, shows that number of deaths, “in the Republic of Serbia in the period January – April 2020 amounted to 34 642, and if related to the same period 2019, when it was 35 654, it recorded decrease by 1 012, or 2.8%.”(S. O. o. t. R. o. Serbia, 2020).

2.1.6. Loosening measures after the “lock-down” (day 61 – 137 since the patient “zero”, end of data series)

After the 51 days of the lock-down, Serbian government denounced the emergency state 6th of May and in the wake of the upcoming parliament elections loosened up social’s measures introduced, one could say dramatically. During June big social public and private gatherings has been allowed, such as football match with over 25,000 supporters, tennis tournament and many graduation and wedding parties. General public understood loosening measures as the pandemic is over. The timeline of the biggest public events was following,

10th of June – Football derby (approx. 25,000 supporters plus players, teams),

13th -14th June – Tennis tournament (approx. 2,000 visitors plus tennis teams plus organizational structure),

21st of June Presidential election (campaigning activities),

7th-14th July Demonstration all over Serbia,

and numerous weddings, graduation parties and social gatherings as the June are the month of it. Almost three months under the lock down and approving big socially dense event such football match to happened, gave signal to general population that the pandemics are over. On the other hand, gave people stronger motivation for socializing as well.

Very soon general population understood that the danger of infection is still present. The number of infected started plummeting again and this time number of younger patients have been in majority as older citizens continued following the recommendations and have not been target population for social gatherings that occurred. The response of the government was announcing potential second lock-down that escalated in citizens gathering all around Serbia and protest against it. Previous period of policy management and in the wake of presidential elections, resulted in general population losing trust in a policy maker which for consequence had acting against general health safety recommendations.

From 23rd of June, which is 13 days after the football match the daily number of infected went over 100 again. This is 108 days since the patient zero. In order to present this in our model we calibrated *contact rate* influencing it by *"cumulative effect of social events"* ,

*(IF TIME < 108 OR TIME >200 THEN AVG_contact_rate*total_infected ELSE IF TIME >108 OR TIME <137 THEN "effect_of_social_gatherings_oncontact_rate_after_the_lock-down"*total_infected ELSE (IF TIME >137 OR TIME < 200 THEN contact_adjustment*total_infected ELSE AVG_contact_rate*total_infected))*

UNITS: touch/day

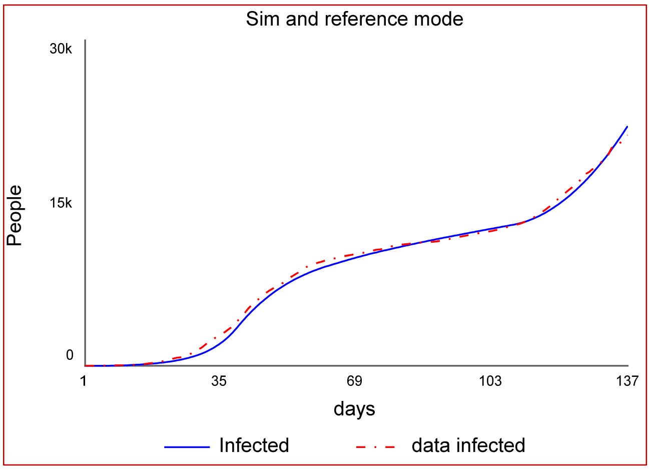


Figure 10: Comparative graph of Infected sim and data after the lock-down

Respectively to the number of infected, number of death cases increased as well. In order to replicate reference mode behaviour of the stock of Death, we fine-tuned counts that roughly match (within the margin of uncertainty) the number of Serbian deaths presenting it through the variable of *"serious cases"* and *"fraction of serious"* that we defined in the relationship to the "*number of daily infected*". This variable was introduced as exogenous to the system structure. Fraction of serios cases is defined trough *"fraction serious low times"* when *total number of infected* is *lower than 99 people* and *"fraction serious high times"*, respectively when higher than 99 people. Educated assumption is that the fraction of serious cases in total infected people is increasing together with the number of infection (more infected people, higher the fraction of serious cases). From there *mortality rate* was scaled *to address serious cases*.

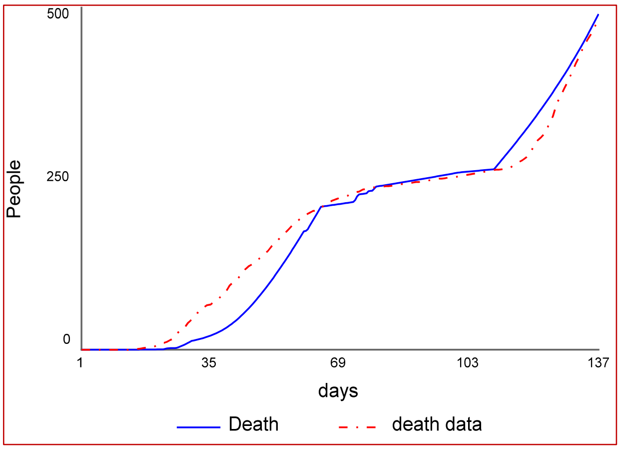


Figure 11: Comparative graph of Death sim and data after the lock-down (day 61 – 137)

Dying=

*(serious_cases*increased_effectiveness_of_medical_treatment_of_critically_ill_patients*mortality_rate)/"sickness_duration*"*

UNITS: people/day

fraction_serious_all_time=

IF daily_confirmed_positive < 99 THEN fraction_serious_cases_low_times ELSE fraction_serious_cases_high_times

UNITS: dmnl

2.1.7. Policy and trajectories (day 138 – 240 - 300) – an overview

Wearing a mask and practicing physical (social) distance whenever is possible, despite agitation of general public did established itself as a new way of behaviour during the time. "Hammer and the dance" expression is referring to policy management strategy,

> *"Governments all around the globe responded initially with a strong confinement stage that has temporarily limited economic activity in order to control the spread of the pandemic – the hammer. Some governments have already started the second phase of gradual lifting of confinement measures and*

> *subsequent restarting of economic activity. During this second phase, the pandemic must be kept under control while it is still not completely suppressed – the dance."*(Tiziana Assenza, 2020)

This in practice is translated trough timing and ways of how policy maker is achieving the "dance" control over the infection spread. By obligatory wearing a masks in closed spaces as offices, shops and public transport, for example; like not re-opening the schools or totally forbidding the work of cafes and restaurants or under the condition of no more than 5-10 people in closed spaces and with obligatory masks. These are some of the popular social measures that are implement all around the globe with to goal to slow down the spread of the infection, but to allowed economic operations.

We presented simple policy structure at this point including *"POLICY mask-on calibrator"* affecting *risky contacts* and *"POLICY social distancing calibrator*" affecting *baseline contact rate*. As we have been mentioning before, fraction of serious cases in this model is dependable on change in daily infections. Therefore, we *added* "*POLICY daily confirmed positive calibrator*" affecting the *"dying"* outflow as well. In this stage of modelling we fine-tuned estimated policy parameters to roughly match the projected deaths you see from this model until November 1st (240 days since the patient "zero"), with the trajectories from middle of July 2020. These trajectories are with the range predicted by the model developed at the Institute for Health Metrics and Evaluation at the University of Washington, (Washington., 2020)

