Pandemic Equation and COVID-19 Evolution

Subjects: Mathematics

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The Pandemic Equation describes multiple pandemic waves and has been applied to describe the COVID-19 pandemic. Using the generalized approaches of solid-state physics, we derive the Pandemic Equation, which accounts for the effects of pandemic mitigation measures and multiple pandemic waves. The Pandemic Equation uses slow and fast time scales for “curve flattening” and describing vaccination and mitigation measures and the Scaled Fermi–Dirac distribution functions for describing transitions between pandemic waves. The Pandemic Equation parameters extracted from the pandemic curves can be used for comparing different scenarios of the pandemic evolution and for extrapolating the pandemic evolution curves for the periods of time on the order of the instantaneous Pandemic Equation characteristic time constant. The parameter extraction for multiple locations could also allow for uncertainty quantification for such pandemic evolution predictions.

Keywords: outbreak ; endemic ; pandemic ; COVID-19 ; Ebola ; SARS ; plaque ; pandemic equation ; HIV ; Spanish Flu

Introduction

A pandemic is defined as an epidemic that occurs on more than one continent [1]. An epidemic is a more severe event than an outbreak of a disease, which is a sudden increase in disease occurrence. An epidemic is a large number of outbreaks spreading to a large geographical area.

Epidemics and pandemics such as the Athenian Plague (430 BC [2], Antonine Plague (165–180 AD) [3], Justian Plague (541 AD) [4]. Black Death (1346–1353), the Seven Cholera Pandemics (1827–1961), Spanish Flu (1918) [5], HIV, Ebola, Severe Acute Respiratory Syndrome (SARS) (2002–2003), and COVID-19 have caused deaths and economic hardship. The predicted dramatic increase in world population of slums (from 1.1 billion people today to over 3 billion expected in 30 years from now [6]) with no access to pure drinking water and related population migration are some of the reasons that mean that future pandemics are unavoidable and might be harder to control. Other factors making pandemics more difficult to control include the overuse of antibiotics and pesticides, widespread problems with healthcare systems worldwide, corruption, wars, and racial problems. In addition, the World Health Organization is relying more and more on private donations from donors who might have their own agenda to promote, making preventing and controlling pandemics more difficult [7]. Unavoidably, pandemics cause stereotypes and psychological problems, exacerbating the pandemic problems.

This is why an expected future mysterious and disastrous pandemic Disease X (20 times more infectious than the COVID-19 pandemic) was discussed in DAVOS 24 (one of the sessions was called “Preparing for Disease X”) [8].

A part of such preparation is the development of simple but effective mathematical approaches to monitor and analyze pandemics, such as the Pandemic Equation [9][10].

When a pandemic comes it develops more rapidly in hot spots and infection rates are dramatically different in different locations. The optimum measures to control a pandemic also vary a lot from nation to nation, from one community to another, or from a university campus to an elementary school. To achieve that control, we need to analyze complex and vastly varying data accurately interpolating overall time and space dependencies of infection rates, related hospital admissions, and deaths, as well as such dependencies for certain groups, for example, immune-suppressed people.

To this end, the Pandemic Equation borrowed such an approach from the quantum theory of solids comprised of practically infinite numbers of nuclei and electrons.

Solids are comprised of nuclei and electrons whose masses are as different as the mass of a behemoth and a sparrow, and the electronic motion, compared to the nucleus motion as fast as a flight of a sparrow, to a behemoth motion.

Similarly, the Pandemic Equation uses a fast time scale of an exponential pandemic growth or decay but varies the characteristic time of its evolution on a much slower time scale.

Another concept borrowed from the solid-state theory is the Fermi–Dirac Distribution function. This function describes a gradual transition between two states and the abruptness of such a transition is controlled by a temperature parameter varying from a very abrupt at low temperatures to very gradual at high temperatures. This function is generalized in this paper to introduce a Scaled Fermi–Dirac function. This function is perfectly suited for the interpolation of complicated transitions in pandemic events related to mitigation measures or the introduction of new drugs.

Pandemics often come in waves having many peaks and valleys. As an example, see **Figure 1** showing the weekly deaths caused by the COVID-19 pandemic. The Pandemic Equation describes a pandemic as a summary of such waves. A more accurate approach introduced in this paper is using another concept similar to so-called Vegard's law in materials science. This law interpolates the properties of a mixture by a linear combination of the properties of the mixture components. In this paper, we introduce a Scaled Vegard's Law that accurately interpolates the transition between the pandemic waves.

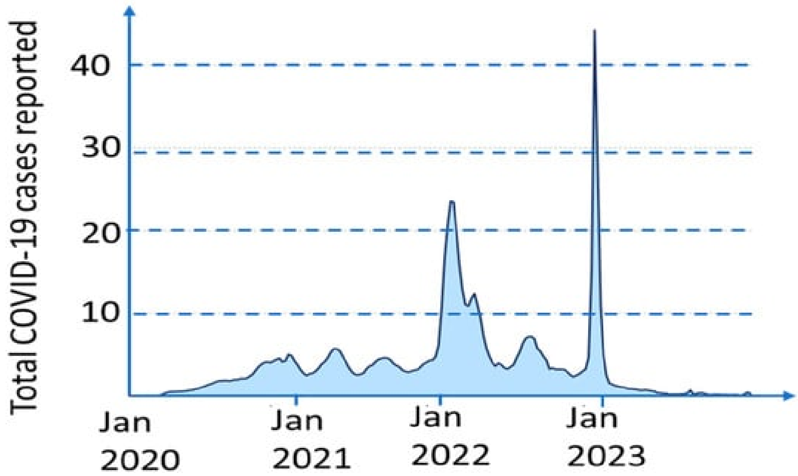

Figure 1. Weekly COVID-19 cases reported worldwide (in millions). Data from [11].

The COVID-19 pandemic was unique in terms of enormous data collection, and we applied the Pandemic Equation method to the COVID-19 epidemic. However, the results of the COVID-19 analysis could teach us valuable lessons and help combat future possible pandemics.

The Pandemic Equation parameters extracted from the pandemic curves can be used for comparing different scenarios of the pandemic evolution and for extrapolating the pandemic evolution curves for the periods of time on the order of the instantaneous Pandemic Equation characteristic time constant. The parameter extraction for multiple locations could also allow for uncertainty quantification for such pandemic evolution predictions.

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