Introduction to Infectious Disease Modelling and its Applications

Course Description

Intensive course: 14 – 25 June, 2027

LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE

UK Health Security Agency







Introduction

Infectious diseases remain a leading cause of morbidity and mortality worldwide, with HIV, tuberculosis and malaria estimated to cause 10% of all deaths each year. Outbreaks of Ebola in recent years have led to unprecedented numbers of deaths and cases. New pathogens continue to emerge in animal and human populations, as demonstrated by the emergence of SARS in 2003, of Highly Pathogenic Avian Influenza (HPAI) in poultry and humans in 2004/2005, swine flu in 2009, MERS CoV in 2013, Zika in 2016 and recently, SAR2-Cov2.

Mathematical models are being increasingly used to understand the transmission of infections and to evaluate the potential impact of control programmes in reducing morbidity and mortality. This two week intensive course, which has now been running for over 25 years, is intended to introduce professionals with an interest in infectious diseases or in veterinary questions to this exciting and expanding area. The emphasis will be on developing a conceptual understanding of the basic methods and on their practical application rather than the manipulation of mathematical equations.

The level of difficulty is appropriate for people with high school level of mathematics and is similar to that of the book "An Introduction to Infectious Disease Modelling", published in 2010, which was written by two of the course organizers (Emilia Vynnycky and Richard White). The book is based on material from this popular and successful course. For further details about the book, see www.anintroductiontoinfectiousdiseasemodelling.com.

Course structure

The course comprises 4 sections, as follows:

Section 1: Basic methods and motives for developing infectious disease models

This section is designed to introduce participants both to the basic methods for developing models of the transmission dynamics of infectious diseases and to the applications of these models. It starts with an introduction to the major concepts used for studying the epidemiology of infectious diseases (the basic reproduction number, incubation periods, serial intervals, herd immunity) and continues with an introduction to the main types of models that can be employed.

Participants learn about the basic methods for setting up deterministic models (difference and differential equations) and will gain practice and confidence in setting up simple models using spreadsheets and a specialist, user-friendly modelling package (Berkeley Madonna). Examples of diseases discussed in this section include influenza, measles, mumps and

rubella. Participants will gain an understanding of the insights into infectious disease dynamics that models can provide, such as the factors influencing the periodicity of disease incidence for immunizing infections (e.g. the incubation period, basic reproduction number, seasonal transmission, vaccination and control programmes) and how the models can be applied to determine optimal control strategies for outbreaks involving new pathogens as well as for endemic infections.

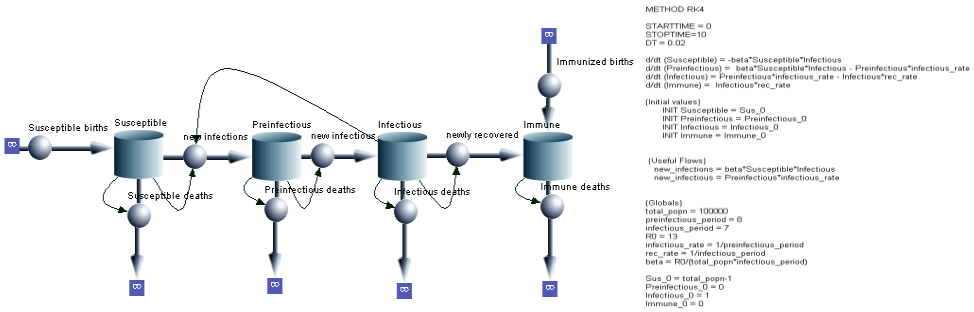


Figure 1: Example of different approaches which can be used to set up models using Berkeley Madonna. Models can be set using either flow diagrams or equations. Participants can work with the approach that they prefer during the course.

Section 2: Analysis of data and applications of modelling of seroprevalence data

Section 2 deals with the methods for analysing seroprevalence or other data on past infection, how they can be used for elucidating past trends in infection incidence and for studying the transmission dynamics and predicting the control of infections. The section starts with a lecture on how to analyse and interpret seroprevalence data, which is followed by a second lecture describing different fitting methodologies. During the subsequent practicals, participants will examine different data sets and estimate (age-dependent) infection incidences (“forces of infection”) for high and low infection transmission settings, using rubella as an example.