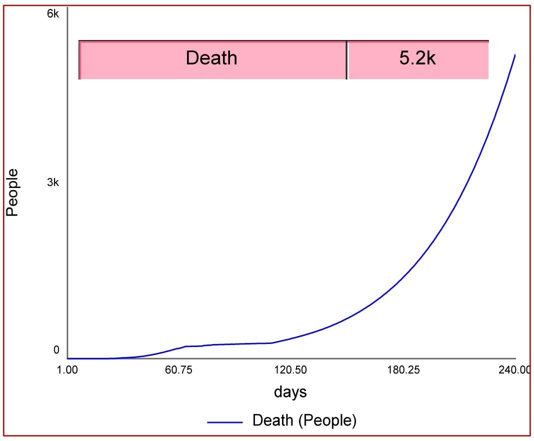


Figure 13: Stock of Death trajectory, 1st of November

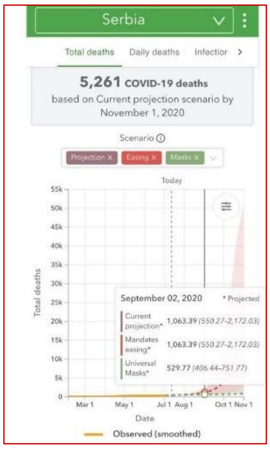


Figure 12: IHME trajectory for 1st of November, assessed 13.7.2020.

risky_contacts =

*IF TIME < 137 THEN fraction_of_susceptible_in_risk_of_infection*total_contacts_infected*

*ELSE total_contacts_infected*fraction_of_susceptible_in_risk_of_infection*(1-"POLICY_mask-on_calibrator"),*

UNIT: touch/day

baseline_contact_rate = 16

UNIT: touch/person/day

fraction_serious_all_time=

IF TIME >137 THEN

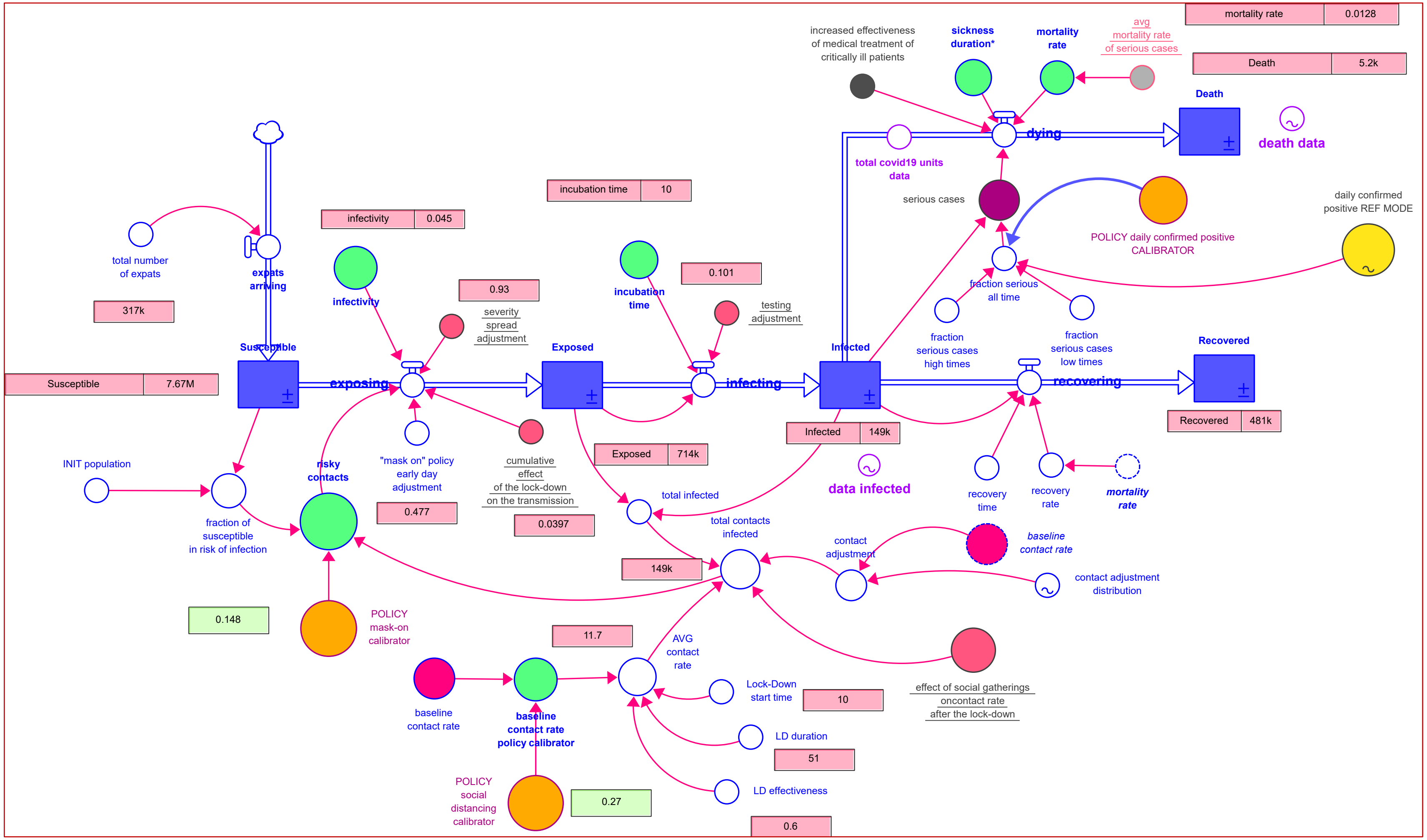
(IF POLICY_daily_confirmed_positive_CALIBRATOR <99 THEN fraction_serious_cases_low_times ELSE fraction_serious_cases_high_times)

ELSE

(IF daily_confirmed_positive_REF_MODE < 99 THEN fraction_serious_cases_low_times ELSE fraction_serious_cases_high_times),UNIT: dmnl

