System Dynamics of Epidemics

Dr Stephen Duncan
Department of Engineering Science
University of Oxford
United Kingdom

The spread of a disease through a population can be modelled in terms of a series of coupled first order non-linear differential equations. The design of strategies for eradicating an outbreak of a disease through vaccination, quarantine and other public health measures, is critically dependent on an accurate measure of the transmissibility of the virus, which can only be obtained from a suitable set of data. Ideally, the transmissibility should be estimated from the number of cases of the diseases that occur over a long period of time in a large population. In the case of smallpox, since the disease has been eradicated from the population, the number of outbreaks in recent times is very limited and estimates of the transmissibility of the disease that have varied widely. Recent work has used data from the Bills of Mortality in London, which recorded the number of smallpox deaths each week from 1708 to 1880. Each week throughout this period, there was an average of 40 deaths due to smallpox, indicating that the disease was endemic, but there were also a series of regular outbreaks of the disease. By modelling the dynamics of the disease as a linear system with a non-linear feedback term, the transmissibility of the virus can be estimated from the *frequency* of outbreaks. It is also possible to show that the outbreaks are related to variations in the susceptibility of individuals to the disease, which in turn, are related to environmental factors such as the weather. This analysis provides an estimate of the transmissibility in early 18^{th} Century London, but given the changes in public health, lifestyle and density of population, this will not necessarily be the same as the transmissibility of the disease in modern times. However, because the transmissibility of measles over the period 1708 to 1748 can also be estimated from the same data source, an estimate of the *relative* transmissibilities of the two diseases over this period can be obtained. Since the transmissibility of measles in modern times is known with a high degree of accuracy, the corresponding modern transmissibility of smallpox can be estimated. Analysing the data in this way leads to estimates of the transmissibility of smallpox that is at the upper end of the current ranges of estimates that have been reported in the literature.