Modelling and the COVID-19 Pandemic

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COVID-19 Actuaries Response Group - Learn, educate, inform and influence

Introduction
Fighting this COVID-19 pandemic requires a good grasp on how the virus spreads, impacts health care demand and could be managed. This bulletin highlights some examples of how mathematical modelling has contributed to the understanding and intervention of this pandemic, “the health crisis of a generation”.

Slowing down the spread of the virus is central to international policies. A common measure for the spread of a disease is the average number of people who will catch a disease from one infectious person, the reproductive number R. If R is greater than 1, then the disease is expected to spread. If R is less than 1, the disease will become extinct. This has been used to define policy objectives, for example whether the policies aim to reduce R to a lower level, but above 1, to slow transmission or to aim to reduce R to below 1 to end the epidemic (Ferguson et al., 2020).

At the start of a new outbreak, there will be much interest on R in an environment when the whole population is susceptible to the new infectious agent. This is the basic reproductive number R_0. The higher the R_0 above 1, the faster the disease can spread.

Early outbreak
During the early stage of the outbreak in January 2020, much effort was put into estimating R_0 of COVID-19 to understand the nature of transmission and enable further modelling. However, R_0 is a calculated number requiring estimates on the duration a person can be infectious, in contact with people and the likelihood of transmission when in contact. Liu Y et al. (2020) reported that there were 12 studies that published R_0 for COVID-19 between 1 January and 7 February 2020. All the studies agree that R_0 is greater than 1, implying that the virus will spread. This finding when combined with statistics on demands for intensive care and death prompted drastic measures to contain the virus in China. However, the range of R_0 of about 1.5 to 7 is wide. It is important to note that there is uncertainty around this figure. Models that uses R_0 in China as an input, such as Ferguson et al. (2020) and Danon et al. (2020) will need to know how the wide range of estimates would affect outputs.

Epidemic in China
Modelling has been used to better understand how the spread of COVID-19 changed over time in the epicentre of the outbreak in Wuhan and how the virus might be ‘exported’ from China to other countries. Kucharski et al. (2020) reported that the median daily reproduction number dropped from 2.35 a week before travel ban on 23 January to 1.05 a week after, suggesting travel bans have a rapid effect in slowing spread. The authors also estimated that it needs only 4 cases in a new population to have more than 50% chance of starting an outbreak, highlighting the importance of tracing newly infected cases and border control. However, attempts to contain the virus through tracing and isolation. A model suggests that we must trace and isolate 8 in 10 contagious persons introduced to a new environment susceptible to the virus to be 40-90% successful in avoiding a COVID-19 outbreak (Hellewell et al., 2020).

Given the severe financial impact of the epidemic in China, attempts have been made to model when the epidemic would be under control in China following different interventions. For example, Liu et al. (2020) considered ‘the unprecedented strict quarantine measures in almost the whole of China to resist the epidemic’. They concluded that the epidemic would peak in February and be controlled by the end of March, 2020 with stringent lockdown in China. At the time of writing at around end of

March, the epidemic is indeed under control and lockdown measures are being lifted in parts of China. However, China is now worried about potential waves of new outbreak from imported cases from other countries. New cases, possible flare ups, are indeed being detected in China as shown in the following new case time series since 1 March 2020:

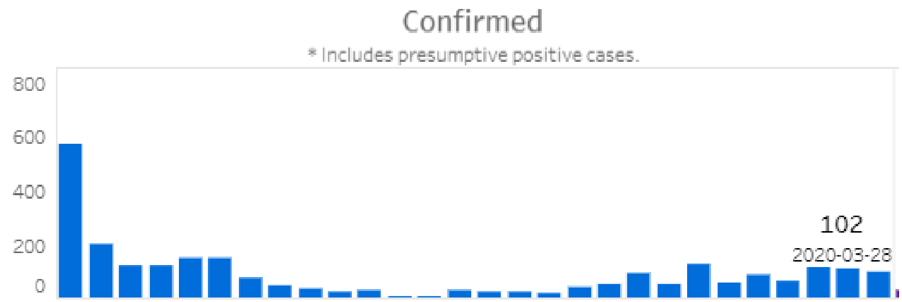

Tableau Public based on Johns Hopkins University dataset

https://public.tableau.com/profile/covid.19.data.resource.hub#!/vizhome/COVID-19Cases_15840488375320/COVID-19Cases

Pre-pandemic
By mid-February COVID-19 had spread to some 25 countries but pandemic wasn't declared by the WHO yet. There were concerns that COVID-19 may overwhelm health care systems in countries with less comprehensive public health facilities in the African continent. Gilbert and co-workers (2020) estimated the risk of 'importing' COVID-19 from China into Africa, by examining the volume of air travel flying from various infected provinces in China into Africa.

