Mathematical Models of Epidemics

Christopher Lin, Math 89S Spring 2016

Epidemics occur often, and result in both severe human and monetary losses. However mathematical modeling of the spread of infectious diseases can reveal important insights into their behavior, and help scientists and policy makers prevent or reduce their adverse impacts.

What is an Epidemic?

Generally, an epidemic is the spread of a disease to a large number of people over a short period of time. Epidemics are divided into two major types: common source, and propagated outbreaks. Common source outbreaks occur when individuals are exposed to the same toxin or infectious agent. The epidemic of leukemia in Hiroshima following the atomic bomb detonation, or an outbreak of E. coli from a batch of infected vegetables would be examples of epidemics caused by a common source. More relevant to our discussion in this paper, are propagated outbreaks. In a propagated outbreak, disease is spread from person to person, such as in the case of influenza or syphilis. A propagated outbreak can also be spread by other vectors, such as mosquitoes in the case of malaria. When an epidemic spreads to encompass multiple countries or continents, it is often reclassified as a pandemic (Principles of Epidemiology in Public Health Practice).

Epidemics can cause massive human and economic losses. The Spanish Flu epidemic in 1918 caused between 40 and 50 million deaths. Asian influenza in 1957 killed 2 million, and Hong Kong influenza in 1968 resulted in 1 million deaths (What are Epidemics). Every year, in the United States alone, more than 200,000 people are hospitalized due to influenza, and anywhere from 5% to 20% of the population becomes infected. It is estimated that between 3,000 to 49,000 people die from influenza each year (Seasonal Influenza). Economic damage can also be severe; one study estimated that the 2002 SARS outbreak in East Asia resulted in a 2.63% drop in GDP in Hong Kong, and a 1.5% drop in GDP in mainland China (Lee and McKibbin, 2004).

Because epidemics hold possibly dire consequences for entire countries, regions, or continents, it is extremely important for scientists and policy makers to prevent epidemics if possible. However, due to the complex and large-scale nature of epidemics, it is basically impossible to perform non-retrospective studies. Furthermore, any sort of controlled experiment in which a population is infected with a disease would be incredibly unethical. Thus, the best way to study, predict, and experiment with the behavior of epidemics is through mathematical modeling.

Mathematical Modeling

One of the first to develop a mathematical model of disease was the Swiss scientist and mathematician, Daniel Bernoulli, who was best known for his work with the mathematics of fluid mechanics. In 1766, Bernoulli, using a simple compartmental model and census data, was able to show that vaccinating

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H.A. Lauwerier

Mathematical Models Of Epidemics:

Mathematical Models in Epidemiology Fred Brauer,Carlos Castillo-Chavez,Zhilan Feng,2019-10-10 The book is a comprehensive self contained introduction to the mathematical modeling and analysis of disease transmission models It includes i an introduction to the main concepts of compartmental models including models with heterogeneous mixing of individuals and models for vector transmitted diseases ii a detailed analysis of models for important specific diseases including tuberculosis HIV AIDS influenza Ebola virus disease malaria dengue fever and the Zika virus iii an introduction to more advanced mathematical topics including age structure spatial structure and mobility and iv some challenges and opportunities for the future There are exercises of varying degrees of difficulty and projects leading to new research directions For the benefit of public health professionals whose contact with mathematics may not be recent there is an appendix covering the necessary mathematical background There are indications which sections require a strong mathematical background so that the book can be useful for both mathematical modelers and public health professionals

Mathematical Epidemiology Fred Brauer,Pauline van den Driessche,J. Wu,2008-04-13 Based on lecture notes of two summer schools with a mixed audience from mathematical sciences epidemiology and public health this volume offers a comprehensive introduction to basic ideas and techniques in modeling infectious diseases for the comparison of strategies to plan for an anticipated epidemic or pandemic and to deal with a disease outbreak in real time It covers detailed case studies for diseases including pandemic influenza West Nile virus and childhood diseases Models for other diseases including Severe Acute Respiratory Syndrome fox rabies and sexually transmitted infections are included as applications Its chapters are coherent and complementary independent units In order to accustom students to look at the current literature and to experience different perspectives no attempt has been made to achieve united writing style or unified notation Notes on some mathematical background calculus matrix algebra differential equations and probability have been prepared and may be downloaded at the web site of the Centre for Disease Modeling www cdm yorku ca **Mathematical Epidemiology of Infectious Diseases** O. Diekmann,J. A. P. Heesterbeek,2000-04-07 Mathematical Epidemiology of Infectious Diseases Model Building Analysis and Interpretation O Diekmann University of Utrecht The Netherlands J A P Heesterbeek Centre for Biometry Wageningen The Netherlands The mathematical modelling of epidemics in populations is a vast and important area of study It is about translating biological assumptions into mathematics about mathematical analysis aided by interpretation and about obtaining insight into epidemic phenomena when translating mathematical results back into population biology Model assumptions are formulated in terms of usually stochastic behaviour of individuals and then the resulting phenomena at the population level are unravelled Conceptual clarity is attained assumptions are stated clearly hidden working hypotheses are attained and mechanistic links between different observables are exposed Features Model construction analysis and interpretation receive detailed attention Uniquely covers both deterministic and stochastic viewpoints Examples

