

Mathematical models and the fight against diseases in Africa

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A new initiative proposes to build capacity across Africa to collect data and conduct quantitative analyses necessary to understand the dynamics of major diseases afflicting the continent, with an initial emphasis on HIV/AIDS

In this age of molecular biology, the healthcare industry, politicians and the community at large are trying to find 'magic bullet' drugs and vaccines to conquer disease. Although smallpox has been eradicated and polio may soon be a scourge of the past, many pathogens replicate rapidly and mutate prodigiously, enabling them to evolve ways to circumvent our immune systems, as well as our drugs and vaccines. To fight and win the war against new emerging infections such as HIV/AIDS, TB and now SARS (severe acute respiratory syndrome), it is important to understand the temporal and spatial dynamics of the pathogens in human and, in some cases, animal reservoirs or vector populations. It is also necessary to understand the complex web of socio-economic factors pertinent to controlling the spread of disease, so that feasible, affordable and, most importantly, effective public-health policies can be devised and implemented.

Beyond magic bullets

Host-pathogen interactions, embedded in their ecological or socio-economic settings, are complex, non-linear systems that cannot be understood without the help of detailed mathematical and statistical analyses. The most important ingredi-

ent in such analyses, however, is the skill required to build dynamical systems and statistical models then used to derive the necessary insights. Unlike physical systems that have canonical theories to guide and direct the construction of models, biological systems are too complex to yield to codified laws of Nature. Modelling biological systems is an art as much as it is a science, requiring experience with and dedication to the biological problems at hand, as well as a sound technical knowledge of appropriate mathematical and statistical theories.

While South Africa has many talented scientists trained in quantitative methods, relatively few of them have been drawn into the modelling and statistical fields of epidemiology. A decisive infrastructural investment is needed to address the health crises in Africa. Prior to the advent of HIV, for instance, tuberculosis was killing half-a-million people in Africa each year but now, because of the virus, it is responsible for a tenfold increase in mortality rate in some African countries. Furthermore, there is a growing threat from drug-resistant strains of malaria, another major cause of morbidity and mortality. The initiative we describe below is designed to enhance capacity across Africa to collect data and conduct quantitative analyses necessary to understand the dynamics of the major diseases afflicting the continent.

The success of this initiative will be measured in terms of the number of professionals trained to apply mathematical modelling to the disease challenges that we face. It will also be assessed by the extent to which such professionals are recruited to staff disease-control centres across Africa with a mandate to collect and analyse the data necessary to help formulate effective public-health policies at a regional level. This means persuading some of the very best students to pursue

careers as quantitative epidemiologists and professionals in health care policy rather than becoming physicists, engineers, economists, and policy-makers in academia and industry.

A centre of excellence

Mathematical modelling and statistical analysis of epidemics is a highly topical area of research. It should involve scientists from a number of diverse fields, including population dynamics, demography, data collection and analysis, computer simulation, public health, epidemiology, clinical medicine, molecular biology and economics. The South African Department of Science and Technology (DST) has taken a first step in establishing a programme that will bring together experts from these various areas. Together with DST's director-general, Rob Adam, and members of his staff, we are working to establish a South African centre of excellence (CoE) that will foster the training of professionals and develop much-needed capacity in modelling and analysing the infectious diseases that currently impede socio-economic initiatives, such as the New Partnership for Africa's Development (NEPAD).

With a grant from the DST, the nine of us are involved in an initiative that we hope will lead to the establishment of the envisaged CoE. This initial funding is being used to run an epidemiological modelling short course and an HIV/AIDS modelling workshop in December this year (see below). This will be followed by a workshop in the middle of 2004, at which a decision will be made on the establishment of the planned centre. It is our intention that the proposed workshop should catalyse the establishment of the CoE with a clearly outlined scientific programme that focuses on the principal epidemiological and public-health issues confronting South Africa with a view to developing capacity in epidemiological modelling throughout Africa. Our current three-year project plan has already been submitted to the DST for consideration. This plan aims to link the proposed development of a centre with other major health initiatives in South Africa.

The centre we have in mind is intended to enhance efforts already under way in modelling the HIV/AIDS epidemic and to provide a new and sharper focus for epidemiological research, with a strong African perspective. In this initial phase, we will concentrate on bringing experts together for detailed discussion on the way forward, as well as seeking to attract new entrants into the subject.

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Modelling short course

The short course is designed as an introduction to epidemiological modelling for students and professionals who have the equivalent of an undergraduate background in a quantitative field such as physics, applied mathematics, or engineering, and will assume that participants have knowledge of differential equations and linear algebra. No knowledge of how to simulate dynamical models using computers will be expected. The course will be run in conjunction with the new African Institute for Mathematical Sciences (AIMS) at its Muizenberg (Cape Town) campus, from 1–6 December 2003. The course will be attended by the AIMS's inaugural class of 30 students from countries in north, west, east and southern Africa, as well as participants from South Africa who are not students at AIMS but who wish to participate in this educational opportunity. A team from Berkeley, organized by one of us (W.M.G.), are planning to run a nine-lecture, three-computer-lab course covering the basics of epidemiological theory and computer simulation.

