SYSTEM DYNAMICS PRACTICE IN A NON-IDEAL WORLD MODELLING DEFENCE PREPAREDNESS

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Abstract

In an ideal setting the conduct of a strategic intervention using systems thinking and system dynamics modelling might start where the client identifies he has a complex, dynamic problem, and seeks the services of a consulting team. The team then goes through a logical, progressive series of interviews with stakeholders, workshops, group model building exercises leading to presentations to senior executives outlining strategic alternatives. Whilst much of the literature suggests this is how it should happen, in practice it can be quite different.

This paper describes how, in response to a government audit, a major system dynamics project was initiated by the Australian Defence Organisation. A scoping study was commissioned which recommended 'textbook' practice. The Defence Department, however, launched straight into quantitative modelling. Problems understanding of the problem and ultimate purpose of the modelling soon surfaced. In parallel, and somewhat fortuitous, a doctoral research project focusing on the same problem was conducted into qualitative dimensions of the problem specification.

The paper discusses the evolution of the project and the significant learning that took place as a result of the interplay of qualitative and quantitative modelling activities. It also highlights the fact that the outcomes were less than hoped for, principally because of project management failure from the outset. Lessons for system dynamics modellers are identified.

Keywords: System dynamics; systems thinking; cognitive mapping; defence preparedness.

Background

The key peacetime output of a Defence Force is 'preparedness'. In 1996 the Australian National Audit Office (ANAO) reported critically on the Defence Department's preparedness methodology: preparedness objectives did not address interactions between Army, Navy and Air Force; competing resource implications were not well understood; performance information systems for preparedness planning were inadequate. The ANAO directed the Department to develop management systems to address the interaction between defence budgets and the operational, logistical, and training dimensions of defence preparedness.

In 1997, the Preparedness and Mobilisation Directorate of Australian Defence HQ contracted the University of New South Wales (UNSW) Australian Defence Force Academy system dynamics group to advise on the development of a system dynamics based Defence Preparedness Resource Model (DPRM). DPRM was to be that element of Defence's

Command and Control System which addressed the linkages between specified levels of preparedness and the resources required to achieve them, including:

- resources required to achieve and maintain defined levels of preparedness;
- resources required to change between levels of preparedness; and
- potential impact on defence preparedness of changes in resource allocation.

Recommended Approach to the Modelling Project

The UNSW system dynamics group developed a series of prototype preparedness models (submarine squadron, aviation units and small combat elements) to assess the project feasibility. Recommendations were made concerning project scope, modelling methodology, project management and risk management.

<u>Recommended SDM Development Methodology</u>

System dynamics modelling differs dramatically from traditional software application development. Common software systems development frameworks, including standards such as AS 3563 (Software Quality Management System) and proprietary methodologies such as SSADM or JSD, are not applicable.

System dynamics modelling often involves situations where there are systemic problems which have defied traditional interventions. Key aims of such modelling include improving understanding of the problem context and identifying interrelationships and possible intervention points. Accordingly, scope definition, model specification and model building tend to be iterative processes, with mutual learning between the modeller and the client.

In the absence of an 'accepted' methodology, the following seven stage iterative framework, based on experience and drawing on Checkland and Scholes (1990), Wolstenholme (1993) and Richardson (1981), was recommended to the Defence Organisation. See Figure 1.

