Introduction to Infectious Disease Modelling and its Applications

Intensive course: 4th–15th June, 2007

Course Description

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. New pathogens continue to emerge in animal and human populations, as demonstrated by the emergence of SARS in 2003 and of Highly Pathogenic Avian Influenza (HPAI) in poultry and humans in 2004/2005.

Mathematical models are being increasingly used to elucidate the transmission of infections in populations and to evaluate the potential impact of control programmes in reducing morbidity and mortality. This 2 week intensive course is intended to introduce professionals with an interest in infectious diseases in either developing or developed countries 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.

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 modelling package (Berkeley Madonna). Examples of diseases discussed in this section include measles, mumps, rubella and influenza. 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.

Section 2: Analysis and applications 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 of infections. The section starts with a lecture on how to analyse and interpret seroprevalence data and during the subsequent practicals, participants will examine different data sets and estimate (age-dependent) infection incidences (“forces of infection”) for high and low infection incidence settings, using rubella as an example.

These estimates are then used to analyse how control policies can lead to a reductions in transmission but increases in infection incidence in adult life (and other unexpected events), depending on the study setting. This is accompanied by a lecture discussing issues relating to the introduction of control programmes for viral and bacterial infections and the insights which might be provided by modelling. Participants will also study how seroprevalence data can be used to elucidate mixing patterns of subgroups in given populations and the implications for the impact of control.

Section 3: Stochastic modelling and its applications

Stochastic models are often used to describe the transmission dynamics of infections in small populations e.g. for predicting the course of outbreaks and critical population sizes for the persistence of infection. They will gain experience in setting up their own simple models for outbreaks, the long-term dynamics of directly transmitted infections and understand how stochastic models may be used to analyse outbreak data.

Section 4: Applications of modelling

The lectures in this section are designed to discuss both methodological issues in modelling and to illustrate several major current areas of applications of mathematical models, namely modelling the transmission of sexually transmitted infections (STIs) and HIV, tuberculosis, vector-borne diseases, zoonoses and other veterinary diseases. The methodological lectures consist of a session discussing sensitivity analyses and methods for fitting models to data and a session discussing the different approaches for developing models. 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 starts with a lecture on the early mathematical models for STIs, covering the history of STI modelling, and the more general role of core groups in sustaining infections in populations. The subsequent lecture in this stream covers the development of models to understand the spread and control of HIV and then by a lecture and practical discussing the within-host modelling of HIV. This stream concludes with a lecture and practical on modelling *M tuberculosis* transmission.

The second stream consists of lectures and practicals on the application of modelling to vector-borne diseases and veterinary epidemiology. The stream starts with a lecture and practical introducing the general issues relating to modelling problems in veterinary epidemiology, illustrating the principles using avian influenza in the UK. It is then followed by a lecture discussing the structure of models for vector-borne diseases, followed by a lecture and practical on models for malaria transmission. This is followed by a lecture and practical on the real-time modelling of outbreaks, using the Foot and Mouth disease outbreak in the UK as an example.

Teaching methods

A variety of teaching methods are employed, including lectures, computer practicals, small group work and paper discussions. The course will introduce participants to the use of mathematical models for analysing a wide range of problems involving many different pathogens, and will equip participants with the skills to build and analyse simple models for their own area of interest. In addition, participants are introduced to a disease outbreak problem during the first week, which is designed to illustrate how mathematical models may be effectively employed to analyse data and to predict the impact of control programmes. During the course they will work in small groups to develop a suitable model to address this problem, analyse the data and to specify the assumptions required, gaining further experience of the software packages. Participants will present their analyses on the final day of the course.

A typical day lasts from 9.00-5.30 (with breaks for lunch and coffee/tea), with each half-day session consisting of a lecture and an accompanying practical. Optional seminars by both external and internal speakers are scheduled at about midday during the course, which are designed to deepen participants' insights into the applications of mathematical models. We use periodic review sessions to consolidate and expand on concepts covered during the course. Paper discussion sessions are included to enhance understanding of modelling papers and to encourage critical thinking of model structures and the underlying assumptions.

Tutors are available during the course to discuss questions participants may have on the course material. In addition, a short "clinic" is scheduled for the final Thursday of the course, during which tutors are available to discuss questions relating to the participants' own work in more depth.

Final word

The course has been developed in collaboration between modellers, epidemiologists and statisticians at the London School of Hygiene & Tropical Medicine, the Health Protection Agency Centre for Infections (Colindale, UK) and the University of Sao Paulo, Brazil. 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.

London, January 2007