2.1.8. Complete model structure, main graphs and CLD

Figure 14: Stock and Flow model structure



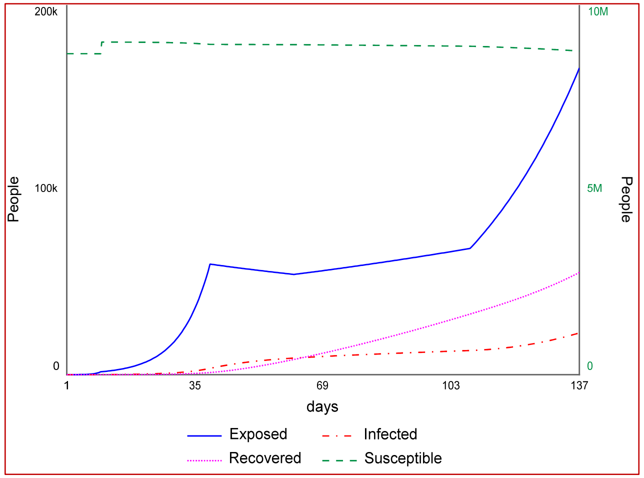


Figure 16: SEIR(D) model Serbia

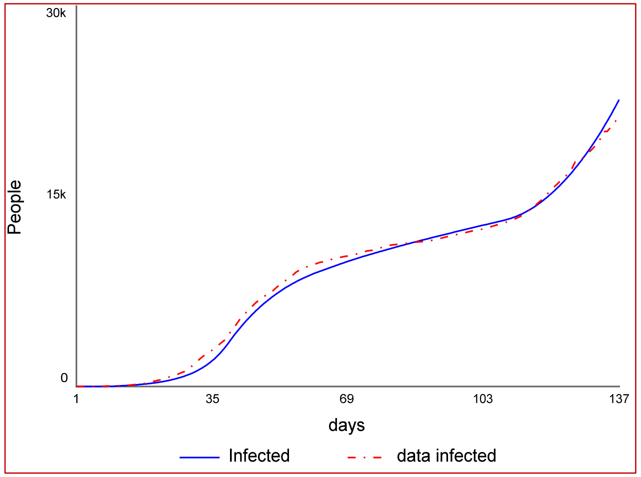


Figure 15: Stock Infected sim and ref mode

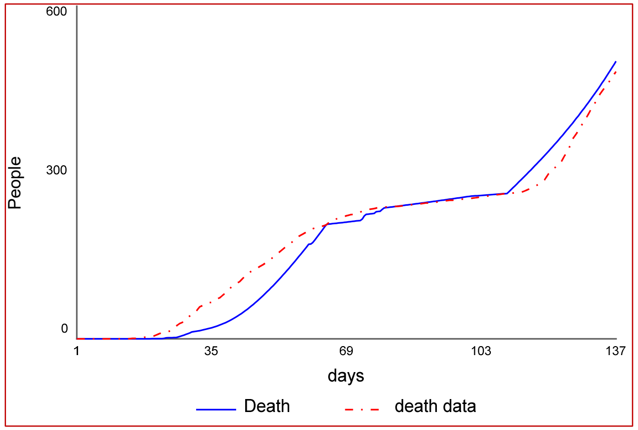


Figure 18: Stock Death sim and ref mode

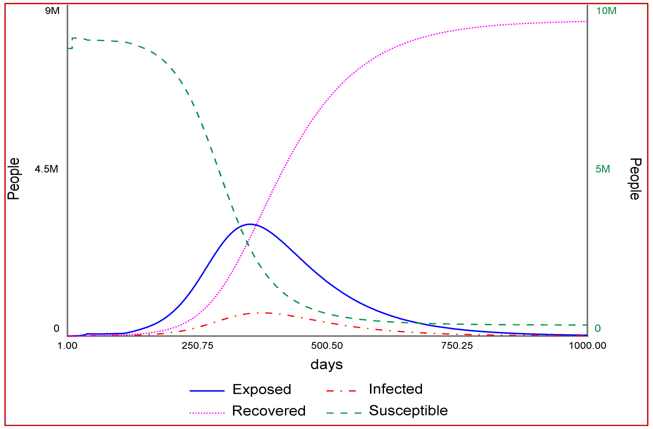
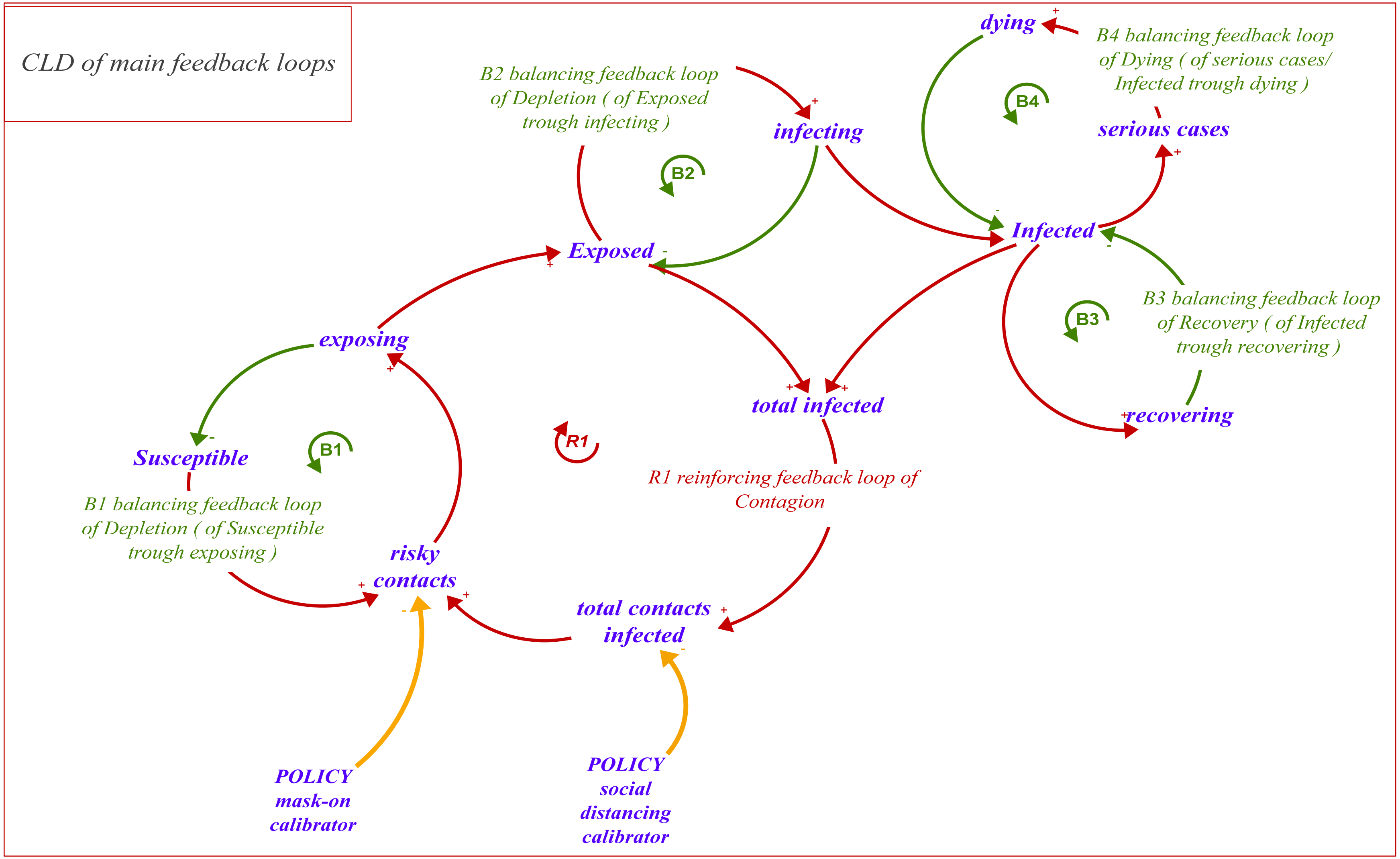


Figure 17: sim calibrated for estimates for 1st of November IHME on trajectories from 13th July 2020

Figure 19: CLD of feedback loops



Chapter 3 - Model testing

3.1. Model assumptions and boundaries

The equilibrium dynamics without policy interventions are characterized by two phases: a lock-down phase that was initiated by emergency state and that have for a goal to brings new infections under control, and a following phase after denouncing the lock-down policy during which the epidemic continues to progresses until the population reaches a state of herd immunity as we assumed in our model.

The assumptions:

- We assumed that when people recover, they build permanent immunity. Re-infection is not an option in this model.
- Further we assumed that expats arriving are without exclusion susceptible. The truth can be that some of them have been already, exposed, infected and even recovered.
- Variables used to fine-tune model to replicate reference mode have been assumed, but conceptualized to fit the context of the challenge during replication of the reference mode;
- Fraction of "serious cases" is increasing with the number of infected people, when the daily number increase starts with 99 people and vice versa.

The boundaries:

- Vaccine has not been of interest for the purpose of this case study;
- No attention on the stock of Recovered as it has not been of interest for the purpose of this case study as the data regarding it was inconsistent;
- Covid-19 hospital capacities - Information about Covid-19 hospital capacities came late in the research phase therefore they haven't been used
- Quarantine has not been included due to lack of access to the data, but contextually has been included trough dynamics created by social distancing.
- No economic parameters have been part of the policy strategy
- Modelling outflow "dying" and matching the stock of Death has been challenging. The solution that we offered in this model is grounded in logic of

> the number of serious cases as a result of total infected (tested and confirmed). The death or infection figures simulated by this model here are NOT firm predictions, but rather indicators of the direction and severity of the epidemic under various conditions.