Figure 1: Seven Step System Dynamics Modelling Methodology

Stage	Model Focus	Client Focus
Stage 1: **<u>Project Planning</u>** **Tools include:** • text & flow charts • project mgt, risk mgt and configur-ation mgt tools	<u>Project scoping and outcomes definition</u> • deliverables • timeframe • budget • skills required • risk assessment • team specification	Confirm scope and deliverables with client • clarify client's understanding of system dynamics • clarify expectations from modelling
Stage 2: **<u>Problem Conceptualisation</u>** **Tools include:** • text & graphs • causal loop or influence diagrams • SSM 'rich pictures' • 'hexagons' • cognitive mapping • past review reports	State 'problem' contexts, symptoms and patterns of behaviour over time. <u>Identify basic organisation structures</u> • core business processes • outcome performance measures • patterns of resource behaviour over time • system boundaries & time horizon <u>Identify feedback relationships</u> • key 'resource states' • key resource 'flows' • key delays • key interrelationships Restate 'problem', e.g. using SSM	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 Output graphs & tables from the SYSTEM DYNAMICS model(s)	**Initial Prototype(s)** MAP - MODEL - SIMULATE - VALIDATE - REITERATE High level system 'map': Basic 'stock-flow' model of key business processes • 20 - 40 variables • key stocks (resources) & flows • key auxiliaries • key targets performance indicator(s) • key information or material feedbacks • key delays Run simulation - validate Where there are a variety of core processes in the organisation, they may need to be developed as independent sub-models	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
	Detailed Prototype(s)
	MAP - MODEL - SIMULATE - VALIDATE - REITERATE
	• Iteratively elaborate model, challenging
	  * system boundaries
	  * stocks, flows, auxiliaries
	  * complexity/simplicity in business rules
	• add multi-dimensional arrays if applicable
	• Identify & build policy levers & reports
	  * variables relevant to decision makers
	  * output reports for 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** • Do validation and verification tests • Iteratively revise model	Confirm model outputs with subject area experts Independent testing
Stage 6: **Model Handover**	**Installation & Training**	Installation & Training
Stage 7: **Model in use**	Experience in use of model identifies need for fine-tuning.	Evaluate model against original criteria.

Project Risk Management

The UNSW report advised that the proposed project was technically complex and demanded both a high degree of domain knowledge and a high level of technical modelling competence. There were also aspects of the proposed scope which had characteristics of a "wish list", the technical feasibility of which had not been demonstrated. It was concluded that the project had significant risk which could, however, be managed. Key areas of risk included:

a. Modelling technical feasibility risks:
   - Aspects of the User Requirement not being technically capable of being met.
   - Certain modules proving significantly more complex to model than anticipated.
   - Quality control and project management failure.

b. Modelling personnel competency risks:
   - The consultant not having the modelling proficiency.
   - The consultant not having the military domain knowledge.
   - The consultant not having the capacity to project manage the task.

c. Defence Management Risks

- Defence failing to specify an appropriate scope for the modelling elements.
- Defence failing to specify in sufficiently explicit terms the contact deliverables.
- Defence failing to ensure that the users are trained to use the technology.
- Defence failing to ensure knowledge transfer from consultant to Defence.

Of these risk areas requiring attention, three potential failure modes were stressed:

- poor project management;
- piecemeal implementation; and
- lack of structured modelling methodology.

The issue of 'piecemeal implementation' was associated with both project management and modelling methodology. At the start, the potential was evident for the project to be compartmentalised into a series of discrete 'easy-to-understand' generic modelling tasks, with the presumption that these could then simply be 'bolted together'. This ran the danger of so circumscribing the consultant to low-level detailed modelling activities that high-level cross-sectoral relationships would not be understood or addressed.

Noting the complexity of the project and the fact that the technical feasibility of some of the requirements had not been proven, the need for a senior consultant project manager, separate from the modelling team and able to take an holistic view, was stressed. Again, the potential was evident from the start that personalities and 'political agendas' on the client steering committee would distract the modelling-learning process.

Because of the complexities of the project, the diverse understandings of 'preparedness' highlighted by the ANAO audit, and especially because of the client team had limited understanding initially of system dynamics, the iterative seven stage modelling methodology illustrated in Figure 1 was strongly recommended.

Each of these strictures were ignored and, as a consequence, the project results were less than hoped for.

Project Implementation – Practice Versus Theory

In April 1998 a request for tender was issued. The Defence Department subsequently hired a technically competent system dynamics consultant who also had domain expertise in the field of defence preparedness. The contract simply provided for supply of labour, with the Defence Department 'project managing' the exercise. The consultant firm's quality control processes (ISO 9000 certified) were explicitly excluded from the contract.

At no stage did the Defence Project Manager employ any formal risk management or project management methodology (such as PRINCE™2). To all intents and purposes the recommended system dynamics methodology (Figure 1) was ignored. Instead the project launched forthwith onto model development.