The authors identified Egypt, Algeria and South Africa to be at high risk of importing the virus, while their public health systems have moderate to high capacity to respond to outbreaks. Nigeria, Ethiopia, Sudan, Angola, Tanzania Ghana and Kenya have moderate risk of importing COVID-19. They have variable health care capacity and are relatively vulnerable to consequences of a pandemic. By matching countries at risks of importing the virus and their capacity to cope, resources can be prioritised. The researchers proposed 'Resources, intensified surveillance, and capacity building should be urgently prioritised in countries with moderate risk that might be ill-prepared to detect imported cases and to limit onward transmission.'

Pandemic
On 11 March, WHO declared COVID-19 to be a pandemic. The next day, the UK announced that the government would change tactics from trying to contain the virus to delaying spread, but without rules on social distancing, in contrast to lockdown measures in China and Italy. On 16 March, Ferguson and colleagues (2020) released the results of their modelling of the impacts of potential interventions on the spread, intensive care demand and deaths related to the virus in the UK. They concluded that, without interventions, the UK could expect to see 510k people killed by the virus in 2020. For context, total UK deaths in 2018 was 616k. They considered 2 types of strategies: Suppression and Mitigation summarised in the table below.

	Suppression	Mitigation
Aim	Reduce average new infections generated by each case, called reproduction number R to below 1.	Reduce health impact, not to interrupt transmission completely.

End result	Reduce case numbers to low levels like SARS or Ebola, for as long as possible or until a vaccine is available.	Herd immunity. Population immunity builds up, leading to rapid decline in cases.
Interventions	Case isolation. Household quarantine. Social distancing: 70+/ all. Close schools. Combination.	Similar but without social distancing for all.
Duration	On-off 2 thirds of 18 months. 5 months but risk a come-back in winter, as the population would not have achieved herd immunity.	3 months.
Deaths	6-120k over 2020 and 2021, depending on scenarios.	250k in 2020

The model proposed that combined interventions of isolating symptomatic cases and their household, social distancing of the whole population and closure of educational institutions over 5 months would suppress the number of people needing critical care beds to be within capacity at each point in time. However, this risks a come-back of the virus to crash critical care capacity in the winter of 2020, as the population would not have had the required immunity. The authors suggested a scenario where the suppression strategy is implemented over at least two thirds of 18 months, with school closure and social distancing triggered on-and-off by critical care capacity, with the other policies being in place.

Their results highlighted the severity of the pandemic on the UK and urgent actions were needed to avoid a catastrophe. As number of cases and deaths continued to rise, the UK subsequently introduced school closure and social distancing measures. By 23 March the UK was under lockdown with rules including the banning of gathering of more than 2 people in public and people should only leave their homes for essential activities.

With a high proportion of infected people displaying little or no symptoms, the lack of a blood test to confirm how many people are indeed infected is problematic to modelling. For example, without the number of people infected, we would not know if the proportion of infected at risk of severe disease is 1 in 10, 100 or 1,000. Lourenco and colleagues (2020) showed that this uncertainty could lead to a wide range of estimates for the percentage of people infected and immune in the UK, ranging from 5% to 70% by around mid-March. This has an important policy implication. If the population is, say 70% infected and immune, no stringent measure is needed because we have achieved herd immunity. If it is only 5% immune, then the UK has challenging days ahead and the lockdown is essential.

Comments

A wide range of mathematical models, designed with different purposes and features, have played important roles in understanding the nature, projection and management of this COVID-19 pandemic. They have informed policies to contain and delay spread. However, the inputs, processes and outputs of the various models are subject to uncertainty and limitations. This means that we need to treat the results carefully. Members of the Actuarial Profession are tasked to manage pandemic risks in insurance or reinsurance firms. It is important that the profession is at the forefront of understanding and modelling pandemics.

We recommend that the Institute and Faculty of Actuaries:

1. Ensures it has access to international thought leaders in the area of pandemic modelling. This may be done through collaborative research or appointing eminent leaders in this field to be honorary fellows.

2. Creates opportunities for members to learn and network with experts from other disciplines that involve in pandemic management.
3. Encourages members to engage with international modelling community by sharing models, expertise and experience.

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