Health Systems Simulation

David Lyell
University of New South Wales, Australia

Rosemarie Sadsad
University of New South Wales, Australia

Andrew Georgiou
The University of Sydney, Australia

INTRODUCTION

The health system is the culmination of organisations, institutions, and resources which work together for the purpose of providing health care and improvement in health (WHO, 2006). This system comprises a number of different levels (Proctor, Reid, Compton, Grossman, & Fanjiang, 2005) as shown in Figure 1. The highest level is the environment which provides the regulatory, policy, and funding frameworks in which the lower levels of the health system operate.

The health system is a *complex system* (Plsek & Greenhalgh, 2001) meaning that it is highly coupled and many outcomes are the result of the interactions that occur between many different parts (Plsek, 2003). Not only can interactions occur between different parts at the same level, but they can also interact across levels.

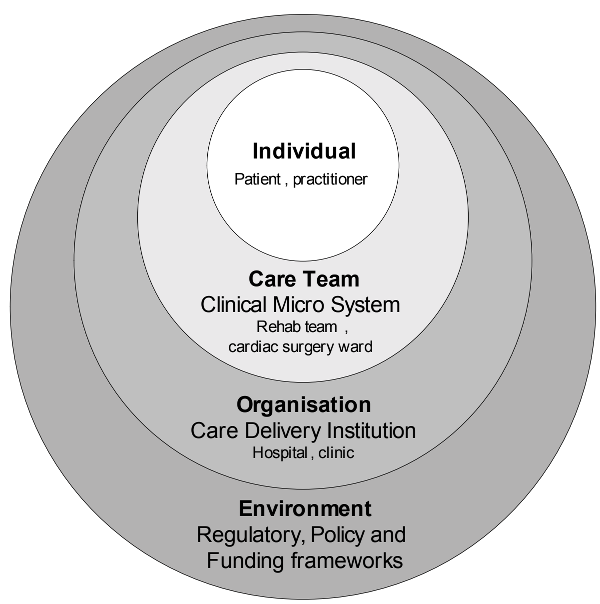
Adding to the complexity of the health system is that these interactions play out over time, often with effects being distant in both time and place to causes (Forrester, 1961). This *dynamic complexity* (Sterman, 2000) arises when systems change over time, are tightly coupled (characterised by strong interactions), are governed by feedback, and play out over time. Research has shown that people are very poor at understanding problems with dynamic complexity, with performance on tasks and outcomes declining as complexity or the strength of feedback increases (Paich & Sterman, 1993).

In this way, the health system is more than simply the sum of its parts because all aspects of the system need to function together in order to provide health care. One of the main difficulties in health care reform therefore is the systemic nature of health care. Reform to one area will undoubtedly affect other areas.

Most problems arising from the operation of the health system are studied and addressed using conventional reductionist methods, which reduce, isolate, and freeze aspects of the system at a given time. This fails to deal with the dynamic complexity inherent in the health system and which is often the source of the problem. The result is that all too often, well intentioned interventions make the original problem worse by failing to fully understand the complexities involved in the origin of a problem (Sterman, 2000).

In this article, we introduce *system simulation* as a means of exposing the underlying causes and systemic structures of problems within the health care system, as well as providing a tool for assessing the likely impact of new interventions. The following sections will examine the advantages of simulation, areas of application, how simulation experiments can overcome some of the limitations of randomised control trials (RCTs), and various simulation methodologies as well as the challenges of conducting simulation experiments.

Figure 1. Conceptual drawing of the 4 levels health care system (Adapted from Proctor et al., 2005)



HEALTH SYSTEM SIMULATION

Health system simulation is the application of modelling and computer simulation methods to study the interactions between individuals and/or components of a system and how these interactions over time produce the behaviour observed in the health care system.

There are both quantitative and qualitative modelling and simulation methods, however this article will focus exclusively on quantitative modelling and simulation. See Kuipers (1994) for a discussion on qualitative simulation methods.

Health system simulation helps develop an understanding of the dynamic relationships and systemic causes of problems. Interventions can be developed to address these problems and can be tested *in silico* to determine their suitability. This allows for risk free experimentation where stakeholders can try out *what if* scenarios and have the ability to play out the results of interventions over time.

Health care system simulation has been applied to a number of areas (Homer & Hirsch, 2006), including:

- Disease epidemiology: heart disease, diabetes, HIV/AIDS, cervical cancer, chlamydia infection, dengue fever, and drug resistant pneumococcal infections
- Substance abuse epidemiology: heroin addiction, cocaine prevalence, and tobacco reduction
- Patient flows through emergency and health care
- Health care capacity and delivery in areas such as population health planning, dental care, and mental health, as well as how the health system will be able to cope with natural disasters and terrorist incidents
- Interactions between health care and disease epidemiology
- Performance management
- Evaluation of the performance and impact of information and communications technology applications on health care (Anderson, 2002), including Computerised Physician Order Entry systems and electronic prescribing systems designed to reduce medical errors leading at adverse events.

The common characteristics of these areas are that they have features of dynamic complexity and involve large scale or multiple settings in which it would be difficult to conduct traditional experimental methods.

SYSTEM SIMULATION CAN OVERCOME SOME LIMITATIONS OF RANDOMISED CONTROL TRIALS

Randomised control trials (RCT) are often regarded in health care circles as the *gold standard* for evaluating the effectiveness and quality of health interventions (Muir Gray, 1997), with alternative research methods often judged by the degree to which they approximate RCT design.

While being recognised as the best way to evaluate new drug and treatment interventions, many problems which face the health system are complex, dynamic, and cannot be reduced to a single or linear cause and effect relationship. In these situations conducting RCT experiments may not be possible or ideal. When this occurs, system simulation can provide an alternative means of investigation.

For example, RCTs are not practical when the timeframe is too long (Black, 1996). Changes in population health, the management of chronic illness, and planning for future infrastructure will occur over years, decades, or even a lifetime. Aside from the impracticalities of conducting a study over such durations, in many cases decisions can not be put off that long. A computer simulation on the other hand can replicate many aspects of the experiment in a matter of minutes.

The scale of a study may also prohibit the use of RCTs (Black, 1996). This is especially the case in any study that deals with an entire population, such as epidemics or health delivery and capacity. The simulation researcher on the other hand can simulate the entire population.

Trials may be too expensive to conduct, as is the case with major implementations of information and communications technology or building new infrastructure. Simulation experiments overcome the cost barrier as these are tested *in silico* without the need for expensive purchases or capital investment. In a similar vein, this eliminates wasted money should simulation suggest that that a particular piece of new technology or infrastructure is not beneficial.

In certain circumstances an RCT may be unethical or too risky to conduct, especially when it may place the health and welfare of participants or other people at