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Stochastic Modelling of Covid-19

In this article Kees van Heugten, Rob Smit and Servaas Houben show the benefits of a stochastic model for Covid-19 infections in the Netherlands.

Due to the current Covid-19 pandemic, there are several models that describe the behaviour of viruses. Studying the models that are publicly available, the authors of this article concluded that these tend to be deterministic, projecting only the most likely outcomes in terms of the number of people who will suffer from the virus. Governments introduced measures in response to Covid-19, because severely ill people need medical or intensive care. The Corona-dashboards generally used give information about relevant metrics, like the number of infected in the country, the reproduction factor and the number of people that get hospitalized or need to go to the intensive care, but not confidence intervals around these. This article in introduces such a model.

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THE STATUS OF AN INDIVIDUAL IN THE POPULATION

In general, the virus models use more or less the same statuses that an individual can have in relation to the virus. An individual can be healthy (never infected), be infected, can become sick due to the virus, can recover from sickness (and possibly be immune for a certain period), can become healthy again or die due to the sickness.

THE ASYMMETRICAL BEHAVIOUR OF COVID-19

The Covid-19 virus behaves asymmetrically: there are infected individuals who do not infect others, as well as individuals who infect a lot of others people (see Figure 1). This aspect is described by Smith in Nature (2005). Due to this behaviour we see local outbreaks of the virus and 'super spread events'.

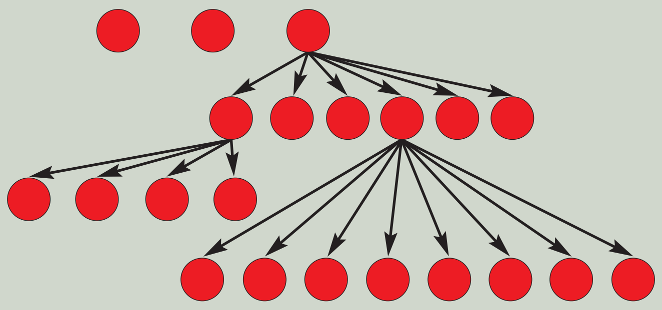

Figure 1: asymmetrical infection process

Deterministic models that work with a population reproduction factor do not take this behaviour into account, which can result in an under estimation of the expected capacity for hospitals and ICU. In our Covid-19 model we therefore introduce individual reproductions factors that are assumed to drawn from a skewed probability distribution. To get the required skewness we use the discrete Gamma distribution.

SIMULATIONS USING THE ASYMMETRICAL BEHAVIOUR OF COVID-19

Based on the age distribution of the Dutch population and taking into account the assumptions regarding the levels of sickness (asymptomatic, medium symptomatic sick and severely sick) and corresponding assumptions regarding the duration of immunity, we simulated the stochastic behaviour of Covid-19.

Figure 2 illustrates the number of severe sick individuals per 10,000 inhabitants. It is assumed that there are 10 hospital and ICU beds available per 10,000 inhabitants and the maximum hospital capacity is 23. Without taking measures, we observe that the average number of beds will be 40 in 10,000, so the capacity of beds will be too limited. Therefore, measures need to be taken to 'flatten the curve' to avoid the expected capacity problems.

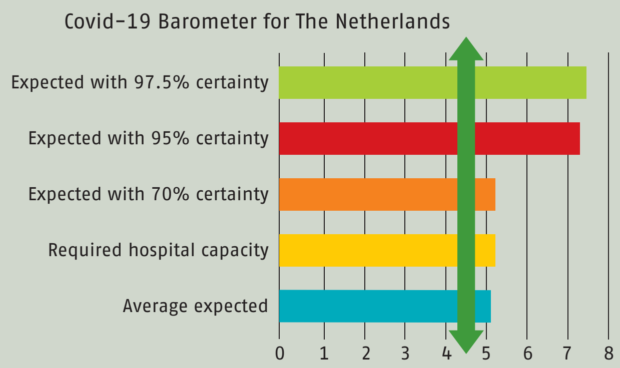

Figure 2: number of severe sick, without intervention

Figure 3 illustrates the number of severe sick individuals per 10,000 inhabitants, assuming that measures are taken. When the number of severely sick individuals is above 2 per 10.000 or the number of infected individuals is more that 1% of the population, measures are introduced to reduce the reproduction factor to 1. As a result, one can observe that on average the number of severely sick individuals has a maximum value of 10 per 10,000 which matches the capacity of available beds. Looking at the 50 scenarios that are simulated we see that planning based on the average number can still result in capacity problems in relation to the number of available beds: there are scenarios that require almost 50% extra capacity than expected.