The consultant was directed to prepare three joint combat capability models (land, air and maritime). The project was tightly controlled by the Defence project manager, reported frequently to a 'Preparedness Working Group' with representative from stakeholder groups across the Australian Defence Organisation (ADO), and obtained detailed advice, through a series of technical workshops, on 'business rules' to be input during model development.

The consultant produced a number of technically excellent and highly innovative system dynamics models which contributed significantly to the understanding of this complex area.

However, in mid-1999, the project was wound up without achieving the fundamental objective, a Defence Preparedness Resourcing Model.

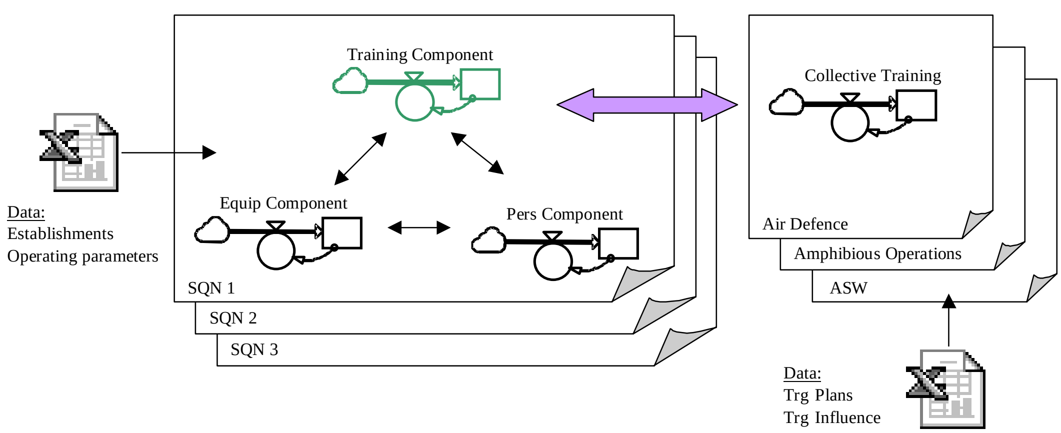
Revisiting the Nature of the Defence Preparedness Problem

Amongst the most vexing questions confronting the executive of the Australian Defence Organisation (ADO), financial planners, force element and force element group commanders are: *What does it actually cost to achieve extant levels of preparedness? What will it cost to achieve future desired levels of preparedness? How much will it cost to, say, have a have a Brigade group prepared 28 days from today's date to undertake an amphibious lodgement 500 km from its home base? How much will it cost to raise this force from its current level of operational capability, its current preparedness, to a fully operational level in, say, three months? What factors might preclude achieving a specified level of preparedness? What premium might have to be paid to meet this level of preparedness a week earlier if strategic circumstances dictate?* The inability of the ADO to answer such questions prompted the commissioning of the ANAO investigation into defence preparedness and the DPRM project summarised above.

Management of resources associated with defence preparedness requires more than a simple accounting approach. 'Preparedness' is not just aggregation of people and equipment. 'Preparedness' does not simply mean readiness to do a single specified task, but readiness to undertake any of a wide variety of possible tasks. Thus preparedness involves personnel who have undertaken (recent) individual and collective training for diverse scenarios, with diverse equipment and weapons platforms. As they move from one training scenario to another, there is decay in skills gained through previous training. Further, some of the training may involve unfamiliar combinations of force elements. Hence new skill-sets have to be developed.

Recognition of the complex web of interactions and the detail and dynamic complexity of managing preparedness led to this serious attempt to use system dynamics modelling techniques to build a set of decision-support tools to inform development of strategy regarding defence preparedness.

Figure 2: Complex Interactions in 'Preparedness'



System dynamics modelling had been used with significant success within the ADO to address specific problems for more than a decade. Problem areas addressed span manpower modelling, management of training, maintenance scheduling and operational issues arising out of the operation of fleets of fixed wing aircraft, rotary wing aircraft, wheeled vehicles, and submarines.

In each case the problem space was bounded in fairly clear terms. Consequently, in each case the solution space, within which the model might reside, was also bounded with reasonable clarity. The cross-organisational impacts were limited.