For the purpose of this case study research analysis, we stayed focus on a basic and simple structure of SEIR(D) model in order to present mostly effects of social policies on a virus spread. The more structurally complex model would potentially demand a team effort of epidemiologist, virologist and other crucial medical personnel together with an economist, then analytic, ideally with medical background and at least two SD modelers of which one should have advance modelling skills. The Author believe that including ILE (Interactive Learning Environment) method would bring added value for the overall quality of a model and to iterative learning loop,

> *"The epidemiological perspective on modelling infectious disease spread involves consideration of a larger number of modelling parameters detailing the spread of and recovery from the disease, additional compartments corresponding to age categories, and other related choices*."(Bertozzi, Franco, Mohler, Short, & Sledge, 2020)

3.2. Initializing parameters

Parameter	UNITS	Value
INIT population	people	8,700,000
INIT Exposed	people	5
INIT Infected	people	1
INIT Recovered	people	0
INIT Death	people	0
toal number of expats	people	317,000
incubation time	day	10
infectivity	person/touch	0.045
severity spread adj	dmnl	0.930
testing adj	dmnl	0.101
recovery time	day	21
baseline contact rate (people/person/day)	touch/person/day	16
"mask on " policy early days adj (dmnl)	dmnl	0.4770
avg moratlity rate serious cases	dmnl	0.0128
cumlative effect of the lock down on the transmission	dmnl	0.0397
cumulative effects of social events during may/juny on baseline contact rate (days 108-137 since patient zero)	touch/person/day	38.4
fraction serious cases "high times"	dmnl	0.7290
fraction serious cases "low times"	dmnl	0.0585
lock-down start/emergency state start (day)	day	10
lock-down duration (day)	day	51
Data series duration - reference mode	days	137

Table 1: Initializing parameters - reference mode

- Population used in the model is the 2020. population live count from worldometers.info(data, 2020);
- Expats number (Stojanovic, 2020);
- Stocks have been simply initiated to achieve reference mode data in stocks of Infected and Death;
- Lock-down start time, duration (T. g. o. t. r. o. Serbia, 2020b);
- Epidemiological parameters:
    - infectivity,
    - incubation time and
    - sickness duration,

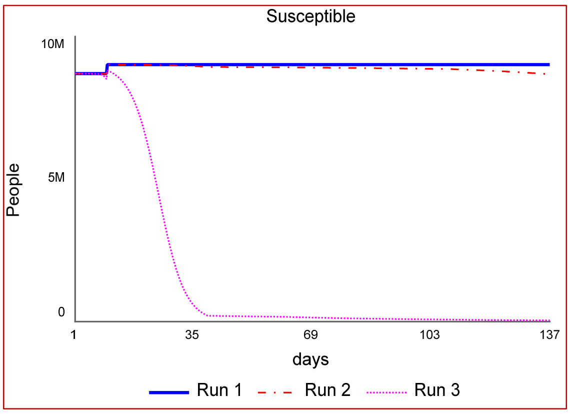
are estimated within the range of epidemiological data available and fine-tuned within the range for the purpose of our model;

- Calibrating parameters:
    - severity spread adjustment
    - cumulative effect of the lock-down on the transmission
    - testing adjustment
    - fraction serious “high time” and “low times”
    - avg mortality rate of serious cases
    - increased effectiveness of medical treatment of critically ill patients,

are assumed by the Autor for the purpose of this case study research analysis and they potentially presents structures that could be developed in future scenarios. Idea was that contextually they add to conceptual sense while calibrating model to roughly match (within the margin of uncertainty) reference mode behaviour.

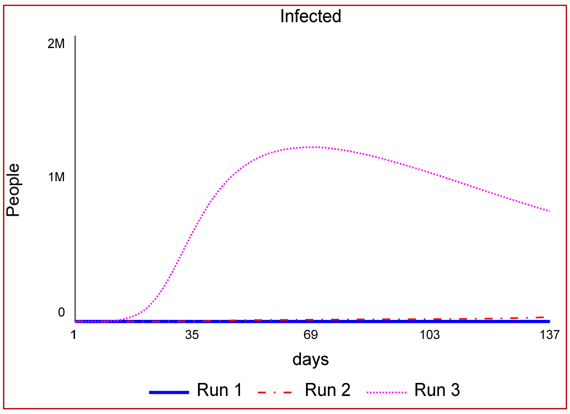
3.3. Sensitivity analysis and extreme condition test

As contact rate is the single most important social element in disease transmission, we set range "baseline contact rate" 0-32 (0-16-32) and run simulation during the first 137 days as sensitivity of model output on changes in contact rate should result in *earlier increase in infections,* thus *sooner depletion* of the stock of *Susceptible* and respectively *significant* amount of *deaths.* (When model initiated, the value is 16)



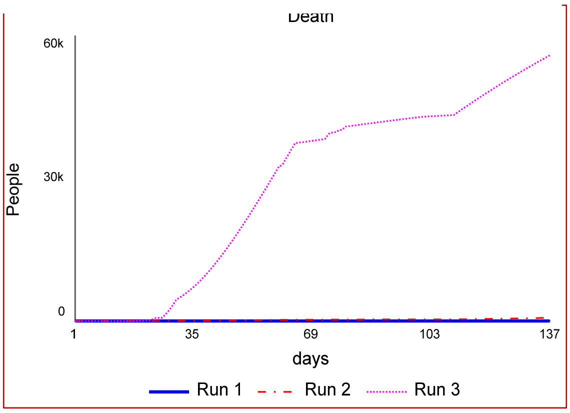
	baseline contact rate	*Susceptible*
Run 1	***1***	*9016981.23763*
Run 2	***16.5***	*8677089.37525*
Run 3	***32***	*44107.5445247*

Figure 20: Sensitivity analysis SUSCEPTIBLE



baseline contact rate	*Infected*
Run 1 ***1***	*1.34745996655*
Run 2 ***16.5***	*31424.2299879*
Run 3 ***32***	*774023.592222*

Figure 20: Sensitivity analysis INFECTED



baseline contact rate	*Death*
Run 1 ***1***	*0.0967397281431*
Run 2 ***16.5***	*672.438245371*
Run 3 ***32***	*55963.8262981*

Figure 21: Extreme condition test DEATH

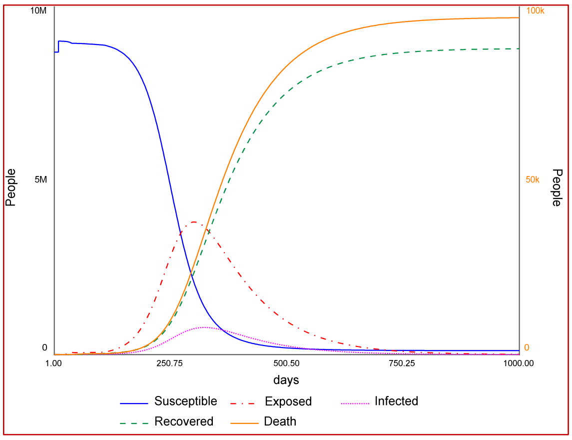


Figure 22: Extreme condition testing

Sensitivity testing produced expected behaviour of all 3 stocks, due to changes in density contact. As grounded in epidemiological theory and as we have been referring earlier in this research, contact rate is high leverage point of model to affect with policies.

In order to test behaviour of the model output considering extreme conditions we set time for sim run on 1000 days under the conditions initiated by reference mode and as expected we got reasonable behaviour that is a result of sudden plummeting of infected before policy intervention, S-shaped behaviour, limits to growth archetype.

Chapter 4 – Policy scenarios

4.1. IHME scenario 13.7. trajectories for 1st November 2020

Two characteristics make COVID-19 challenging to control: transmission dynamics and the fact that many infections and transmissions are asymptomatic and can go undetected. Socially optimal policy should consider strong first policy reflex, as confinement (lock down, emergency state – *"the Hammer"*), what many countries did do and then gradually managing re-opening during which the infection will progress, but (hopefully) in more controlled manner (*"the Dance"*). This part varies from country to country as it is very sensible toward different elements such as health system state ad capacities, economic profile, geo-political, cultural and so on.