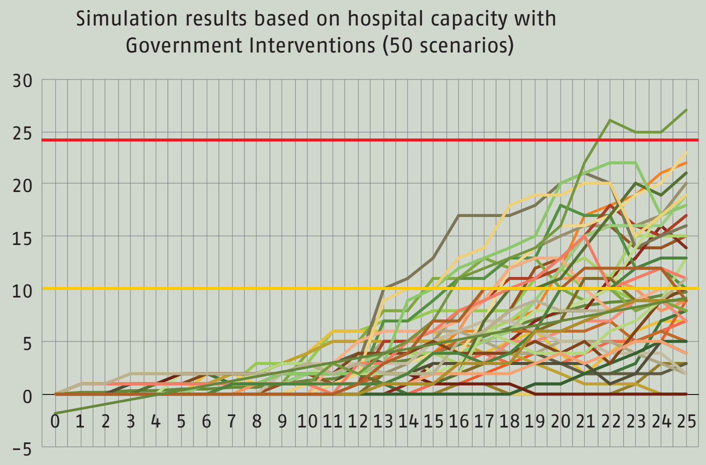

Figure 3: Number of severe sick, with intervention

INTRODUCING A STOCHASTIC DASHBOARD

The current dashboards that are used by governments do not take into account the stochastic nature of the Covid-19 virus, which can lead to an underestimation of the capacity needed. The authors therefore introduce a Corona-dashboard that takes into account the stochastic nature of Covid-19 (figure 4).

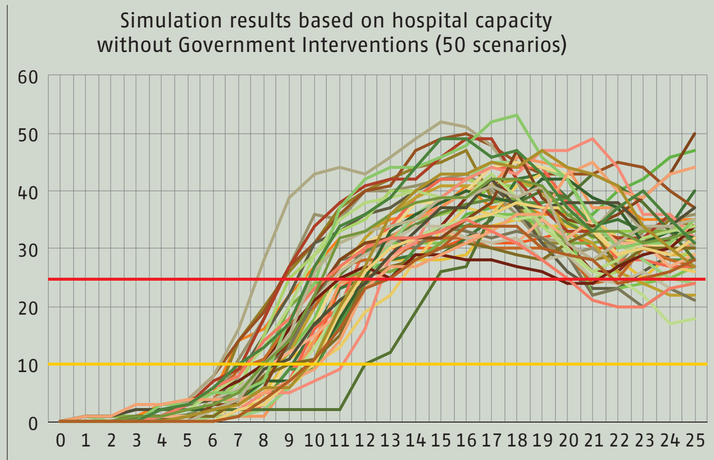

Figure 4: Barometer Covid-19 hospital and ICU capacity

This dashboard shows the average capacity needed within four weeks from the current date (predicting the capacity at September 28, 2020), based on the number of infections, the current reproduction factor, taking into account the local outbreak character of the virus and the skewness of infections. The hospital and ICU capacity is represented by the green vertical line of 5 beds per 10.000 (50% of the capacity as shown in figure 2 and 3). The dashboard not only shows the average number of beds per 10,000 inhabitants, but also the confidence level of the number of beds once more or less beds are reserved to cover for Covid-19 patients. This dashboard gives the policy makers extra information regarding planning, in addition to the use of models that are only based on averages.

NEXT STEPS

In this article we introduced a new Corona-dashboard, that takes into account the stochastic nature of Covid-19. Policy makers can use this dashboard to plan the capacity taking into account the confidence level that they require, i.e. the level of risk they are willing to assume.

To arrive at a more reliable Corona-dashboard, the authors recognized the following questions that need to be answered:

- Do asymptomatic sick individuals infect others? And if so, do they infect with a lower reproduction rate compared to the infected and symptomatic cases?
- What is the level of skewness of the Covid-19 infections? The confidence levels depend on the assumed level of skewness of the infections
- What is the duration of immunity and is this related to the level of sickness of an individual?

A Corona-dashboard taking into account the confidence level is a useful tool for policy makers and will even be more useful when these questions are answered, to get smaller and more precise intervals.

For the interested reader we refer to our educational website www.crownactuaries.eu for further information and discussion. ■