Educating Senior Managers in Systems Concepts
Case Study of Public Health Policy Development

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Postgraduate system dynamics students at the Australian Defence Force Academy (ADFA) are mature experienced managers, generally from technical disciplines, who have been imbued with a strongly linear causal deterministic world view. In addition, their study is on top of a demanding full time work load. This is not the most auspicious environment for communicating systems concepts.

A variety of teaching-learning strategies have been implemented over the past decade to create an environment conducive to students confronting their mental models. In recent years the key teaching-learning experience has become a consulting project, ideally in a topic remote from the students' discipline or experience.

This paper focuses on projects by 2 teams comprising engineering and logistics officers, which involved modelling policy options confronting public health officials in relation to breast cancer screening and cardio-vascular treatment. The course goals and strategies are presented and the project achievement is discussed, both in terms of education outcomes and client satisfaction.

The Teaching-Learning Context at ADFA

System dynamics modelling has been offered since 1990 to postgraduate students undertaking Masters Degrees in Engineering Science, Information Science and Management Studies. Most of the students are in their early to mid 30s. About 70% are from the military, mainly senior Majors or Lieutenant Colonels (or their equivalents). The rest are mainly from executive levels in the federal public service.

The military students have a strong basis in structured problem solving, built around the 'military appreciation process'. Most of the civilians work in policy advising areas of Government and have strong analytical skills. However, the predominant world view of both is linear causal deterministic and task, rather than goal, oriented. The focus is on getting the job done, not asking whether it is the right job. Recognition of the significance of feedback concepts is limited.

Objectives of the System Dynamics Course

The course seeks to bring about a shift from the predominant linear causal paradigm to viewing the world (where appropriate) in terms of systemic and feedback relationships. It seeks to develop the following competencies: that students …

- know key system dynamics concepts in the context of general systems theory;
- know the key concepts of *qualitative* system dynamics and can apply these to the conceptualisation and specification of complex technical, environmental, human and organisational problems;
- know the key concepts of *quantitative* system dynamics and can apply these to the modelling of complex systemic problems;
- communicate effectively to a client the systemic dimensions of a problem and the systems thinking solution approach which is proposed / has been applied;
- demonstrate the personal, leadership and team qualities which facilitate mutual learning of the systemic dimensions of the problem between team and client.

Content Overview and Teaching / Learning Strategy

To achieve these objectives the formal lecture component addresses the following:

- Learning styles and 'type indicators', human dynamics
- Systems thinking - hard systems, soft systems
- Causation, feedback and time dynamics
- Cognitive mapping, causal loop diagrams and system archetypes
- Simulation modelling using Powersim™ system dynamics software
- Formulating, designing, analysing and validating system dynamics models

The subject relies on experiential learning as its primary mode of teaching. 90% of the assessment relates to a 'consulting' assignment undertaken by syndicates of three students. Each consultancy is a significant systemic management or policy problem tasked by a government department or private firm. Syndicates undertake a complete analysis of the problem and develop a system dynamics decision support system to assist in problem resolution. *These are real projects with real clients.* Annex A summarises the methodological approach syndicates are required to follow.

A critical element of the experiential learning process is the handling of human dynamics within the team and the development of team skills. To foster attention to these, 20% of the assignment mark is peer assessment and 15 % self assessment. Marks require justification if they go outside limits and are subject to guidelines relating to the student's contribution to the team and to the task.

Table 1: Team Skills Guidelines for Self and Peer Assessment

Treated each client and team member with respect recognising that each has innate value
Valued everyone equally regardless of rank or status – every team member is important
Took the initiative in serving the team – contributed ideas but was prepared to let them go
Treated others as s/he expected to be treated (contributed fairly, undertook agreed tasks etc)
Listened actively and tried to understand the others viewpoint
Accepted difficult relationships as one's own problem, and valued the differences
Put the interests of other team members first so as to build community
Took responsibility for her/his own actions (as if s/he were responsible for implementation

Outside the Comfort Zone – Tackling Problems in Unfamiliar Territory

Until 1996 most student syndicates applied for projects broadly related to their field of expertise. However, their familiarity with the area often resulted in poor problem definition because they 'knew' the problem. They found it difficult to break from the 'linear-causal mind-set'. Their familiarity also led to 'modelling the system' rather than the problem behaviour. The 1998 syndicates addressed a variety of problems far removed from military engineering or logistics, including:

- Vinyard Development
- Disposal of the Australian Wool Stockpile
- Primary School Location and Development
- Cervical Cancer Screening Pathways
- Coronary Heart Disease Pathways

The balance of this paper discusses the last two projects, both from their contribution to public health policy analysis and in relation to the education value of the projects.

