Government Responses to COVID-19: A Model of the Public Health Space

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Purpose

During the first quarter of 2020, governments around the world were confronted by a new virus that represented a major threat to public health. After a short time, it was designated as COVID-19, comparisons were quickly made with the 'Spanish Flu' of a century earlier, and its scale rapidly developed from an epidemic in a province of China to a worldwide pandemic.

The recommendations of public health agencies had varying degrees of success in convincing elected governments what needed to be done. Progressively, most countries implemented measures relating to spatial distancing, isolation, quarantine and travel. The results were enormously varied, with tens of thousands dead in some areas, and very few in others.

Public policy decisions were dependent, to varying degrees, on modelling of the spread of the disease, and to a lesser extent of the impacts of various forms of intervention. Many people were critical of the models that were thought to be in use, and concerns were exacerbated by the unwillingness of many governments to publish those models.

It's many years since I performed any modelling, and the art and science has moved a long way since then. However, I've conducted research in recent years on responsible data analytics, including responsible use of AI/ML techniques. My concern is that a great many people are stuck in old-fashioned 'applied science' mode. (Archetype: 'when you've got a hammer in your hand, everything looks like a nail'). In order to deal with novel problems, we need to avoid being tool-driven, and adopt an instrumentalist, problem-driven approach.

I accordingly set out to develop a model of states and flows that would encapsulate the minimal meaningful model that could have helped policy-makers who were being forced into doing 24-hour-cycle decision-making. Based on early whiteboarding, it's necessary to represent at least 15 states and 35 flows.

The purpose of the present exercise is <u>not</u> necessarily to produce something that is directly implementable. The minimum model is already complex, and much data is lacking.

The purposes I have in mind for the model <u>are</u>:

- as a framing tool for the problem-space:
    - to help people get their mind over the big picture
    - to help people appreciate the partialness of currently-computable models
- as an antidote to the problem of putting undue emphasis on outputs from limited, currently-computable models

A big-picture view encourages questions to be considered such as:

- Which data that we're missing right now would be the most valuable to have?
- What are the rates of infection among various segments of the population that are showing no symptoms?
- What degree of immunity do people have who have been infected and have passed their personal danger period?
- What is the degree of effectiveness of the various kinds of interventions?
- What are the key factors determining whether herd immunity arrives before the first vaccine?

My strong impression is that the models that have been actually used are epidemiological in origin and nature, and are relevant to only a sub-set of the problem-space, and even there have limitations. (Specifically, the models mostly appears to be based on SIR, SEIR, or SEIRD, which distinguish only the states of Susceptible - {Exposed} - Infectious - Recovered / Resistant - {Dead}). Such models may be highly valuable within the particular, constrained problem-space to which they are applicable, but potentially highly misleading even in adjacent parts of the overall problem-space.

The more general model that I'm working on exists in graphical form, supported by a textual description below.

Legend

This section provides a brief, textual outline of the intended meaning of the graphical model.

The relevant **Pool (1)** comprises people within a population (which might be the count of people in a country, a sub-jurisdiction, or a city) who have not yet moved to another of the following states.

Arrivals are assumed to feed into Pool (1), and **Departures** to extract individuals from it.

Each person in any state may move to **99 (Dead)**.

After each time-interval (typically 24 hours), each person in **Pool (1)** may:
- remain there (for an indefinite period)
- move to Tested (2)
- move to Isolation (9), in particular if determined to have been in close contact with a person who is known to be Infected
- move to Hospital-Queue (5) if their condition warrants it
- move to Inoculated (90) if they have received vaccination

Each person in **Tested (2)** may:
- remain there (for between 0 intervals – the Dutton case – and c.3 days, awaiting the result)
- move back to Pool (1) if the result was negative
- move to Detected (3) if the result was positive
- move to Hospital-Queue (5) if their condition warrants it
- move to Inoculated (90) if they have received vaccination

Each person in **Detected (3)** may:
- remain there (for between 0 and c.3 days depending on communications and logistics)
- move to Quarantine (4)
- move to Hospital-Queue (5) if their condition warrants it
- move to Detected-Recovered (80)

Each person in **Quarantine (4)** may:
- remain there for a fixed or variable number of time intervals (e.g. 7, 14 or 21 days)
- move to Hospital-Queue (5) if their condition warrants it
- move to Detected-Recovered (80)

Each person in **Hospital-Queue (5)** may:
- remain there for zero or more time intervals, depending on hospital capacity and their condition
- move to Hospital (6)
- move back to Quarantine (4)
- move to Detected-Recovered (80)

Each person in **Hospital (6)** may:
- remain there for a number of time intervals, depending on their condition and hospital capacity
- move to ICU-Queue (7)
- move back to Quarantine (4)
- move to Detected-Recovered (80)

Each person in **ICU-Queue (7)** may:
- remain there for zero or more time intervals, depending on hospital capacity and their condition
- move to ICU (8)
- move back to Hospital (6)
- move to Detected-Recovered (80)

Each person in **ICU (8)** may:
- remain there for a number of time intervals, depending on their condition and ICU capacity
- move back to Hospital (6)

Each person in **Isolation (9)** may:
- remain there for between 1 and 21 days, depending on the date of the infection contact
- move back to Pool (1)
- move to Tested (2)
- move to Hospital-Queue (5) if their condition warrants it
- move to Inoculated (90) if they have received vaccination

Some of the Model's Simplifications and Known Limitations

The current form of the model may not be applicable to **sub-populations based on demographic characteristics**, such as 'over 70s', 'people with prior CV-relevant conditions' or 'pre-school children'.