In the Serbian Covid-19 scenario, Serbian government was efficient in introducing "the Hammer" element of the policy strategy. As the situation developed, after denouncement of the emergency state and as the numbers plummeted after a while and Serbia factually experienced its first serios wave of infection and pressure on the health system, it is obvious that introducing "the Dance" part of the policy strategy haven't been as effective as the "The Hammer" was. In order to get the infection under the control again Serbian government shifted their focus back on infection control.

Once again Serbian policy maker introduced obligatory measures of wearing masks in closed spaces and open one as well, if distance is not possible to maintain, physical (social) distancing, limitation on number of people in closed spaces and recommended home schooling.

In order to assess the effects of masks and physical distancing we introduced simple policy structure, *"POLICY mask-on calibrator"* affecting risky contacts, *"POLICY Social distancing calibrator"* affecting baseline contact rate and keeping "*POLICY daily confirmed positive CALIBRATOR*" on 99 which is activating higher fraction of serious cases (explained earlier) and we managed with success to roughly match (within the margin of uncertainty) the projection for the 1st November (240 days since patient "zero") for the stock of *Death* presented in the model developed at the Institute for Health Metrics and Evaluation at the University of Washington, (Washington., 2020). In the scenario estimation is based on trajectories of 13.7.2020.

"The Institute for Health Metrics and Evaluation (IHME) is an independent population health research centre at UW Medicine, part of the University of Washington, that provides rigorous and comparable measurement of the world's most important health problems and evaluates the strategies used to address them. IHME makes this information freely available so that policymakers have the evidence they need to make informed decisions about how to allocate resources to best improve population health."(Washington, 2020)

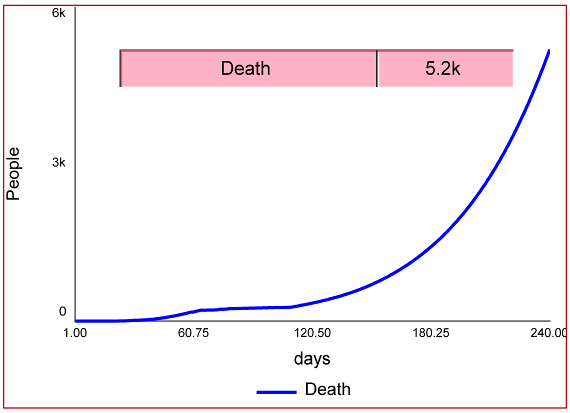


Figure 23: Death on 1st November, simulation result

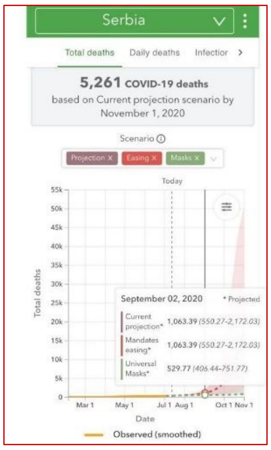


Figure 24: IHME estimates for 1st of November, trajectory 13.7.2020.

POLICY mask-on calibrator = 0.00183

POLICY Social distancing calibrator = 0.161

POLICY daily confirmed positive CALIBRATOR = 99

risky_contacts =

*IF TIME < 137 THEN fraction_of_susceptible_in_risk_of_infection*total_contacts_infected ELSE total_contacts_infected*fraction_of_susceptible_in_risk_of_infection*(1-"POLICY_mask-on_calibrator")*

baseline_contact_rate_policy_calibrator=

*IF TIME > 137 THEN (1-POLICY_social_distancing_calibrator)*baseline_contact_rate ELSE baseline_contact_rate*

4.2. IHME scenario 2, 06.8. trajectories for 1st December 2020

In the second scenario analysis we wanted to try to match as close as possible IHME estimates for 1st of December for Serbia, from 06th of August trajectories.

In this case we calibrated the *"POLICY daily confirmed positive CALIBRATOR" on 98* as it has direct impact on fraction of serious cases in our model, thus on the stock of Death. Modelling, thus simulating stock of Death presented itself as challenge from modelling point of view.

As we explained earlier, this variable was introduced as exogenous to the system structure. Fraction of serios cases is defined trough *"fraction serious low times*" when *total number of infected* is *lower than 99 people* and *"fraction serious high times*", respectively when equal or higher than 99 people. Educated assumption is that the fraction of serious cases in total infected people is increasing together with the number of infection (more infected people, higher the fraction of serious cases).

This assumption that we made we wanted to test trough policy implication: Having in mind that previous policy measure already started to have cumulative impact on decrease of the infection spread, we assumed that number of infected will show decrease over time as well, thus the fraction of serious cases. Therefore, we tuned this variable to decrease on the value 98 and to activate *"fraction serious cases low times"*.

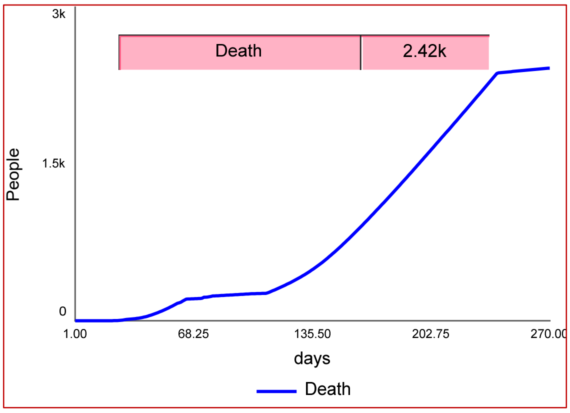


Figure 25: Death on 1st of December, simulation

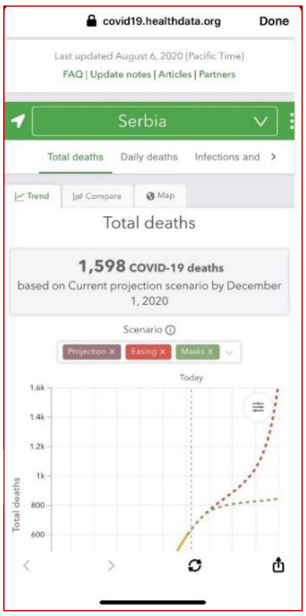


Figure 26: IHME estimate for 1st of December, trajectories 06.08.2020.

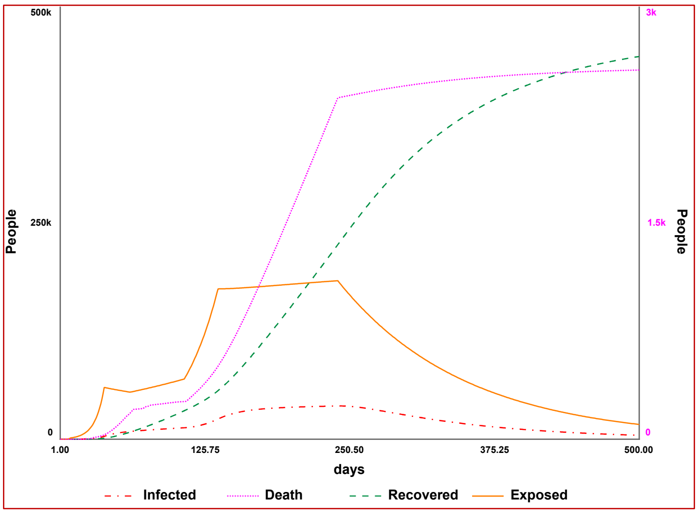
POLICY mask-on calibrator= 0.75

POLICY social distancing calibrator = 0.75

POLICY daily confirmed positive CALIBRATOR = 98

Result of our simulation shows certain discrepancy with IHME estimate for the stock of Death on 1st of December. As mentioned before the way of modelling the deaths can be referred to as not agile as it was partially exogenously modelled in order to try to replicate reference mode behaviour. But when we produce simulation over the period of 500 days or 1000 days, contextually the rightly assumed trend is present: decrease of the number of infected, thus serious case and thus total deaths. The assumption that we tested was that due to introducing obligatory masks and social distance policy measures the number of estimated deaths will show decrease from trajectories from mid of July and the beginning of the August, which our simulation confirmed. Overall conclusion is that modelling the outflow "dying" is highly dependable on the data transparency regarding the death statistics, moreover the criteriums for their counting, among others.