System Dynamics and Public Health Policy

These projects were experimental. The client, the Federal Health Department, had minimal prior experience with system dynamics. The consultant teams, as discussed, had no technical expertise in the public health sector. A senior epidemiologist, Dr Michael Fett, acted as technical advisor in relation to health issues.

Coronary heart disease and cervical cancer are significant public health problems. In particular, there is considerable professional debate on the appropriate timing and extent of intervention measures, and on how the feedback effects of intervention will impact on the at risk population.

The principal analytical tool in this field is statistical modelling. The prevailing paradigm is correlation rather than causation. As far as the authors could ascertain, system dynamic modelling is not available as part of any post-graduate course in public health in Australia. Internet searches internationally did not find systems dynamics courses associated with medical schools or schools of public health. Literature searches found few system dynamics papers in the field of public health, other than those concerned with hospital management and hospital waiting lists.

The focus of the two ADFA projects was to understand, from the literature and from researchers, the behavioural patterns and time dynamics of the respective diseases, especially in the context of intervention options, and to describe in system dynamics terms the key interrelationships.

While the primary goal was educational, Health officials had a strong interest. If they considered the projects a success, there would be a case for system dynamics modelling to be added to the suite of tools for public health policy analysts and to become an integral component of post-graduate courses in public health.

Overview of the Projects and their Results

One of the projects (referred to as *Coronary*) examined the impact of changes in cardiovascular risk factors on death rates from coronary artery disease. The other project (referred to as *Cervical*) examined policy settings for optimising the cost-effectiveness of cervical cancer screening. The following extracts from the project reports give an overview of the 'consultancies'.

1.1 Clarifying policy and program objectives (Coronary & Cervical)

Coronary:

"Cardiovascular disease kills almost 55,000 Australians a year, primarily as a result of coronary heart disease, stroke and peripheral vascular disease. Direct costs of health care, which include hospital, nursing home, medical and pharmaceutical costs, amounted to $2.2 billion in 1989 –90"[1]. ... Identification and implementation of the most effective reduction measures could improve population health at much reduced costs, reducing the burden on the public and private health systems.'

'The aim of this project is to examine the effect of changes in cardiovascular disease risk factors on coronary artery disease in order to aid the Commonwealth Government in determining National Health Priorities for research and funding.'

Cervical:

'In 1991, a report entitled *Cervical Cancer Screening in Australia: Options For Change* was released by the Australian Institute of Health[2]. The key recommendation in this report was the requirement to improve the direction and cost-efficiency of the national [cervical cancer] screening program.'

'The purpose of this report and the accompanying model is to enable the evaluation of medical intervention policies in the cervical cancer-screening pathway. As a proof-of-concept the model will demonstrate the utility of the system dynamics approach in simulating modern health care issues.'

1.2 Comprehending feedback and delay concepts in the content areas of the model (*Coronary only*)

'The risk factors associated with coronary artery disease exhibit time dynamics, with each risk factor showing different characteristics. These vary from immediate effect to long delay times to effect, and from reversible effects to non-reversible effects. This issue is made more complex by the synergistic nature of risk factors.'

'The Aerobic Sub-Model predicts risk associated with aerobic capacity. In the Aerobic Sub-model, aerobic capacity is used as a measure of fitness. The unit of measure is litres of oxygen per minute. A decrease in aerobic capacity is associated with the total cumulative impact of:

- normal decay in aerobic capacity [with increasing age]
- carbon monoxide level [in the blood]
- atherosclerosis"

Figure 1 illustrates both the modular nature of the development of this model and the clear nature of the feedbacks.

