**COVID1: Model description**

**A close up of a clock

Description automatically generated**

**The model is described by a set of differential equations for each age group (i=1 for** **age 0-19 years, i=2 for age 20-49 years, i=3 for age 50-69 years, and i=4 for age 70+ years):**

*pi* – proportion of the infections which become symptomatic by age

γ*1,* γ*2*- progression rates from exposed (E) to infectious (A and P) to symptomatic (I)

*di* – diagnostic rate (elevated after the start of the COVID measures at t=δ1)

*hi* – hospitalization rate among severe cases by age

– hospitalization rate among diagnosed by age (calculated)

*r1-3 -* recovery rate of the asymptomatic, mild symptomatic and hospitalized cases

*-* recovery rate of the diagnosed symptomatic cases by age (calculated)

– range of fatality rate among hospitalized by age based on the ICU capacity

*qi* – proportion of the hospitalized in critical condition by age

*fs -* slope of the sigmoid function (fixed)

– ICU capacity threshold

*A screenshot of a cell phone

Description automatically generated*

**2. Forces of infection**

The force of infections (represent the risk of the susceptible individuals in age group i to acquire infection through contacts with infected individuals from different age group and infection status:

where

*βa*, *βp*, *βs*, *βd*, *βh* – transmission rate from contacts with asymptomatic, pre-symptomatic, symptomatic, diagnosed and hospitalized cases (before the start of COVID measures at t= δ1)

*Rsd*(t)– reduction of transmission due to social distancing (scaled up linearly from 0 to between t= δ1 and t= δ2)

*cij*– contact matrix (proportion of the contact with other age groups)

*Ni*– population size by age

**Table S1. Parameters and ranges used in the analysis. (Fixed in black, Scenarios in blue, Calibration in red**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Description** | **Values and ranges** | **Type** | **Ref.** |
| ***γ1*** | **Progression rates from exposed (E) to infectious (A or P) (latent time)-1** | **(3 days)-1** | Fixed |  |
| ***γ2*** | **Progression rates from pre-symptomatic (P) to symptomatic (I) (pre-symptomatic time)-1** | **(2 days)-1** | Fixed |  |
| ***pi*** | **Proportion of the infections which become symptomatic by age** | * **Sc1: 70%** * **Sc2: 90%** | **Scenarios** | **IC – 66%** |
|  | **Diagnostic rate if symptomatic by age (*j*) before (*i=1*) and after (*i=2*) COVID measures are initiated** | ***d1,j*=1%, *d2,j*=1-10%)** | Calibration |  |
| ***id*** | **Symptomatic infectiousness duration** | ***7 days*** | Fixed |  |
| *βi* | **Daily transmission from infected from asymptomatic, pre-symptomatic, symptomatic, diagnosed and hospitalized groups in absence of COVID measures** | ***=βs\*(βa , βp , 1, βd , 0)***  ***Sc1: βa =0.25,***  ***Sc2:βa =0.1***  ***βp*** calculated to get 44% pre-sympt. transmission  ***βs =R0/(βp/γ2 + id) giving 0.24-0.4 for R0 = 3-5***  ***βd =0.5-0.75*** | Calculated | ***IC(R0=2.0-2.6)***  ***Christophe 10% asymp, IC 66% asymp*** |
|  | **Maximal reduction of transmission due to social distancing (scaled up linearly between t= δ1 and t= δ2)** | ***50%-90%*** | Calibration | ***IDM mobility paper*** |
| **δ0** | **Number of days between the start of the simulation (day 0) and the 1st diagnosed case from data (Feb.28)** | ***40-50*** | Calibration | ***Bedford*** |
| **[δ1, δ2]** | **Period of scaling up COVID measures** | **March 8-29** | Fixed |  |
| *mi* | **Proportion of symptomatic case which remain mild by age** | **99.8%, 96.9%, 87.1%, 74.5%** | Fixed | **IC need hosp. 0.2%, 3.1%, 12.9%, ~25.5%** |
| *hi* | **Hospitalization rate among severe cases by age** | ***h1=0.1, h2=0.15, h3=0.15-0.3, h4=0.15-0.3*** | Calibration | **MIDAS: 2.7-5.9 days** |
|  | **Hospitalization rate among symptomatic and diagnosed cases** |  | Calculated |  |
| ***r1*** | **Recovery rate of asymptomatic cases** | **(5 days)-1** | Fixed |  |
| ***r2*** | **Recovery rate of mild symptomatic cases** | ***1/id*** | Fixed | **Josh** |
|  | **Recovery rate of the symptomatic and diagnosed cases** |  | Calculated |  |
| ***r3*** | **Recovery rate of the hospitalized cases** | ***1/id*** | Fixed | **Josh** |
| ***hd*** | **Time from hospitalization to death** | **11.2 days** | fixed | **Sanche20** |
|  | **Fatality rate by age among hospitalized before reaching ICU capacity\* (overall mortality when hospitalized/time to death) adjusted for underreporting of mild cases** | **=α\*CFR/(1-mi)/hd**  **CFR: (0%,0.2%,2.1%,15.9%)**  **α =1-2** | calibration | Italy death chart  IC – overall 50% of critical cases + fraction of non-critical |
|  | **Fatality rate by age among hospitalized after reaching ICU capacity** |  | guess |  |
| *qi* | **Proportion hospitalized who need critical care** | **5%, 5.4%, 18.8%, 54.1%** (unused now) | fixed | IC |
|  | **ICU threshold (calculated on the basis of existing ICU capacity)** | 3000 (unused now) | fixed | IC - world |