The application of system dynamics modelling to the full gambit of preparedness resource management issues involved a quantum step in terms of complexity of task. The problem space was ill-defined. Undertaking this modelling task involved major risks both to the delivery of effective project management and to the delivery of the modelling products. To a much greater extent than previously, there was unwelcomed exposure to organisational cultural pressures, for which those managing the project were ill-prepared. Some pressure emanated from those who were keen to bring about the downfall of this modelling initiative.

Cognitive Mapping of the Preparedness Domain

At the same time as tenders were being called for the DPRM project, the UNSW system dynamics group offered to provide (gratis) cognitive mapping assistance to the project to facilitate understanding of the problem. The doctoral student concerned was an officer with the rank of Lieutenant Colonel and with significant domain expertise. There was a four month delay before the offer was accepted, by which time modelling was well under way.

a. The cognitive mapping exercise was explicitly identified[1] as a research task, quite distinct from the DPRM contract, which offered to "provide insights into the nature of a range of preparedness issues" including: Systematic analysis of stakeholder views of their role in Defence preparedness.

b. Stakeholder understanding of preparedness.

c. Objective measures of preparedness.

d. How preparedness data might be used to inform executive decision-making.

e. How preparedness data might be best used in formulating advice to Government.

In other words, the objectives of the research were to address the very questions which, in the recommended modelling methodology of Figure 1, should have been addressed at the outset.

The cognitive mapping process proceeded in parallel with the modelling work from July to December 1998. The process involved two 1-hour structured interviews with seven of the key stakeholders. The initial interview was taped and a transcript made. From interview notes and the transcript a cognitive map was built in Banxia® *Decision Explorer*.

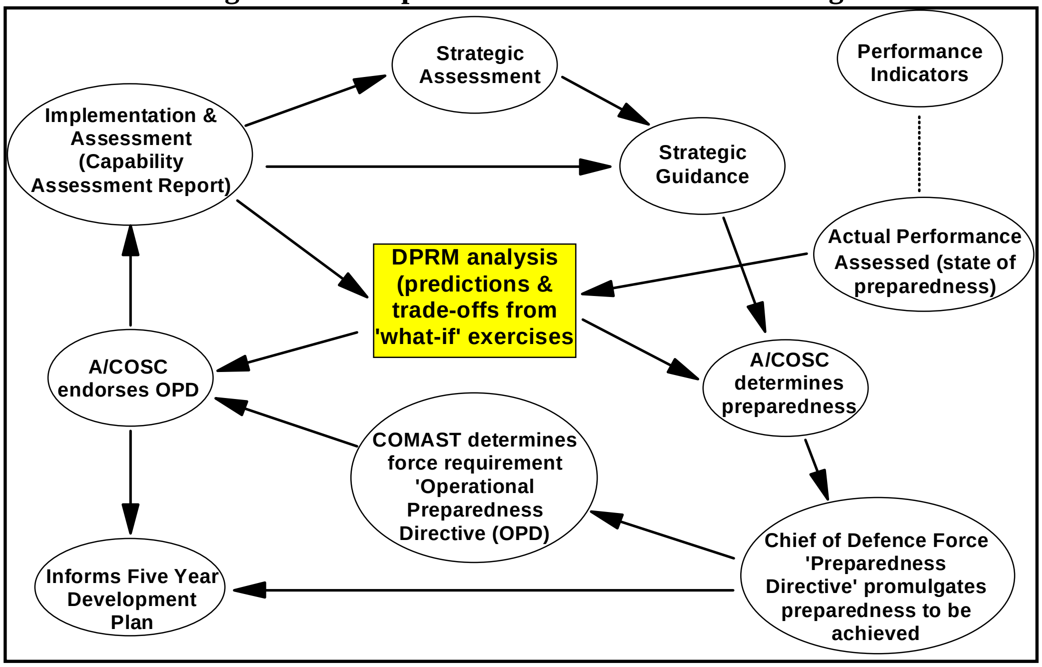
This was followed by a debriefing session to confirm that the respondents views had been properly captured. In some cases a subsequent set of interviews was undertaken after several months. The insights from all interviews were fed back to individual interviewees and summarised to the steering committee. The system dynamics modelling consultant was also briefed.