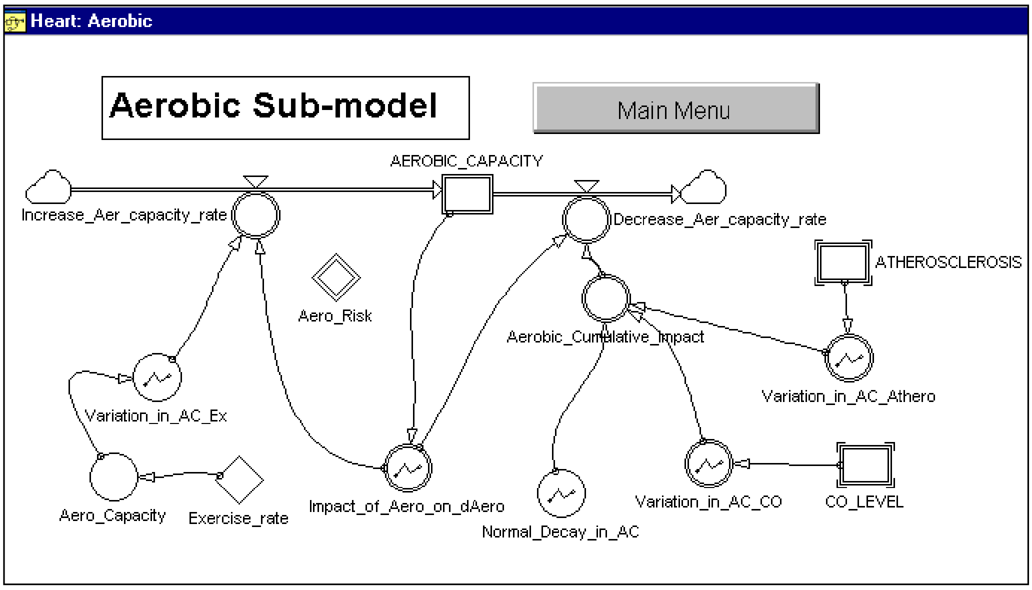

Figure 1:Aerobic sub-model showing feedback relationships

1.3 <u>Integrating content areas to develop a multi-disciplinary perspective (Coronary & Cervical)</u>

Coronary:

'Smoking is a factor associated with increased blood pressure. How many cigarettes over what period cause a change in blood pressure, and what is the magnitude of the change? Is the change in blood pressure not only related to the amount of cigarettes, is it also affected by the characteristics of the smoker, such as per cent overweight, existing blood pressure and level of exercise. Does this quantitative change vary in size with variation in gender and age? These knowledge shortfalls are a limitation to the model, and have been highlighted as an area for future development.'

'The relationship between drinking, cholesterol and blood pressure is associated typically with a 'J' curve meaning that below a certain number of drinks there are beneficial effects on overall mortality. Drinking always has an adverse effect on blood pressure, despite this initial good effect on blood cholesterol.'

Cervical:

'The World Health Organization[3] and the International Agency for Research on Cancer[4] have made recommendations about the requirements for an effective cervical cancer-screening program. A program of this nature deals with all aspects of what is referred to as the screening pathway. These aspects include: screening the target population at regular intervals, provision of acceptable and accessible services for the taking of Pap smears, ensuring follow-up of women with abnormal smears, and a system for monitoring and evaluation of the program as a whole. In summary, a comprehensive approach was recommended.'

'The current population of women [in Australia] over 17 years old is about 7 million. It will be closer to 10 million in 2045. The Screened Population is currently about 75-80% of the total female population over 17 years old. The number of invasive cervical cancer cases expected in the general population is in the order of 1500 per year, with about half currently prevented. The number of invasive cervical cancer deaths is approximately 350 per year.'

'The patterns of mortality rates from cervical cancer have declined in recent years, primarily due to improved detection and management of precursor lesions and early disease. At present, the detection of pre-invasive lesions through the use of the Pap smear is currently the screening intervention of choice on a population basis. As more women participate in screening programs, the incidence and mortality rates for cervical cancer are expected to improve.'