of applications given throughout Extensive coverage of the latest research into the mathematical modelling of epidemics of infectious diseases Provides a solid foundation of modelling skills The reader will learn to translate model analyse and interpret with the help of the numerous exercises In literally working through this text the reader acquires modelling skills that are also valuable outside of epidemiology certainly within population dynamics but even beyond that In addition the reader receives training in mathematical argumentation The text is aimed at applied mathematicians with an interest in population biology and epidemiology at theoretical biologists and epidemiologists Previous exposure to epidemic concepts is not required as all background information is given The book is primarily aimed at self study and ideally suited for small discussion groups or for use as a course text   An Introduction to Mathematical Modeling of Infectious Diseases Michael Y. Li,2018-01-30 This text provides essential modeling skills and methodology for the study of infectious diseases through a one semester modeling course or directed individual studies The book includes mathematical descriptions of epidemiological concepts and uses classic epidemic models to introduce different mathematical methods in model analysis Matlab codes are also included for numerical implementations It is primarily written for upper undergraduate and beginning graduate students in mathematical sciences who have an interest in mathematical modeling of infectious diseases Although written in a rigorous mathematical manner the style is not unfriendly to non mathematicians   **Mathematical and Statistical Modeling for Emerging and Re-emerging Infectious Diseases** Gerardo Chowell,James M. Hyman,2016-07-27 The contributions by epidemic modeling experts describe how mathematical models and statistical forecasting are created to capture the most important aspects of an emerging epidemic Readers will discover a broad range of approaches to address questions such as Can we control Ebola via ring vaccination strategies How quickly should we detect Ebola cases to ensure epidemic control What is the likelihood that an Ebola epidemic in West Africa leads to secondary outbreaks in other parts of the world When does it matter to incorporate the role of disease induced mortality on epidemic models What is the role of behavior changes on Ebola dynamics How can we better understand the control of cholera or Ebola using optimal control theory How should a population be structured in order to mimic the transmission dynamics of diseases such as chlamydia Ebola or cholera How can we objectively determine the end of an epidemic How can we use metapopulation models to understand the role of movement restrictions and migration patterns on the spread of infectious diseases How can we capture the impact of household transmission using compartmental epidemic models How could behavior dependent vaccination affect the dynamical outcomes of epidemic models The derivation and analysis of the mathematical models addressing these questions provides a wide ranging overview of the new approaches being created to better forecast and mitigate emerging epidemics This book will be of interest to researchers in the field of mathematical epidemiology as well as public health workers   Mathematical Models for Communicable Diseases Fred Brauer,Carlos Castillo-Chaavez,2012-01-01 This graduate level textbook appeals to readers interested in the mathematical theory of disease transmission models It is

self contained and accessible to readers who are comfortable with calculus elementary differential equations and linear algebra The book provides insight into modeling cross immunity between different disease strains such as influenza and the synergistic interactions between multiple diseases e g HIV and tuberculosis diseases transmitted by viral agents bacteria and vectors e g mosquitos transmitting malaria to humans and both epidemic and endemic disease occurrences   *Mathematics of Epidemics on Networks* István Z. Kiss,Joel C. Miller,Péter L. Simon,2017-06-08 This textbook provides an exciting new addition to the area of network science featuring a stronger and more methodical link of models to their mathematical origin and explains how these relate to each other with special focus on epidemic spread on networks The content of the book is at the interface of graph theory stochastic processes and dynamical systems The authors set out to make a significant contribution to closing the gap between model development and the supporting mathematics This is done by Summarising and presenting the state of the art in modeling epidemics on networks with results and readily usable models signposted throughout the book Presenting different mathematical approaches to formulate exact and solvable models Identifying the concrete links between approximate models and their rigorous mathematical representation Presenting a model hierarchy and clearly highlighting the links between model assumptions and model complexity Providing a reference source for advanced undergraduate students as well as doctoral students postdoctoral researchers and academic experts who are engaged in modeling stochastic processes on networks Providing software that can solve differential equation models or directly simulate epidemics on networks Replete with numerous diagrams examples instructive exercises and online access to simulation algorithms and readily usable code this book will appeal to a wide spectrum of readers from different backgrounds and academic levels Appropriate for students with or without a strong background in mathematics this textbook can form the basis of an advanced undergraduate or graduate course in both mathematics and other departments alike