The current form of the model does not support **sub-populations based on living conditions**, such as retirement homes, dormitory accommodation such as backpackers' hostels, or street-living.

The current form of the model also does not explicitly allow for **differential treatment of sub-populations**, although this could be achieved by assigning attributes to people, and applying different ratios to state-transitions depending on those attributes (e.g. a higher proportion of people over 70, once infected, are admitted to hospital).

It may be inappropriate to allocate all Arrivals to Pool (1). It may be necessary to allow for the possibility of **direct entry for a proportion of Arrivals** (or zero time-delays in intermediate states), enabling them to move directly to Tested (2), Isolation (9), Quarantine (4) or Hospital-Queue (5).

The terminal state **Dead (99)** needs to be categorised more finely according to cause of death:

a. CV was the cause of death
b. CV was a significant factor in the death, by compounding prior conditions
c. CV infection was present at death
d. CV infection was assumed present at death
e. no known CV infection

Excess mortality can then be computed as (a+b).

Undetected (64) is currently only semi-connected, but flows to Dead (99) will occur, and by definition need to be allocated to one of causes of death a. to e. above.

Undetected (64) could have a feed in from Pool (1) and from Isolation (9), but a rationale is needed for assigning proportions to the flows. It could then also feed to Tested (2), and perhaps directly to Detected (3) or Hospital-Queue (5).

Undetected-Recovered (88) is currently fed from an only semi-connected state. However, it can be estimated if tests for immunity are applied to samples with known demographics.

In its current form, the model lacks representation of **non-CV instances** of admission to hospital and ICU, and non-CV causes of death.

Although the flow from Pool (1) to Undetected (64) is by definition unmeasurable and challenging to estimate, instances from it do migrate forwards, and become measurable when they present, are tested and prove to be positive. In its current form, the model lacks representation of **transitions of CV-instances from Undetected (64) to Hospital-Queue (5) and onwards**.

The Nature of the SEIR Model

The dominant model that appears to have been used in support of public health policy responses to the COVID-19 pandemic has been an epidemiological model most commonly referred to as 'SEIR'.

One potential application for the present modelling work is as a means of assessing the extent to which SEIR models are appropriate sources of guidance to policy-makers.

Documents that report on applications of the SEIR model generally provide no operational definition for the key concepts. They use each of S, E, I and R as though they were so well-understood, and so consistently applied, that declaration of their meaning, and discussion of those meanings' appropriateness to purpose, were redundant.

The primary reference appears to be Aron & Schwartz (1984). The underlying SIR model may have arisen from, or at least may be related to, Kermack & McKendrick (1927).

Aron & Schwartz postulates that the population consists of four groups:

- S is the fraction of **Susceptible** individuals
  (those able to contract the disease)
- E is the fraction of **Exposed** individuals
  (those who have been infected but are not yet infectious)
- I is the fraction of **Infective** individuals
  (those capable of transmitting the disease)
- R is the fraction of **Recovered** individuals
  (those who have become immune)

Variants that are apparent in various publications, usually also without any discussion concerning their variance from the above notions, include:

- R is sometimes referred to as **'Resistant'** (which presumably strengthens the assumption of immunity) and sometimes as **'Removed'** (presumably removing the assumption of immunity, but it might also include those who are Dead)
- E is also referred to as **'Latent'**. So it might mean 'has been near a source of infection', or 'is infected, but is not yet infectious'
- Leakage from each state may be acknowledged, as a proportion of the count who die
- D is sometimes added, for **Dead (but still infectious)**, e.g. re Ebola (Weitz & Dushoff 2015)

It is unclear whether 'Susceptible' means everyone who has not yet passed on to a later stage, or a sub-set, e.g. everyone with relevant pre-conditions. It appears there is an assumption that zero time passes between the end of being infectious and the beginning of being immune.

It is possible that there are material differences between the meanings of the concepts in the models that are applied by policy-makers, and the definitions of the empirical data whereby comparisons between model results and real-world behaviours are made. There may also be material differences in the meanings of the concepts among the various models.

It would also appear that the SEIRD family of models can only clumsily represent interventions (in particular Isolation, Quarantine, Hospitalisation and ICU-Admission) by means of variations in parameters, rather than by direct representation and simulation.

References

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