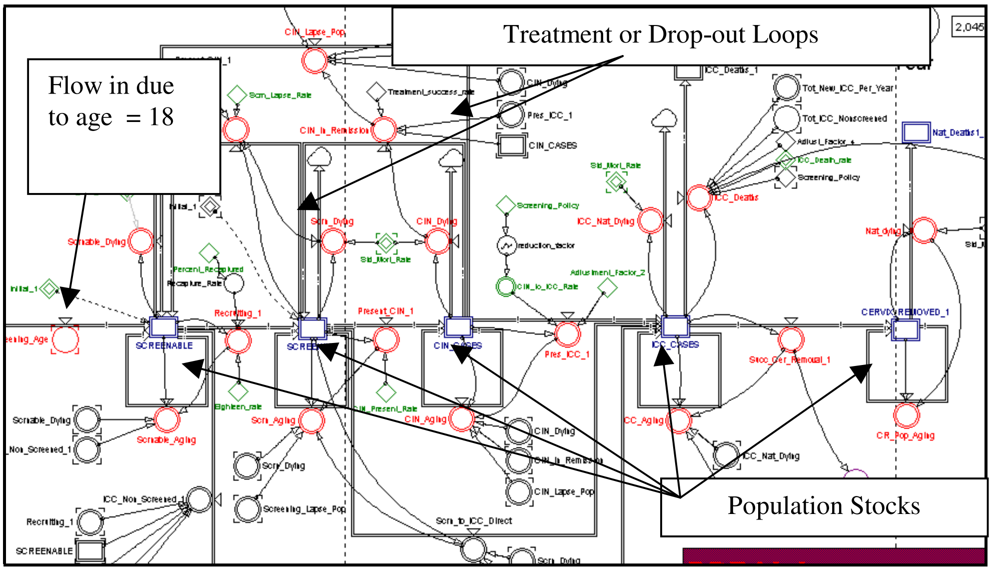

Figure 2: Cervical cancer screening pathways model

2.1 <u>Identifying potential relationships between variables and focussing on the most important (Cervical only)</u>

'Figure 3 is the causal loop or feedback diagram representing the cervical cancer-screening pathway. The purpose of the feedback loop is to assist in identifying basic structures in the screening pathway, along with feedback loops (treatment, death), noting key resource states (female, screening, cervical intra-epithelial neoplasia and invasive cervical cancer populations), resource flows, delays, and inter-relationships. Once these are identified they can be translated to the model.'

'Of critical importance to policy makers are policy levers. The action of leverage within system dynamic modelling is the application of small, well-focused actions applied at the right place. Leverage however, is not usually close in space and time to the symptoms of the problem and is therefore difficult to find. To find high-leverage changes underlying structures in systems must be identified. Computer simulation is considered to be a key in identifying leverage points. Development of the cervical cancer-screening pathway indicates that leverage points may be found within the recapture, screening lapse, and treatment success rates.'