The cognitive mapping process revealed the complexity of the project and the difficulty of managing it with a steering committee representing diverse stakeholders. More significantly, the cognitive mapping highlighted:

- Significantly different 'mental models' regarding 'preparedness' by the members of the steering committee.
- Significantly different 'mental models' regarding the role that the DPRM would play in the strategic guidance process.

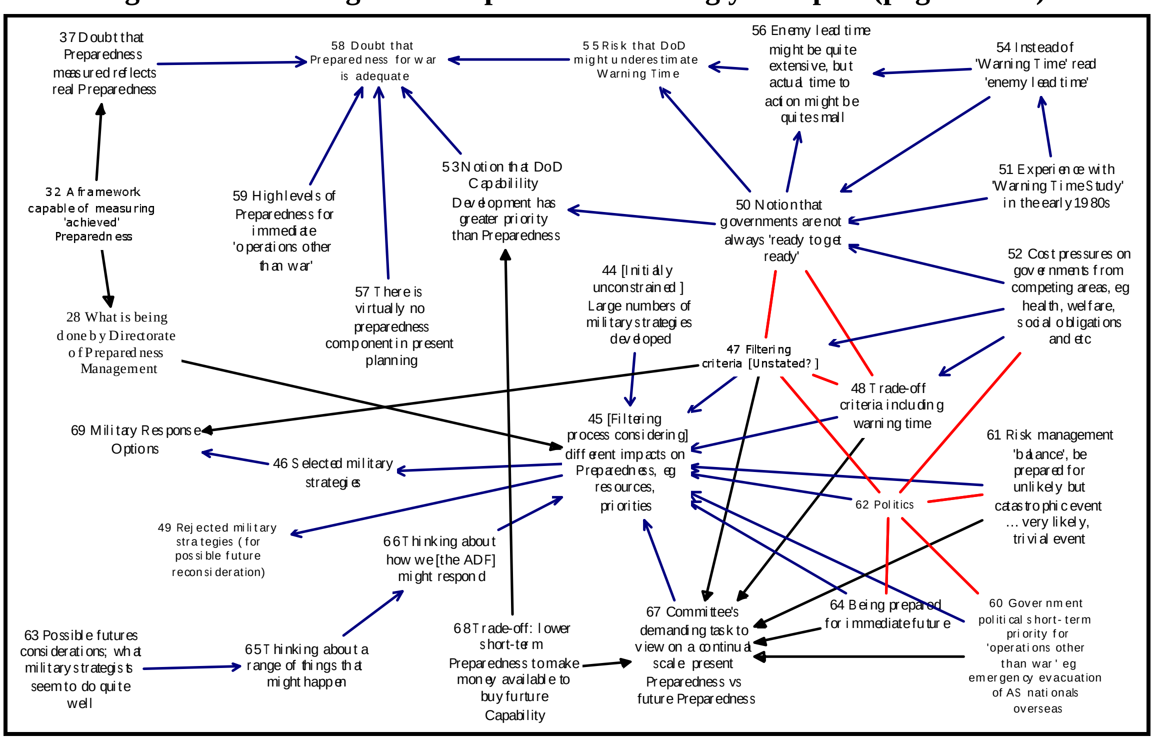
Regarding the first point, the Project Director's early vision was that DPRM would be a strategic decision tool helping to determine appropriate preparedness levels and force requirements. That is, his focus was on the predictive potential not the learning potential.

Figure 3: Perception of End Product of Modelling



Initially, the Project Director's cognitive map of 'preparedness' was very simple, containing fewer than 20 concepts. By way of comparison, the cognitive map of one of the civilian policy advisors had close to 200 concepts. One of 12 pages of that map is depicted below.

Figure 4: Some Cognitive Maps were Exceedingly Complex (page 6 of 12)



When the Project Director was subsequently interviewed, some months later, his cognitive map had expanded to some 120 concepts, suggesting a major paradigm shift in his perception of the nature of the defence preparedness problem space.

One very significant finding of the process was that the cognitive maps of the Army, Navy and Air Force representatives differed significantly, even though this was not apparent in the Committee discussions. At Committee meetings the group would automatically drop back to a highly simplified mental model of preparedness, giving an appearance of congruence of understanding.