Mathematical Models of Epidemics Hendrik Adolf Lauwerier,1981   *Epidemic Modelling* Daryl J. Daley,Joseph Mark Gani,1999 This is a general introduction to the mathematical techniques needed to understand epidemiology It begins with an historical outline of some disease statistics before describing simple deterministic and stochastic models

Mathematical Models for Epidemics Peter Graham Nightingale,1988   *Mathematical Understanding of Infectious Disease Dynamics* Stefan Ma,Yingcun Xia,2009 An Original book with a comprehensive collection of many significant topics of the frontiers in applied presentation of many epidemic models with many real life examples presents an integration of interesting ideas from the well mixed fields of statistics and mathematics A valuable resource for researchers in wide range of disciplines to solve problems of practical interest   Mathematical Modeling in Epidemiology James C. Frauenthal,2012-12-06 The text of this book is derived from courses taught by the author in the Department of Applied Mathematics and Statistics at the State University of New York at Stony Brook The audience for these courses was composed almost entirely of fourth year undergraduate students majoring in the mathematical sciences The students had ordinarily

completed four semesters of calculus and one of probability Few had any prior experience with differential equations stochastic processes or epidemiology It also seems prudent to mention that the author s background is in engineering and applied mathematics and not in epidemiology it is hoped that this is not painfully obvious The topics covered in this book have in some cases been modified from the way they were originally presented However care has been taken to include a suitable amount of material for a one semester course the temptation to add gratuitous subject matter has been resisted Similarly when a choice between clarity and rigor was available the more easily understood exposition was selected By looking only at the table of contents the casual reader could be easily misled into thinking that the main concern of this book is with epidemiology This is not the case The purpose of this book is to illustrate the process of formulating and solving mathematical models   Mathematical Structures of Epidemic Systems Vincenzo Capasso,2008-07-22 The dynamics of infectious diseases represents one of the oldest and ri est areas of mathematical biology From the classical work of Hamer 1906 and Ross 1911 to the spate of more modern developments associated with Anderson and May Dietz Hethcote Castillo Chavez and others the subject has grown dramatically both in volume and in importance Given the pace of development the subject has become more and more di use and the need to provide a framework for organizing the diversity of mathematical approaches has become clear Enzo Capasso who has been a major contributor to the mathematical theory has done that in the present volume providing a system for organizing and analyzing a wide range of models depending on the str ture of the interaction matrix The rst class the quasi monotone or positive feedback systems can be analyzed e ectively through the use of comparison theorems that is the theory of order preserving dynamical systems the s ond the skew symmetrizable systems rely on Lyapunov methods Capasso develops the general mathematical theory and considers a broad range of amples that can be treated within one or the other framework In so doing he has provided the rst steps towards the uni cation of the subject and made an invaluable contribution to the Lecture Notes in Biomathematics Simon A Levin Princeton January 1993 Author s Preface to Second Printing In the Preface to the First Printing of this volume I wrote   The Geographic Spread of Infectious Diseases Lisa Sattenspiel,2009-07-06 The 1918 19 influenza epidemic killed more than fifty million people worldwide The SARS epidemic of 2002 3 by comparison killed fewer than a thousand The success in containing the spread of SARS was due largely to the rapid global response of public health authorities which was aided by insights resulting from mathematical models Models enabled authorities to better understand how the disease spread and to assess the relative effectiveness of different control strategies In this book Lisa Sattenspiel and Alun Lloyd provide a comprehensive introduction to mathematical models in epidemiology and show how they can be used to predict and control the geographic spread of major infectious diseases Key concepts in infectious disease modeling are explained readers are guided from simple mathematical models to more complex ones and the strengths and weaknesses of these models are explored The book highlights the breadth of techniques available to modelers today such as population based and individual based models and