Contact matrix (based on data from UK). The columns represent the distribution of contacts of a person from given age group across all age groups (transposed in the code):

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Proportion contacts with | 0-19 y | 20-49 y | 50-69 y | 70+ y |
| 0-19 y | 0.56 | 0.24 | 0.15 | 0.18 |
| 20-49 y | 0.34 | 0.57 | 0.49 | 0.34 |
| 50-69 y | 0.08 | 0.16 | 0.29 | 0.28 |
| 70+ y | 0.01 | 0.03 | 0.07 | 0.20 |
| **Contactness relative to old (unused)** | **1.83** | **1.59** | **1.26** | **1.00** |

**Initial population**

Total population: 2,118,119

King County age pyramid based on data from 2017

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Proportion of the population | 0-19 y | 20-49 y | 50-69 y | 70+ y |
|  | 22.93% | 45.52% | 23.50% | 8.05% |

Start the epidemic with 2 exposed in the 20-49y and 2 exposed in the 50-69y

**Calibration**

Criteria: 1) time series of cumulative diagnosed cases, 2) times series of cumulative deaths, 3) percentage of cumulative diagnosed cases for each age class at available dates, 4) percentage of cumulative deaths for each age class at available dates, 5) peak in new diagnosed cases (April 11)

Method: minimize (summed) mean squared error across 5 criteria using nsga2 algorithm in mco R package which provides a Pareto frontier of solutions

Decision making: we retain the set of parameter sets meeting a minimum error threshold for each of the 5 criteria, 1) empirically determined threshold, 2) empirically determined threshold, 3) empirically determined threshold, 4) empirically determined threshold, 5) 12 days [TODO these need better defining]

Current set of parameter sets to use for scenarios (optimized for pi = 0.7, will need to re-optimize for other pi values): I have a set of 41 parameterizations by optimizing a population of 500. I can increase this if we are happy with the threshold criteria.

**Return to normal scenarios:**

1) Gradually increase social activity and mobility over 2 months (May15- July 15) back to 75% of the pre-COVID levels (reduce *Rsd* to 25%). Keep influx of infected from outside at 0 by restricting long-distance travel and/or testing at arrival + quarantine.

2) Gradually increase social activity and mobility over 2 months (May15- July 15) back to 90% of the pre-COVID levels (reduce *Rsd* to 10%) for ages below 70 (age groups 1-3) but keep *Rsd*= 50% for age group 4. Keep influx of infected from outside at 0 by restricting long-distance travel and/or testing at arrival + quarantine.

**Intervention scenarios**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Intervention | d | ***βd*** | *h\** | d\* (diagnostic rates in A and P) | fi | r3 |
| Rapid test and isolate symptomatic | Increase to 5% and 10% | Decrease by 50% |  |  |  |  |
| Rapid test isolate and treat symptomatic | Increase to 5% and 10% | Decrease by 75% | Decrease by 50% |  |  |  |
| Rapid test and isolate symptomatic, trace and test contacts | Increase to 5% and 10% | Decrease by 50% |  | Assume 1-2%. Maybe higher in P? Try d\*(A)=0.01, d\*(P)=0.02 |  |  |
| Rapid test, isolate and treat symptomatic, trace, test and treat contacts | Increase to 5% and 10% | Decrease by 75% | Decrease by 50% | Assume 1-2%. Try d\*(A)=0.01, d\*(P)=0.02 |  |  |
| Mass testing and isolate | Increase by .5% | Decrease by 50% |  | Assume .5% |  |  |
| Mass testing, isolate and treat | Increase by .5% | Decrease by 75% | Decrease by 50% | Assume .5% |  |  |
| Effective inpatient treatment |  |  |  |  | Decrease by 50% | Increase to 20% |

**References:**

MIDAS: <https://midasnetwork.us/covid-19/>

IC: Imperial College, Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand

IC-world: Imperial College, The Global Impact of COVID-19 and Strategies for Mitigation and Suppression

Italy deaths: <https://jamanetwork.com/journals/jama/fullarticle/2763401?guestAccessKey=72f61225-c3fd-4fb1-81fd-09b6a1666aaa&utm_source=For_The_Media&utm_medium=referral&utm_campaign=ftm_links&utm_content=tfl&utm_term=031720>

Contact matrix: <https://journals.plos.org/plosmedicine/article?id=10.1371%2Fjournal.pmed.0050074&fbclid=IwAR3ezliJ6eJyDbqGpMky4USQ3-BuOn54Syqruf1QXC06SztZINOzXDGFGwg>

King county demographics:

https://factfinder.census.gov/bkmk/table/1.0/en/ACS/17\_5YR/S0101/0500000US53033