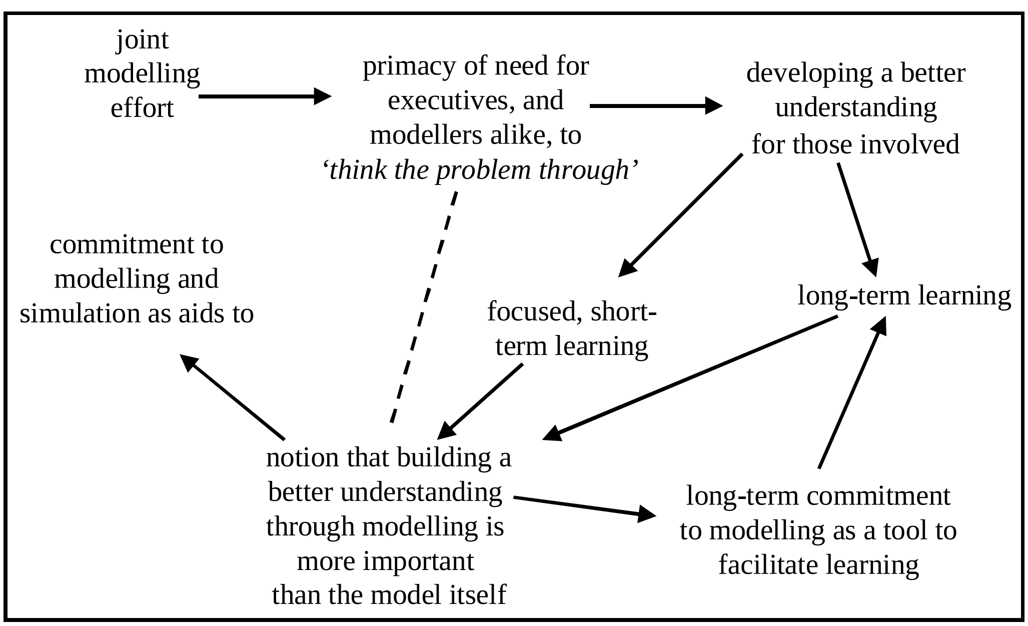
Some of the steering committee felt threatened by having their deeply ingrained assumptions and understanding of defence preparedness surfaced by the cognitive mapping process. They became "too busy" to participate in the interview process. The individuals concerned, from observation, were those who expressed a "spreadsheet" (linear, non-feedback) view of the defence preparedness problem and strategies for its solution.

Interrelationship Between the Qualitative and Quantitative Modelling

The consultant undertaking the quantitative system dynamics modelling was privy to the results of the cognitive mapping process, along with the Defence project manager and the steering committee. His room for manoeuvre, however, was minimal. The project, once initiated, continued its momentum even though the qualitative analysis was raising significant questions regarding understanding of the objectives and rationale.

There is no doubt, however, that the cognitive modelling process, in tandem with the quantitative modelling, helped the steering committee to a much better understanding. The Project Director developed a strong commitment to the modelling as a process to facilitate learning, as summarised in his following cognitive map.

Figure 5: Evolving Perception of Modelling to Facilitate Learning



Eventually, however, the project was wound up with few of its original objectives realised. There was complete dispersal of the corporate knowledge gained in the process and the models themselves were handed to the Revolution in Military Affairs Branch, but with no training in their use and no funding for their maintenance.

Analysing the Project With Benefit of 20/20Hindsight

The project 'failed' for a variety of reasons:

a. Misleading or erroneous assumptions.

b. Lack of senior executive champion.

c. Lack of problem definition.

d. Failure to achieve a shared vision.

Misleading or Erroneous Assumptions

The task was only moderately complex: it would involve dealing with significant amounts of detail, but this was manageable: The task was actually exceedingly complex in terms of detail and dynamism. Whilst a map amalgamating the views of the seven key stakeholders interviewed was not produced, it is suggested that such a map would contain more than 300 concepts.

The task could be completed without instituting a formal project management methodology: The project was managed by staff from separate areas within the ADO. A comprehensively manned project office was never established despite the importance of the project. A formal project management methodology, such as PRINCE™2, was not employed.

Detailed requirements engineering practices were not needed because it was reasonably clear what modelling was required: In reality it was not clear. The 'requirements' often changed. This became the source of ongoing frustration and ultimately led to the demise of the project.