As we mentioned earlier, the death or infection figures simulated by this model here are not firm predictions, but rather indicators of the direction and severity of the epidemic under various conditions.



By analysing policy scenarios, we at the same time performed the process of model validation trough policy lens in reference to IHME estimates.

Figure 27: Sim with Policy 2, 500 days sim time

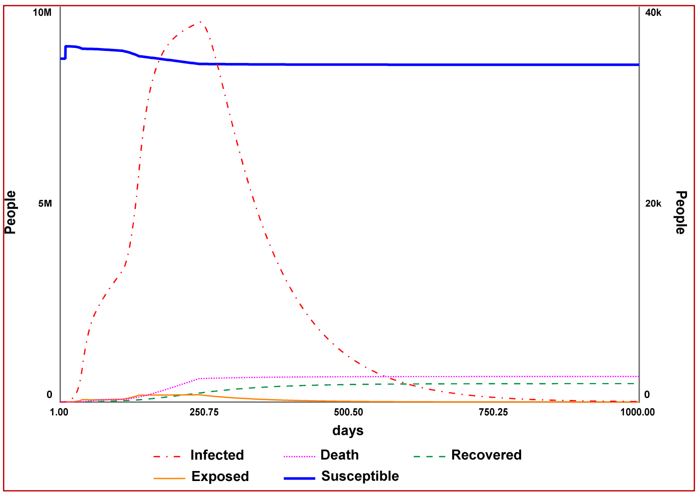


Figure 28: Sim with Policy 2, 1000 days sim time

Chapter 5 - Conclusions and discussions

The Problem, key take away

The Coronavirus crisis has become the biggest worldwide pandemic for over a century and has had a serious impact on public health, societies and economies all around the globe. This scenario brough to light as it has never before (in our lifetime) how care for others is important factor of preserving our selves and how in the time when closeness and warm comfort of a dear person is necessary, actually is recommended to be avoided as we could harm each other. This situation has shone light on real and honest vulnerability of human life and uncertainty of human existence. As well on how intrinsically wrong is to ignore our interdependences, as social beings. Socially responsible behaviour has never been more important and the spirit of true camaraderie as it is now, still.

In relationship to policy maker and trust that lays in government the same apply – successful policy implementation under these conditions highlighted the true governing culture on national levels and removed the lid from burning societal and political issues. The world come to boiling point. Under the final pressure.

As a system thinker by nature and system dynamics by training, among other, I have spent Corona time observing the behaviour of people and how the lack of system thinking and understanding of complex relationships have impact on the smallest but significantly important elements of our own personal lives, the way how we make decisions. Crucial ones. The existential ones. Lack of critical thinking thought and ability to see trough noise has for the result the type of “blindness” in reference to assessing the true identity of the situation.

At the same time, time of disruption is an opportunity for paradigm shift and for changing the ongoing status quo, especially having in mind shift toward the sustainable societies and responsible use of resources, limits to growth. Change in mental models. Lessons learned phase.

The identity of political governing including the way of communicating with general population has been important attributes to successful policy implementation. Case study of Serbian Covid-19 scenario identified weak spots in general policy implementation in scenarios where success of implementation depends on the good will of the population that is based on two important criteriums, and those are: trust in the government and the knowledge level and understanding of the problem. The latter one, by the Authors opinion becomes even more important when the first one is the weak one. Which translates into – not strong societal culture. Without going deeper into subject why certain types of leaders (and styles of leadership) prefer weak societal culture, in the pandemic scenario one element is crucial in producing strong policy response in addressing the virus transmission control and that is - strong and united community acting.

The Policy

The world is impatiently waiting for the vaccine. Freedom of movement is under pressure. Two elements of addressing the infection transmission, the epidemiologic one and the social one. Until now "contact control" was the only way in slowing down the transmission, meaning having a culture of wearing a masks, as it is already culture in Eastern part of the globe and practicing physical (social) distance as much as the circumstances are allowing us to do that. For those that find reason in that policy approach.

The hammer and the dance approach were mostly accepted policy strategy in the world. Strong confinement to slow down new infection and then gradually loosening of the policy in the part that consider mostly contact density. Wearing a mask, even though obligatory in certain situations, is proven to be highly dependable on the individuals.

By trying to match the estimates by IHME, we preformed policy validation testing as well. The purpose of this case study was solely analysing and understanding the effect that mixed policy of wearing a mask and practicing physical, (social) distancing have on infection transmission. In our policy testing we assumed optimal combination of the both elements of the policy suggesting that as such implemented would deliver results that we presented.

In real life, strategy is more complex as it takes in consideration more elements, that by their determination also decide the points in time when and in what volume the policy is implemented. And for how long, like for example home schooling.

The economic criterium for the policy is beyond the scope of this research. But one thing is obvious, the direct cost of this pandemics shone light on many hidden ones, but nonetheless significant in their ramification on overall societal wellbeing.

Overall conclusion from our results is that policy should stay in power as long as we don't reach the point of immunisation and based on the conclusions about length of the immunity achieved by it, maybe even longer. It is to wait and learn. And wear a mask.

Figure 29: Graffiti from the streets of Novi Sad, Serbia #forourheroes #zanašeheroje

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Appendix 1 – List of Equations

Top-Level Model:
*Death(t) = Death(t - dt) + (dying) * dt*
INIT Death = 0
UNITS: People

*Exposed(t) = Exposed(t - dt) + (exposing - infecting) * dt*
INIT Exposed = 5
UNITS: People

*Infected(t) = Infected(t - dt) + (infecting - recovering - dying) * dt*
INIT Infected = 1
UNITS: People

*Recovered(t) = Recovered(t - dt) + (recovering) * dt*
INIT Recovered = 0
UNITS: People

*Susceptible(t) = Susceptible(t - dt) + (expats_arriving - exposing) * dt*
INIT Susceptible = INIT_population-(Infected+Exposed+Recovered-Death)
UNITS: People

*dying = (serious_cases*increased_effectiveness_of_medical_treatment_of_critically_ill_patients*mortality_rate)/"sickness_duration*" {UNIFLOW}*
UNITS: people/day

expats_arriving = PULSE(total_number_of_expats, 10, 0) {UNIFLOW}
UNITS: people/day

*exposing = (IF TIME <39 THEN (IF TIME <10 THEN risky_contacts*infectivity*severity_spread_adjustment ELSE risky_contacts*infectivity*severity_spread_adjustment*"\"mask_on\"_policy_early_day_adjustment") ELSE (risky_contacts*infectivity*severity_spread_adjustment*"\"mask_on\"_policy_early_day_adjustment")*"cumulative_effect_of_the_lock-down_on_the_transmission") {UNIFLOW}*
UNITS: people/day

*infecting = (Exposed/incubation_time)*testing_adjustment {UNIFLOW}*
UNITS: people/day

*recovering = (Infected*recovery_rate)/recovery_time {UNIFLOW}*
UNITS: people/day