HIV workshop

Given that HIV/AIDS is one of the greatest threats to the future and security of many countries in sub-Saharan Africa, especially those in East and southern Africa, the CoE will focus its initial efforts on this pandemic. Attempts to control AIDS through behaviour changes of individuals and the treatment of sexually transmitted infections have not generally been successful. The development of anti-retroviral (ARV) drugs over the last few years and the dramatic fall in the price of these drugs opens a tactical door to prolonging the lives of individuals infected with HIV, although current costs of US\$1000 per patient per year are still far too high for most people living in Africa.

Research initiatives on the practicalities of providing ARV therapy are already under way at several sites in South Africa, but various critical questions still need better and more detailed answers. In addition, the South African AIDS Vaccine Initiative (SAAVI) makes it imperative to answer questions about the potential impact of vaccines and the number of people who would be eligible for vaccination.

Our plan for the workshop, to be held in the Western Cape from 8–15 December 2003, is to start formalizing questions centred on the evolution, epidemiology and economics of HIV/AIDS. Questions we hope to address include: how reliably

can we forecast trends in age-related morbidity and mortality, and the prevalence of related diseases such as tuberculosis; what are the effects that ARV drugs might have on these trends; and what are the costs involved in making such drugs widely available? We also hope the workshop will provide an opportunity to address infrastructural issues regarding delivery of healthcare services necessary to contain HIV/AIDS.

To explore these areas and identify the relevant questions for future efforts requires people with a range of skills and expertise. The key areas are as follows:

Modelling. Some demographic modelling has already been performed by the Actuarial Society of South Africa and models have been developed by the Medical Research Council, by the CSIR as well as by various international bodies. The models have been used to explore specific aspects of the epidemic in South Africa including the estimation of incidence from prevalence data, demographic impacts, intervention options and costing. These exercises provide a foundation for future modelling efforts.

Data. South Africa has the best routine surveillance system for HIV infection in the world, as a result of the annual national antenatal clinic surveys conducted by the Department of Health since 1990. Many other data sets exist that can be drawn on, including studies carried out at sentinel sites, such as Hlabisa and Carletonville, in the gold mining and other industries, and in various universities, hospitals and clinics.

Anti-retroviral drugs. Several studies are either already under way or being planned, in which trials of the provision of ARV therapy in poor communities are being conducted.

Tuberculosis. For many years, South Africa has been one of the leading countries in the world in tuberculosis research, especially through the National Centre for Occupational Health, groups in Cape Town, the Medical Research Council, on the gold mines and other centres.

Economics. Several projects on the economic consequences of HIV in South Africa have already been undertaken, including assessing the impact on industries.

Our workshop will address all these issues. The logistics of the meeting are the responsibility of a committee of five of us (C.M., P.M., C.S. and G.W., with F.H. as chair); the Stellenbosch Institute for Advanced Study (STIAS) is facilitating administrative arrangements and will oversee the financial aspects. The workshop programme will include a South

African and an international speaker on each of the main topics outlined above. The list of invited international speakers includes Betran Auvvert (University of Paris), Chris Dye, Marco Vittoria and one of us (B.W.) from the World Health Organisation in Geneva, Geoff Garnett (Imperial College, London), Robert Grant and Travis Porco (University of California) and the San Francisco City Health Department), and Sydney Rosen (Boston University).

Scientists active in epidemiological modelling and AIDS research, and mathematicians and statisticians wishing to become involved in this field are encouraged to contact Fritz Hahne at STIAS (e-mail: fjwh@sun.ac.za). A website (linked to AIMS) is under construction and will provide interested readers with updates on progress and details as the project unfolds. Funds are available for sponsoring the participation of a limited number of scientists and students in the short course or workshop.

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Additional comments on the modelling initiative

The South African government is to be congratulated on supporting an initiative to develop quantitative skills in disease modelling in Africa. The future of South Africa is inextricably linked with the future of the whole continent. The seminal work by the WHO Commission on macroeconomics and health has unequivocally demonstrated the detrimental role of ill-health on development. HIV/AIDS, malaria and tuberculosis are three infectious diseases that have plagued the people of Africa and have resulted in a huge burden through premature mortality and disability. Fortunately, there is a growing global response to engage with these conditions.

Quantitative skills to inform and support efforts to overcome these diseases are an essential ingredient and it is timely that the relatively strong mathematical skills available in South Africa are brought to bear on major health problems that challenge the continent. As directors of the University of Cape Town's Centre for Actuarial Research (R.D.) and the MRC's Burden of Disease Research Unit (D.B.), we are proud of the South African efforts to quantify the impact of HIV/AIDS and other diseases, in the face of imperfect data. Expanding the skills base for such work and broadening the scope of such work is not only desirable but is critical and we look forward to collaborating with such an effort.

A bigger problem that must be addressed by all governments in Africa is the need to improve health information systems and to generate reliable statistics that can be used to monitor progress in overcoming these diseases.

Debbie Bradshaw and Rob Dorrington