These estimates are then used to analyse how control policies can lead to reductions in transmission but increases in infection incidence in adult life (and other unexpected events), depending on the study setting. Participants will also study how seroprevalence data can be used to estimate mixing patterns of subgroups in given populations and how different contact patterns between individuals affect the impact of control.

The section includes sessions which are part of a groupwork exercise, whereby participants use modelling to analyse data for a outbreak and predict the impact of different interventions.

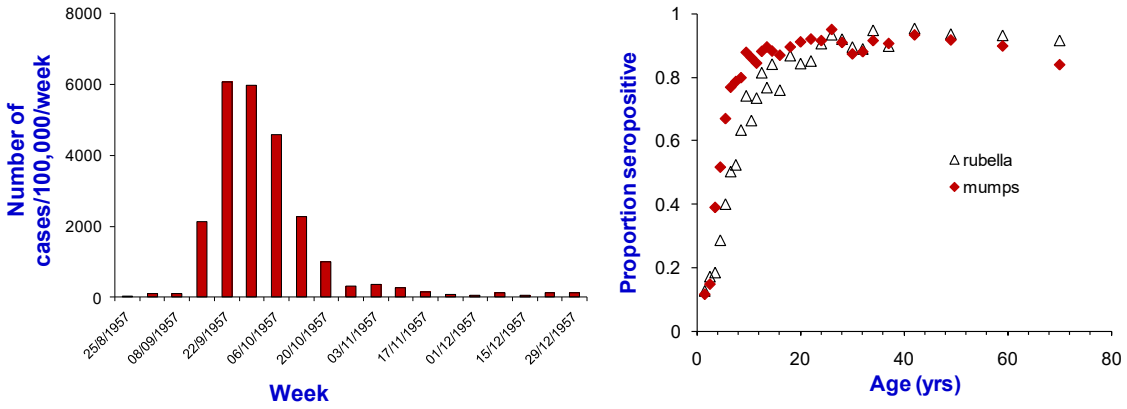


Figure 2: Examples of the kinds of datasets that course participants learn to analyse and use in models in this section. A. Data on the epidemic curve for influenza (from an outbreak during the 1957 influenza pandemic) B. Age-specific serological data for mumps and rubella.

Section 3: Additional methods and dynamics - stochastic and network modelling, health economics and sensitivity analyses

This section provides an introduction to several methodological aspects of modelling, namely stochastic and network models, health economics and sensitivity analyses.

Stochastic models are often used to describe the transmission dynamics of infections in small populations, for example, for predicting the course of outbreaks and critical population sizes for the persistence of infection. This section introduces participants to the basic methods for setting up stochastic models of outbreaks and the long-term dynamics of directly transmitted infections. It also illustrates how distributions of outbreak sizes may be used to infer the success of elimination programmes and extent of ongoing transmission (for example, for pandemic influenza or measles) and the application of stochastic models in describing nosocomial transmission.

The success of control programmes greatly depends on the extent to which different individuals are connected, for example, the individuals that each person contacts and the contacts of those persons. These issues are illustrated in a lecture and practical on network models, which try to capture such detailed contact patterns and have been used in modelling the transmission and control of sexually transmitted infections and Foot and Mouth Disease.

Modelling studies are increasingly including health economics analyses, for example, to estimate the cost-effectiveness of an intervention and such estimates can often be persuasive when making health policy decisions. Modelling studies also need to use sensitivity analyses to determine the effect of different assumptions or inputs on predictions of the incidence or control of an infection. In this section of the course, the basic principles of health economic analyses and sensitivity analyses are introduced in a lecture and practical.

The section includes a lecture and practical introducing the application of the rapidly growing area of phylodynamics, in which modelling is used, in conjunction with molecular data to track

the evolution and course of outbreaks. A lecture discussing methods for fitting models to data and methods for sensitivity analyses is also scheduled.