Independent verification and validation (IV&V) was not required: Detailed V&V was never undertaken and, in fact, the standard quality control procedures of the consultant firm were explicitly excluded from the contract by the client. As a consequence, as evidenced by internal ADO correspondence, not all stakeholders were convinced of the robustness of the models.

Knowledge, derived from those with experience relevant to subject area, would be passed on without hesitation or corruption to the modellers: Observations, correspondence and reports suggest this was not always so. Davenport and Prusak (1998) make the point that '… understanding that there are knowledge markets and that they operate similarly to other markets is essential to managing knowledge successfully in organisations. Many knowledge initiatives have been based on the Utopian assumption that knowledge moves without friction or motivating force, that people will share knowledge with no concern for what they may gain or lose by doing so. … Knowledge initiatives that ignore the dynamics of markets (and of course, human nature) are doomed to fail.'

Everyday terminology used within the Defence Organisation by those involved in capability and preparedness areas, including commanders of Force Elements and Force Element Groups was universally understood: Terminology was often used in quite different ways within Service precincts and across Service boundaries. Despite this a data dictionary was never created. Unfortunately, a degree of precision needed for what was essentially a software development task was never achieved.

Modelling can be done with limited involvement of senior decision-makers: they are too busy to be involved: During the model development process the assumptions, assessments and perspectives of the modeller can be profound influences on the form the model takes. In the absence of executive decision-makers for whom the model is being built the assumptions, assessments and perspective of the modeller (predominantly or alone) are continually tested as the model is verified, validated and further developed. Through these processes, the modeller continually learns about dynamic behaviour and the true nature of the problem being analysed. When key senior executives are involved in these activities they, too, have to think the problem through in detail. As a consequence, they learn, build understanding of business dynamics and develop ownership of the model. Without this involvement, building an in-depth appreciation of the dynamics, and learning, fail.

Most of these problems had been anticipated in the original UNSW advice, but that advice was ignored.

Lack of Senior Executive Champion

The DPRM didn't really fit within the established Defence decision framework, and consequently there was no senior executive (at the '2-star' level or above) who owned it or championed it. Studies at UNSW and elsewhere emphasise that, in high risk software projects where there are multiple stakeholders, the presence of a 'project champion' is essential for success, especially to overcome vested interests and knowledge 'gate-keepers'.

Lack of Problem Definition

The original statement of requirements had characteristics of a wish list … the typical product of a committee. The UNSW advisory report highlighted the criticality of requirements elicitation, specification and management activities. Yet, almost a year after the detailed modelling commenced, one of the key stakeholders was to make the formal protest in writing: "Without a clear, current and detailed Statement of User requirements agreed by the project's major stakeholders, there is considerable risk that the capability being developed will not align with a real need …".

Failure to Achieve Shared Vision

Some of the stakeholders evolved an understanding of systems thinking and system dynamics concepts, but others remained locked in a 'spreadsheet' or 'accounting' mentality.

The primary focus of some of the stakeholders remained focussed on the management of resources (input-output) within the budget year, whilst the ANAO (and the model) focus was on preparedness over time (input-outcome).

Of most significance, however, was the fact that, as demonstrated by the cognitive mapping process, there was lack of consistency in fundamental understanding of the central concept, 'preparedness'. Even after the cognitive mapping exercises helped stakeholders to articulate the vast complexity of the problem, in working group sessions the discussions invariably focussed on a small number of relatively simple interrelationships.

Lessons from the Process

a. In a complex system dynamics modelling project it is essential that a structured project management methodology (such as PRINCE™2) be employed

b. All key stakeholders should 'sign off' to a clear and detailed 'statement of user requirements' before modelling commences. Some form of 'requirements engineering' front end is required to the system dynamics modelling process.

c. A clear system dynamics modelling methodology, such as that outlined in Figure 1, should be adhered to. In particular, the problem conceptualisation phase is critical.

d. Those decision-makers for whom the modelling effort is undertaken must be as closely involved as their busy schedules permit.

e. A project champion should be identified, 'educated' and kept informed. The champion can assist in by-passing 'knowledge gatekeepers' and those with vested interests.

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