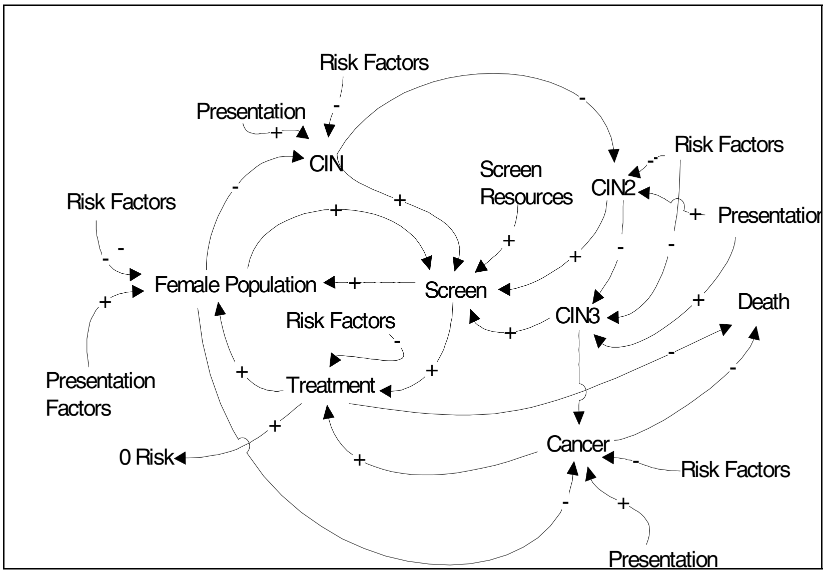

Figure 3: Causal loop pathways for cervical cancer

<u>3.1 Identifying gaps in knowledge and hence priorities for research or further information collection (Coronary & Cervical)</u>

Coronary:

'One of the most important features of the project has been the identification of shortfalls in data-centred approach currently used in Australia and internationally. The relationship between risk factors and coronary artery disease tends to be documented as a correlation relationship rather than a causal relationship … without information on time lags and other time-related effects.

'The search for data has shown that the type of data collected by most areas is 'stove pipe' data, composite data has been difficult to source in the time available. Where composite data has been found, it has been difficult to identify how the composite has been arrived at.'

'A lot of work has been undertaken in the area of research into cardiovascular disease in Australia and overseas. This work has used gathered data to identify the factors associated with cardiovascular disease from a medical viewpoint. Although risk relationships are identified, very little data is available on the composite effect of a number of risk factors on population health. Available data is not well tailored to provide a sound basis for health policy decisions, where a comparison of the effect of different intervention strategies needs to be projected over time and quantified.'

Cervical:

'The variable "Present Cervical Intra-Epithelial Neoplasia_1" represents the proportion of the "Screening" population that develops cervical intra-epithelial neoplasia within the current time-step. The only available data at present about this rate would indicate that for each 1000 women screened approximately 60 would present with cervical intra-epithelial neoplasia. Therefore, a "Cervical Intra-Epithelial Neoplasia Present Rate" of 0.06 has been used. The availability of better data would be of great benefit, as this would allow the variability (risk) with age to be input into the program.'

'The lack of coherent input data limits the objectivity of the conclusions. Currently, the model uses disparate data from a range of sources, which has necessitated the inclusion of a number of adjustment factors to maintain the expected proportionality. A coherent national data collection plan would assist in overcoming this problem.'

'This report stresses the need for coherent national monitoring and data collection of the screening pathway.'

3.2 <u>Testing possible policy and program scenarios and seeking to understand how the results of simulation arise from the interrelationships of the input parameters</u>

Coronary:

'The main model consists of a Benchmark Composite Risk element and a Policy Adjusted Composite Risk element. The Benchmark element provides a measure of 'average' risk values. The Policy Adjusted element measures the risk level resulting from policy changes. The main model compares these two elements to identify the per cent change in risk as a result of a policy adjustment.'

'Using the model the project team found that the most sensitive areas to change in combined risk was, in priority, in the areas of smoking, alcohol and then weight and exercise. Public health decision making will need to analyse the sensitivity to change together with the cost of achieving the change in order to determine the cost effectiveness.'

Cervical:

'The model could well be used to examine policy direction. The model could be used to [examine scenarios to]:

- minimise total costs;
- minimise the occurrence of cancers (and deaths);
- minimise costs per life-year saved; and
- minimise cancer deaths, within a set budget.'

'There is a minimum cervical cancer cost, which is achieved by minimising the amount of screening. However, marginal increases in investment from that point on yield relatively large improvements, by decreasing the number of deaths and by providing a much-improved cost per life-year saved.'

'The two key policy levers are the ability to choose a frequency of cervical cancer screening and the ability to vary the effort put into recruiting women to be part of the screening program. These levers are the key variables to be manipulated in this model. As the model is further developed other levers may become evident.'

'The key conclusion from this model is that maximising the "Screening" population is far more cost effective than decreasing the screening interval. This conclusion appears to apply for most system conditions.'