Section 4: Applications of modelling

The lectures in this section are designed to illustrate several major current areas of applications of mathematical models, namely real-time modelling, the transmission of sexually transmitted infections (STIs) and HIV, tuberculosis, zoonoses and other veterinary diseases. Most of the sessions on the applications of modelling comprise two parallel streams and participants can attend sessions from either stream at any time.

The first stream includes a lecture and practical on modelling sexually transmitted infections, covering the early mathematical models for STIs and the role of core groups in sustaining infections in populations. In addition, there is a lecture and practical on modelling *M tuberculosis* transmission and predicting the impact of control.

The second stream includes a lecture discussing the general issues relating to modelling problems in veterinary epidemiology, and is followed by a practical illustrating the principles using avian influenza in the UK. There is also a lecture on the uses of real-time modeling, which, as was the case during the 2009 swine flu pandemic and during the COVID pandemic, is used for monitoring the extent of ongoing transmission at regular intervals (e.g. daily) during the course of an outbreak.

Attendance and teaching methods

Attendance

Participants may attend the course either in person in London or remotely. The timetable is similar for both modes of attendance.

Lectures and practicals

Participants may attend the course either remotely or in person.

Students attending in person or remotely

A typical day lasts during 9.00am-5.30pm UK time (with breaks for lunch and coffee/tea), with each half-day session consisting of a lecture and an accompanying practical. There will also be review lectures on Wednesday morning of week 1 and on Monday morning of week 2, which are designed to help consolidate the material covered until then. Attendance at these sessions is optional.

Students attending remotely

Students following the course remotely will be able to join the live lectures at the scheduled times, and will also be able to listen to the pre-recorded lectures on the same topic if they choose. Times are scheduled during the day during which students can work on given practicals in virtual rooms with other students with tutor-support. During those sessions, tutors will introduce the practical at the start and sum up at the end, and will be available to answer any questions that arise. For days without a review lecture, question and answer sessions are scheduled during 8.30-9.00am UK time.

Guest Lectures

Lunch-time and evening guest seminars by modellers from both LSHTM and outside LSHTM are scheduled during the course. These seminars are designed to provide further perspectives on the areas of application of modelling and attendance is entirely optional. Many of the lectures will be recorded for students who are not able to attend live (in London or remotely).

Paper discussions

A paper discussion is scheduled during the course, which is designed to familiarize participants with the mathematical modelling literature and to introduce some of the areas of applications of modelling. The topics covered in these papers include tuberculosis and COVID.

Epidemic modelling exercise

During the course, there is a problem-based learning exercise, which is designed to highlight the way modelling methods may be used to solve “real” problems and to give practice in thinking about how models are designed and used to make policy decisions. Participants attending in person will be divided into small groups and will work on a problem relating to pandemic influenza or Ebola. Online participants can work either individually or in groups. Participants are required to discuss and work on the problem during allocated sessions. The exercise concludes with poster or oral presentations on the final day.

Modelling clinic

Tutors are available during the course to discuss questions that participants may have on the course material. In addition, a short “clinic” session will be available during the second week of the course, during which tutors meet or video chat one-to-one with students to discuss questions relating to the participants’ own work in more depth. These sessions are optional.

Social arrangements

For students attending in person, there are several opportunities for social interaction during the course, including a reception on the first day, a guided walk around the sites of special medical interest in London, a meal and an evening excursion and a theatre outing. Networking opportunities will also be scheduled for participants attending remotely.

Final word

The course has been developed in collaboration between modellers, epidemiologists and statisticians at the London School of Hygiene & Tropical Medicine and UK Health Security Agency and its predecessors. The course aims to bring a conceptual understanding of mathematical models and their applications in infectious disease research to individuals who have not had any advanced training in mathematics. It is also suitable for individuals with a background in mathematical disciplines who wish to obtain an understanding of the broad range of applications of mathematical models in infectious disease epidemiology and who may wish to specialize in this area in the future.