"\"mask_on\"_policy_early_day_adjustment" = 0.477
UNITS: dmnl

AVG_contact_rate = IF TIME <"Lock-Down_start_time" OR TIME >"Lock-Down_start_time"+LD_duration THEN baseline_contact_rate_policy_calibrator ELSE baseline_contact_rate_policy_calibrator(1-LD_effectiveness)*
UNITS: touch/person/day

avg_mortality_rate_of_serious_cases = 0.0128
UNITS: dmnl

baseline_contact_rate = 16
UNITS: touch/person/day

*baseline_contact_rate_policy_calibrator = IF TIME > 137 THEN (1-POLICY_social_distancing_calibrator)*baseline_contact_rate ELSE baseline_contact_rate*
UNITS: touch/person/day

contact_adjustment = IF TIME >137 OR TIME <240 THEN contact_adjustment_distribution ELSE baseline_contact_rate
UNITS: touch/person/day

contact_adjustment_distribution = GRAPH(TIME)
Points: (137.0, 45.00), (148.444444444, 34.5942312645), (159.888888889, 27.9222564247), (171.333333333, 23.6443170054), (182.777777778, 20.9013861468), (194.222222222, 19.1426726734), (205.666666667, 18.0150200855), (217.111111111, 17.2919913611), (228.555555556, 16.8283995228), (240.0, 16.5311535278)
UNITS: touch/person/day

"cumulative_effect_of_the_lock-down_on_the_transmission" = 0.0397
UNITS: dmnl

daily_confirmed_positive_REF_MODE = GRAPH(TIME)
Points: (1.0, 1.0), (2.0, 0.0), (3.0, 0.0), (4.0, 1.0), (5.0, 3.0), (6.0, 13.0), (7.0, 6.0), (8.0, 11.0), (9.0, 11.0), (10.0, 2.0), (11.0, 9.0), (12.0, 15.0), (13.0, 17.0), (14.0, 14.0), (15.0, 32.0), (16.0, 36.0), (17.0, 51.0), (18.0, 27.0), (19.0, 54.0), (20.0, 81.0), (21.0, 73.0),

(22.0, 71.0), (23.0, 131.0), (24.0, 82.0), (25.0, 44.0), (26.0, 115.0), (27.0, 160.0), (28.0, 111.0), (29.0, 305.0), (30.0, 148.0), (31.0, 284.0), (32.0, 292.0), (33.0, 247.0), (34.0, 219.0), (35.0, 201.0), (36.0, 238.0), (37.0, 275.0), (38.0, 250.0), (39.0, 424.0), (40.0, 411.0), (41.0, 408.0), (42.0, 445.0), (43.0, 372.0), (44.0, 304.0), (45.0, 324.0), (46.0, 312.0), (47.0, 260.0), (48.0, 224.0), (49.0, 162.0), (50.0, 207.0), (51.0, 296.0), (52.0, 263.0), (53.0, 233.0), (54.0, 222.0), (55.0, 227.0), (56.0, 285.0), (57.0, 196.0), (58.0, 157.0), (59.0, 102.0), (60.0, 93.0), (61.0, 120.0), (62.0, 114.0), (63.0, 114.0), (64.0, 95.0), (65.0, 89.0), (66.0, 82.0), (67.0, 62.0), (68.0, 67.0), (69.0, 52.0), (70.0, 79.0), (71.0, 64.0), (72.0, 58.0), (73.0, 114.0), (74.0, 89.0), (75.0, 34.0), (76.0, 100.0), (77.0, 86.0), (78.0, 105.0), (79.0, 68.0), (80.0, 67.0), (81.0, 34.0), (82.0, 34.0), (83.0, 48.0), (84.0, 25.0), (85.0, 54.0), (86.0, 21.0), (87.0, 31.0), (88.0, 18.0), (89.0, 24.0), (90.0, 69.0), (91.0, 48.0), (92.0, 96.0), (93.0, 74.0), (94.0, 82.0), (95.0, 73.0), (96.0, 69.0), (97.0, 66.0), (98.0, 71.0), (99.0, 73.0), (100.0, 76.0), (101.0, 59.0), (102.0, 57.0), (103.0, 59.0), (104.0, 96.0), (105.0, 94.0), (106.0, 93.0), (107.0, 94.0), (108.0, 91.0), (109.0, 96.0), (110.0, 102.0), (111.0, 143.0), (112.0, 137.0), (113.0, 193.0), (114.0, 227.0), (115.0, 254.0), (116.0, 242.0), (117.0, 276.0), (118.0, 272.0), (119.0, 359.0), (120.0, 309.0), (121.0, 325.0), (122.0, 302.0), (123.0, 289.0), (124.0, 299.0), (125.0, 357.0), (126.0, 362.0), (127.0, 386.0), (128.0, 345.0), (129.0, 287.0), (130.0, 279.0), (131.0, 344.0), (132.0, 351.0), (133.0, 383.0), (134.0, 392.0), (135.0, 389.0), (136.0, 396.0), (137.0, 359.0)
UNITS: People

data_infected = GRAPH(TIME)
Points: (1.0, 1), (2.0, 1), (3.0, 1), (4.0, 2), (5.0, 5), (6.0, 18), (7.0, 24), (8.0, 35), (9.0, 46), (10.0, 48), (11.0, 57), (12.0, 72), (13.0, 89), (14.0, 103), (15.0, 135), (16.0, 171), (17.0, 222), (18.0, 249), (19.0, 303), (20.0, 384), (21.0, 457), (22.0, 528), (23.0, 659), (24.0, 741), (25.0, 785), (26.0, 900), (27.0, 1060), (28.0, 1171), (29.0, 1476), (30.0, 1624), (31.0, 1908), (32.0, 2200), (33.0, 2447), (34.0, 2666), (35.0, 2867), (36.0, 3105), (37.0, 3380), (38.0, 3630), (39.0, 4054), (40.0, 4465), (41.0, 4873), (42.0, 5318), (43.0, 5690), (44.0, 5994), (45.0, 6318), (46.0, 6630), (47.0, 6890), (48.0, 7114), (49.0, 7276), (50.0, 7483), (51.0, 7779), (52.0, 8042), (53.0, 8275), (54.0, 8497), (55.0, 8724), (56.0, 9009), (57.0, 9205), (58.0, 9362), (59.0, 9464), (60.0, 9557), (61.0, 9677), (62.0, 9791), (63.0, 9848), (64.0, 9943), (65.0, 10032), (66.0, 10114), (67.0, 10176), (68.0, 10243), (69.0, 10295), (70.0, 10374), (71.0, 10438), (72.0, 10496), (73.0, 10610), (74.0, 10699), (75.0, 10733), (76.0, 10833), (77.0, 10919), (78.0, 11024), (79.0, 11092), (80.0, 11159), (81.0, 11193), (82.0, 11227), (83.0, 11275), (84.0, 11300), (85.0, 11354), (86.0, 11381), (87.0, 11412), (88.0, 11430), (89.0, 11454), (90.0, 11523), (91.0, 11571), (92.0, 11667), (93.0, 11741), (94.0, 11823), (95.0, 11896), (96.0, 11965), (97.0, 12031), (98.0, 12102), (99.0, 12175), (100.0, 12251), (101.0, 12310), (102.0, 12367), (103.0, 12426), (104.0, 12522), (105.0, 12616), (106.0, 12709), (107.0, 12803), (108.0, 12894), (109.0, 12990), (110.0, 13092), (111.0, 13235), (112.0, 13372), (113.0, 13565), (114.0, 13792), (115.0, 14046), (116.0, 14288), (117.0, 14564), (118.0, 14836), (119.0, 15195), (120.0, 15504), (121.0, 15829), (122.0, 16131), (123.0, 16420), (124.0,