Conclusions from Perspective of Department of Health

Some of the project team comments reflect their lack of experience in the field of public health and the time constraints of the project. However, the majority of the comments reflect positively on the extent to which people without expertise in the field were able to acquire an understanding of many of the important concepts in the process of building a model. The acquisition in such a brief time by the project teams of familiarity with many public health concepts leads one to speculate about the additional educational advantages from model building that might be had by trainee practitioners in public health.

Some of these issues are fundamental to anyone working in the field (for example: comprehending fundamental concepts and terminology in the discipline and content areas of the model). Others are specific responsibilities assumed by different organisations within the health system (for example: clarifying policy and program objectives by health departments; identifying gaps in knowledge and hence priorities for research or information collection by research research organisations).

Other potential benefits from the more widespread application of system dynamics modelling in this area include:

- using models to introducing managers and generic policy makers to the fields of public health and health policy.
- use of models by policy making and service delivery organisations and staff for program planning, implementation and evaluation.
- use of models by health information agencies, researchers and research organisations to identify information and knowledge gaps.

Time constraints and lack of background in the subject area resulted in models that were not sufficiently accurate to be used directly for policy analysis. Nevertheless, the projects demonstrated to a range of officials and agencies within public health education and practice, the benefits that can be gained from system dynamic model building. Consequent on these projects, further work has been undertaken by Dr Fett, and has generated significant interest in the Health Department.

Conclusions from Educational Perspective

Comparison of those syndicates who were operating in familiar territory with these two syndicates in particular suggested:

Table 2: Comparison of systems modelling project approaches

'Familiar Territory' Syndicates	Health Policy Syndicates
Minimal time on 'problem conceptualisation' … they *knew* the problem	Extensive time spent on problem conceptualisation
Strongly influenced by linear causal paradigm, but this was not obvious because so much of the problem understanding was assumed.	Strongly influenced by linear causal paradigm, but this was obvious early in the project and was addressed.

Teams thought they knew it all and did not seek lecturer guidance until over 50% of suggested project time had elapsed (most were off track to some degree).	Teams sought lecturer guidance early in the process to confirm their under-standing of systemic issues (they were off track!) and maintained ongoing liaison with lecturer
Major effort focussed on the technical aspects of using the software as this was their main area of unfamiliarity.	Software modelling came late in the day after variable relationships were understood.
Comparatively little attention was given to ensuring clients understood the system dimensions of the problem. Focus was on the 'gee whiz' graphics of the software presentation. Elegant multi-media presentation made up for substance.	Major focus was on mutual learning about systemic issues between team and client. Focus was on the variable relationships and feedback implications of different policy options. Attention was given to data deficiencies.
Team competencies not well exercised as students 'slipped' into their expert roles and 'did their own thing'.	Team competencies well exercised. The lack of subject area knowledge meant they had to work cooperatively..

Overall, the learning experience of these two syndicates was much richer and their subsequent understanding of system dynamics much deeper than for those syndicates who selected projects in areas related to previous or current work experience.

The University of New South Wales evaluates student ratings of all subjects. Student assessment of the Systems Dynamics subjects, at both undergraduate and postgraduate levels is very favourable in relation to student interest and perceived value. Over 95% of 1997 and 1998 respondents indicated that they would most certainly recommend the subject to other students. A significant number of these students, however, rated the subject as more difficult than their other (more technical) units. Subsequent questioning revealed that the biggest hurdle was achieving the paradigm shift to a systems world view. The use of projects outside the comfort zone of students would seem to make this transition easier.

Acknowledgements

Bronwyn Jones, Chris Martin, Tim Sanders, Richard Barber, William Horrocks and Bill Sowry, who built the coronary heart disease and cervical cancer models.

Annex A: System Dynamics Consulting Methodology

System dynamics modelling differs dramatically from traditional computer application development, and hence the diverse computer business systems frameworks (including standards such as AS 3563 (Software Quality Management System) and proprietary methodologies such as SSADM, JSD, IBM 'Business Systems Planning' etc) are not directly applicable, although elements of these certainly have application. As yet no SDM development methodology has gained widespread acceptance. The following methodological framework, which draws on Wolstenholme et al[5] and Richardson and Pugh[6], is used by the ADFA students.