covers specific applications as well Sattenspiel and Lloyd examine the powerful mathematical models that health authorities have developed to understand the spatial distribution and geographic spread of influenza measles foot and mouth disease and SARS Analytic methods geographers use to study human infectious diseases and the dynamics of epidemics are also discussed A must read for students researchers and practitioners no other book provides such an accessible introduction to this exciting and fast evolving field   **Stochastic Epidemic Models with Inference** Tom Britton,Etienne Pardoux,2019-11-30 Focussing on stochastic models for the spread of infectious diseases in a human population this book is the outcome of a two week ICPAM CIMPA school on Stochastic models of epidemics which took place in Ziguinchor Senegal December 5 16 2015 The text is divided into four parts each based on one of the courses given at the school homogeneous models Tom Britton and Etienne Pardoux two level mixing models David Sirl and Frank Ball epidemics on graphs Viet Chi Tran and statistics for epidemic models Catherine Lar do The CIMPA school was aimed at PhD students and Post Docs in the mathematical sciences Parts or all of this book can be used as the basis for traditional or individual reading courses on the topic For this reason examples and exercises some with solutions are provided throughout   *Mathematical models in epidemics* H.A. Lauwerier,1984   *Mathematical Analysis of Infectious Diseases* Praveen Agarwal,Juan J. Nieto,Delfim F.M. Torres,2022-06-01 Mathematical Analysis of Infectious Diseases updates on the mathematical and epidemiological analysis of infectious diseases Epidemic mathematical modeling and analysis is important not only to understand disease progression but also to provide predictions about the evolution of disease One of the main focuses of the book is the transmission dynamics of the infectious diseases like COVID 19 and the intervention strategies It also discusses optimal control strategies like vaccination and plasma transfusion and their potential effectiveness on infections using compartmental and mathematical models in epidemiology like SI SIR SICA and SEIR The book also covers topics like biodynamic hypothesis and its application for the mathematical modeling of biological growth and the analysis of infectious diseases mathematical modeling and analysis of diagnosis rate effects and prediction of viruses data driven graphical analysis of epidemic trends dynamic simulation and scenario analysis of the spread of diseases and the systematic review of the mathematical modeling of infectious disease like coronaviruses Offers analytical and numerical techniques for virus models Discusses mathematical modeling and its applications in treating infectious diseases or analyzing their spreading rates Covers the application of differential equations for analyzing disease problems Examines probability distribution and bio mathematical applications   *An Introduction to Mathematical Epidemiology* Maia Martcheva,2015-10-20 The book is a comprehensive self contained introduction to the mathematical modeling and analysis of infectious diseases It includes model building fitting to data local and global analysis techniques Various types of deterministic dynamical models are considered ordinary differential equation models delay differential equation models difference equation models age structured PDE models and diffusion models It includes various techniques for the computation of the basic reproduction number as well as approaches to the

epidemiological interpretation of the reproduction number MATLAB code is included to facilitate the data fitting and the simulation with age structured models   Modern Infectious Disease Epidemiology Alexander Krämer,Mirjam Kretzschmar,Klaus Krickeberg,2010-01-23 Hardly a day goes by without news headlines concerning infectious disease threats Currently the spectre of a pandemic of influenza A H1N1 is raising its head and heated debates are taking place about the pro s and con s of vaccinating young girls against human papilloma virus For an evidence based and responsible communication of infectious disease topics to avoid misunderstandings and overreaction of the public we need solid scientific knowledge and an understanding of all aspects of infectious diseases and their control The aim of our book is to present the reader with the general picture and the main ideas of the subject The book introduces the reader to methodological aspects of epidemiology that are specific for infectious diseases and provides insight into the epidemiology of some classes of infectious diseases characterized by their main modes of transmission This choice of topics bridges the gap between scientific research on the clinical biological mathematical social and economic aspects of infectious diseases and their applications in public health The book will help the reader to understand the impact of infectious diseases on modern society and the instruments that policy makers have at their disposal to deal with these challenges It is written for students of the health sciences both of curative medicine and public health and for experts that are active in these and related domains and it may be of interest for the educated layman since the technical level is kept relatively low   **Deterministic and Stochastic Models of AIDS Epidemics and HIV Infections with Intervention** W. Y. Tan,Hulin Wu,2005 Only book on extensive deterministic models statistic models stochastic models and state space models and statistical methods for HIV epidemic involving IV drug usage and HIV epidemic in homosexual populations Provides most recent biological insights into HIV pathogenesis and HIV kinetics at the cellular level and illustrates how to build up mathematical models based on these biological insights Only publication that provides in depth analysis of HAART treatment protocols and discusses possible improvements to the HAART protocol The book also provides connection between pharmacokinetics with treatment in HIV infected individuals

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