16719), (125.0, 17076), (126.0, 17728), (127.0, 17728), (128.0, 18073), (129.0, 18360), (130.0, 18639), (131.0, 18983), (132.0, 19334), (133.0, 20100), (134.0, 20109), (135.0, 20498), (136.0, 20894), (137.0, 21253)
UNITS: People

death_data = GRAPH(TIME)
Points: (1.0, 0.0), (2.0, 0.0), (3.0, 0.0), (4.0, 0.0), (5.0, 0.0), (6.0, 0.0), (7.0, 0.0), (8.0, 0.0), (9.0, 0.0), (10.0, 0.0), (11.0, 0.0), (12.0, 0.0), (13.0, 0.0), (14.0, 0.0), (15.0, 1.0), (16.0, 1.0), (17.0, 2.0), (18.0, 3.0), (19.0, 3.0), (20.0, 4.0), (21.0, 7.0), (22.0, 10.0), (23.0, 10.0), (24.0, 13.0), (25.0, 16.0), (26.0, 23.0), (27.0, 28.0), (28.0, 31.0), (29.0, 39.0), (30.0, 44.0), (31.0, 49.0), (32.0, 58.0), (33.0, 61.0), (34.0, 65.0), (35.0, 66.0), (36.0, 71.0), (37.0, 74.0), (38.0, 80.0), (39.0, 85.0), (40.0, 94.0), (41.0, 99.0), (42.0, 103.0), (43.0, 110.0), (44.0, 117.0), (45.0, 122.0), (46.0, 125.0), (47.0, 130.0), (48.0, 134.0), (49.0, 139.0), (50.0, 144.0), (51.0, 151.0), (52.0, 156.0), (53.0, 162.0), (54.0, 168.0), (55.0, 173.0), (56.0, 179.0), (57.0, 185.0), (58.0, 189.0), (59.0, 193.0), (60.0, 197.0), (61.0, 200.0), (62.0, 203.0), (63.0, 203.0), (64.0, 206.0), (65.0, 213.0), (66.0, 215.0), (67.0, 218.0), (68.0, 220.0), (69.0, 222.0), (70.0, 224.0), (71.0, 225.0), (72.0, 228.0), (73.0, 230.0), (74.0, 231.0), (75.0, 234.0), (76.0, 235.0), (77.0, 237.0), (78.0, 237.0), (79.0, 238.0), (80.0, 238.0), (81.0, 239.0), (82.0, 239.0), (83.0, 240.0), (84.0, 241.0), (85.0, 242.0), (86.0, 242.0), (87.0, 243.0), (88.0, 244.0), (89.0, 245.0), (90.0, 245.0), (91.0, 246.0), (92.0, 247.0), (93.0, 248.0), (94.0, 249.0), (95.0, 250.0), (96.0, 250.0), (97.0, 251.0), (98.0, 252.0), (99.0, 252.0), (100.0, 253.0), (101.0, 254.0), (102.0, 255.0), (103.0, 256.0), (104.0, 257.0), (105.0, 258.0), (106.0, 259.0), (107.0, 260.0), (108.0, 261.0), (109.0, 262.0), (110.0, 263.0), (111.0, 263.0), (112.0, 264.0), (113.0, 264.0), (114.0, 267.0), (115.0, 270.0), (116.0, 274.0), (117.0, 277.0), (118.0, 281.0), (119.0, 287.0), (120.0, 298.0), (121.0, 306.0), (122.0, 311.0), (123.0, 317.0), (124.0, 330.0), (125.0, 341.0), (126.0, 360.0), (127.0, 370.0), (128.0, 382.0), (129.0, 393.0), (130.0, 405.0), (131.0, 418.0), (132.0, 429.0), (133.0, 442.0), (134.0, 452.0), (135.0, 461.0), (136.0, 472.0), (137.0, 482.0)
UNITS: People

dying_1 = NAN(serious_cases_1) {DELAY CONVERTER}
"effect_of_social_gatherings_oncontact_rate_after_the_lock-down" = 38.4
UNITS: touch/person/day

Exposed_1 = NAN(infecting_1,exposing_1) {DELAY CONVERTER}
exposing_1 = NAN(risky_contacts_1) {DELAY CONVERTER}
fraction_of_susceptible_in_risk_of_infection = Susceptible/INIT_population
UNITS: dmnl

fraction_serious_all_time = IF TIME >137 THEN (IF POLICY_daily_confirmed_positive_CALIBRATOR <99 THEN fraction_serious_cases_low_times ELSE fraction_serious_cases_high_times) ELSE

(IF daily_confirmed_positive_REF_MODE < 99 THEN fraction_serious_cases_low_times ELSE fraction_serious_cases_high_times)
UNITS: dmnl

fraction_serious_cases_high_times = 0.729
UNITS: dmnl

fraction_serious_cases_low_times = 0.0585
UNITS: dmnl

increased_effectiveness_of_medical_treatment_of_critically_ill_patients = IF TIME > 100 THEN 0.5 ELSE 1
UNITS: dmnl

incubation_time = 10
UNITS: days

Infected_1 = NAN(dying_1,infecting_1,recovering_1) {DELAY CONVERTER}
infecting_1 = NAN(Exposed_1) {DELAY CONVERTER}
infectivity = 0.045
UNITS: person/touch

INIT_population = 8700000
UNITS: People

LD_duration = 51
UNITS: Days

LD_effectiveness = 0.6
UNITS: dmnl

"Lock-Down_start_time" = 10
UNITS: day

mortality_rate = avg_mortality_rate_of_serious_cases
UNITS: dmnl

POLICY_daily_confirmed_positive_CALIBRATOR = IF TIME > 240 THEN 98 ELSE 99
UNITS: People

"POLICY_mask-on_calibrator" = 0
UNITS: dmnl

"POLICY_mask-on_calibrator_1" = {DELAY CONVERTER}
POLICY_social_distancing_calibrator = 0
UNITS: dmnl

POLICY_social_distancing_calibrator_1 = {DELAY CONVERTER}
recovering_1 = NAN(Infected_1) {DELAY CONVERTER}
recovery_rate = 1-mortality_rate
UNITS: dmnl

recovery_time = 21
UNITS: day

*risky_contacts = IF TIME < 137 THEN fraction_of_susceptible_in_risk_of_infection*total_contacts_infected ELSE total_contacts_infected*fraction_of_susceptible_in_risk_of_infection*(1-"POLICY_mask-on_calibrator")*
UNITS: touch/day

risky_contacts_1 = NAN(Susceptible_1,total_contacts_infected_1,"POLICY_mask-on_calibrator_1") {DELAY CONVERTER}
*serious_cases = Infected*fraction_serious_all_time*
UNITS: People

serious_cases_1 = NAN(Infected_1) {DELAY CONVERTER}
severity_spread_adjustment = 0.93
UNITS: dmnl

"sickness_duration" = IF TIME < 30 THEN 3 ELSE 9*
UNITS: Days

Susceptible_1 = NAN(exposing_1) {DELAY CONVERTER}
testing_adjustment = 0.101
UNITS: dmnl

*total_contacts_infected = (IF TIME < 108 OR TIME >240 THEN AVG_contact_rate*total_infected ELSE IF TIME >108 OR TIME <137 THEN "effect_of_social_gatherings_oncontact_rate_after_the_lock-down"*total_infected ELSE (IF TIME >137 OR TIME < 240 THEN contact_adjustment*total_infected ELSE AVG_contact_rate*total_infected))*
UNITS: touch/day

total_contacts_infected_1 = NAN(total_infected_1,POLICY_social_distancing_calibrator_1) {DELAY CONVERTER}

total_covid19_units_data = 12661
UNITS: People

total_infected = Exposed+Infected
UNITS: People

total_infected_1 = NAN(Infected_1,Exposed_1) {DELAY CONVERTER}
total_number_of_expats = 317000
UNITS: People

{ The model has 61 (61) variables (array expansion in parens).
In root model and 0 additional modules with 0 sectors.
Stocks: 5 (5) Flows: 5 (5) Converters: 51 (51)
Constants: 31 (31) Equations: 25 (25) Graphicals: 4 (4)
}

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