Table 3:Seven Step System Dynamics Modelling Methodology

Stage	Model Focus	Client Focus
Stage 1: **<u>Project Planning</u>** **Tools include:** • text & flow charts • CPM & GANTT charts • budget templates • risk templates	Outcome objectives for the modelling project Project scoping • deliverables • timeframe • budget • skills required • risk assessment	Confirm scope and deliverables with client • clarify client's understanding of system dynamics • seek realistic expectations from modelling
Stage 2: **<u>Problem Conceptualisation</u>** **Tools include:** • text & graphs • 'wire diagrams' • causal loop diagrams • influence diagrams • concept mapping • SSM 'rich pictures' • 'hexagons' • cognitive mapping • social surveys • statistical data • past review reports	State 'problem' contexts, symptoms and patterns of behaviour, and past 'solutions' **<u>Identify basic organisation structures</u>** • core business processes • optimisation objective functions (outcome performance measures) • patterns of resource behaviour over time • system boundaries • time horizon of study **<u>Identify feedback relationships</u>** • key 'resource states' • key resource 'flows' (business rules) • key delays • key interrelationships Restate 'problem'	Confirm understanding of business with client Confirm understanding of the 'problem' with the client Confirm organisation performance measures with the client
Stage 3: **<u>Model Formulation</u>** **Tools include:** System dynamics software Spreadsheet for tabular data entry Output graphs & tables from the system dynamics model(s)	**<u>Initial Prototype(s)</u>** MAP - MODEL - SIMULATE - VALIDATE - REITERATE High level system 'map': Basic single dimension 'stock-flow' model of key business processes • 20 - 40 variables • key stocks (resources) & flows • key delays • key auxiliaries • key targets / goals / performance indicator(s) • key information or material feedbacks • key delays Run simulation - validate	Confirm basic logical structure and model functioning with client Confirm key variables Confirm business rules

Stage 4:
<u>Model Development</u>
 	
Tools include:
System dynamics software
Spreadsheet for tabular data entry
Output graphs & tables from the system dynamics model(s)
	Detailed Prototype
	MAP - MODEL - SIMULATE - VALIDATE -REITERATE
	• Iteratively elaborate model, challenging
	  * system boundaries
	  * stocks, flows, converters
	  * complexity / simplicity in representing business rules
	• Introduce multi-dimensional arrays where applicable to simplify model structure
	• Use spreadsheets / databases for mass data entry (esp. for arrays) via DDE linkages
	• Identify & build key policy levers & reports
	  * variables under control of decision makers
	  * output reports relevant to decision makers
		Confirm basic structure and logic with subject area experts
		
		Confirm key variables with subject area experts
		
		Confirm business rules with subject area experts

Stage 5: **<u>Model Validation</u>**	**Quality Assurance** Undertake validation and verification tests Iteratively revise model	Confirm outputs with subject area experts Independent testing
Stage 6: **<u>Model Handover</u>**	Installation & Training	Installation & Training
Stage 7: **<u>Model in use</u>**	Experience in use of model identifies need for fine-tuning.	

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1 Bennett, S. and Gajanayake I. (1997) *Surveillance of cardiovascular mortality in Australia 1983-1994*. Australian Institute of Health and Welfare, Canberra

2 Australian Health Ministers' Advisory Council - Cervical Cancer Screening Evaluation Committee (1991).. *Cervical cancer screening in Australia: options for change*. Australian Government Publishing Service, Canberra

3 Wilson JMG and Junger C (1968). *Principles and practice of screening for disease. WHO Public Health Paper 34*. World Health Organization, Geneva

4 Hakama M, Miller AB and Day NE (eds) (1986). *Screening for cancer of the uterine cervix*. International Agency for Research on Cancer, Lyon

5 Wolstenholme, E., S. Henderson & A. Gavine (1993). The Evaluation of Management Information Systems - A Dynamic and Holistic Approach, Wiley, Chichester

6 Richardson, G. and A. Pugh (1981) Introduction to System Dynamics Modelling, Productivity Press, Portland