To model or Not to Model

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ABSTRACT: *Systems thinking and system dynamics literature contains myriad examples of disparate analytical techniques. Integration of qualitative and quantitative techniques could be powerful in addressing messy, dynamic, systemic problems. Unfortunately, there has been little empirical research undertaken with the aim of determining how to integrate soft systems analysis and quantitative modelling. Consequently, qualitative vs quantitative arguments continue after more than 35 years of system dynamics practice. This paper describes empirical case study research aimed at providing insights into when to use qualitative analysis, when to build quantitative models, and what threatens effectiveness of both forms of analysis.*

Keywords: Problem conceptualisation; qualitative modelling; system dynamics modelling.

INTRODUCTION

The original impetus for the research described in this article came from studies of accident cases. What appeared on the surface in the weeks and months preceding the accidents was both 'normal' and frighteningly similar to what we see around us every day. However, when a closer look was taken and systems thinking applied, valuable insights were gained, particularly into the behaviour of people and the complex, dynamic systems-of-systems of which they were an integral part. The analytical techniques were then applied more broadly, to cases where accidents did not occur. In the non-accident cases, the findings about detail and dynamic complexity, and behaviour of people were similar to the accident cases. A recurrent theme was that players failed to understand what was happening around them, they failed to learn from incidents that occurred along the way, and made errors of judgement or errors in their assessments and management of risks, though this was rarely admitted. It was commonly found that managers and decision-makers lacked understanding of the complexity they faced. As a result they were often seriously challenged when making decisions or when developing strategies involving significant risks.

Critical pre-cursors to effective decision-making are awareness and understanding. Effective management involves corrective action derived from this awareness and understanding, followed by ongoing cycles of double loop learning (Argyris, 1982) and adjustment of mental models (Kelly, 1955; Senge, 1990; Sterman, 1994). System dynamics modelling can be very helpful here, but:

> …system dynamics models have little impact unless they change the way people perceive a situation. The model must help organize information in a more understandable way. The model should link the past to the present by showing how the present conditions arose, and extend the present into persuasive alternative futures under a variety of scenarios determined by policy alternatives. In other words, a system dynamics model, if it is to be effective, must communicate with and modify the prior mental models. Only people's beliefs, that is, their mental models will determine action (Forrester, 1987).

Unfortunately, even when system dynamics techniques are used to enable understanding and learning, understanding and learning can be stifled. This paper suggests that rather than seeking to identify when best to apply system dynamics modelling, it can be much more profitable to focus on when understanding and learning are inhibited, and how, after correction of such situations the ways people perceive situations may be improved.

Why Effective Management and Decision-Making in a Complex World is so Elusive

Before case studies are introduced, it is necessary to reflect on the nature of complexity and how this impacts on decision-making. Managers are challenged by the massive complexity they face. Here we need to consider both detail and dynamic complexity (Kline 1995; Flood 1999; Senge 1990). Managers and practitioners alike have limited ability to solve exceedingly complex problems. To demonstrate this, Kline, 1995, defines an *Index of*

Complexity C, based on numbers of independent *variables* needed to describe the state of a system, independent *parameters* needed to distinguish the subject system from others, and control *feedback loops* within the system and connecting the system to the surroundings.

Applying the *Index of Complexity* to socio-technical systems, where there are not only numbers of humans but complex hardware and many feedback loops both within the system and to the world, Kline suggests a value of *C* greater than 10^{13} (Kline 1995, 61). By stark contrast Kline suggests human ability to reliably predict all aspects of behaviour, even with computer assistance, is limited to systems described by $C \approx 4$ [not 10^4](Kline 1995, 61-65). Limited human ability to understand and make predictions regarding dynamic behaviour of complex systems has also been established through controlled testing (Sterman 1989a, b, and c; Paitch and Sterman 1993). The deductions are frightening. Human ability to deal with complexity, to solve complex problems is in considerable doubt. Use of intuition and judgement can be inappropriate in dynamic situations.

In an organisational context additional forces militate against effective decision-making. These include:

a. Bounded rationality, and defensive routines of executive decision-makers (Argyris, 1994).
b. Fallacious or inappropriate mental models (Senge 1990) or psychological constructs (Kelly 1956).
c. Restrictive 'systems of meaning' (Flood 1999, 110-115).
d. 'Systems of knowledge-power' in which executive decision-makers are players (Flood 1999, 116-122).

Before an effective strategic intervention can be designed human decision-making limitations, and forces prevailing within organisations, need to be acknowledged. The critical issue is that any form of analysis we might undertake has to be able to reside in a world of fuzzy thinking (Kosko, 1994), human idiosyncratic decision-making, and organisational politics. To reveal how messy and difficult real problems are, the cases described below were chosen. The research methodology was developed to analyse the factors underlying the accident cases. This was then applied to the non-accident cases.

Case Studies

The following cases were studied primarily because they were messy, real, and somewhat controversial:

a. Black Hawk helicopter crash - Two Army helicopters crashed during a routine training exercise near Townsville in Queensland on 12 June 1996: 18 soldiers died and 12 were injured (Australian Army, 1996).
b. Death of Katie Bender - Katie died when struck by a piece of flying debris from a demolition site in Canberra in July 1997 (ACT Magistrates Court, 1999).
c. Fire in the engine room of HMAS WESTRALIA - On 5 May 1998, resulted in the deaths of four Naval personnel (Department of Defence, Australia, DPUBS: 32871/98 1998).
d. Explosion and fire at Esso's Longford Gas Plant No.1. - On 25 September 1998, an explosion and subsequent firer caused the death of two workers and injuries to eight others (Parliament of Victoria, 1999).
e. Business Process Re-engineering (BPR) of the Defence Acquisition Organisation (DAO) during 1998.
f. Defence Preparedness Resource Modelling (DPRM) during 1998 and 1999 (McLucas and Linard, 2000).

Concept Mapping and System Dynamics Modelling

The research method involved systems thinking and concept (cognitive) mapping (Eden, 1988) in two ways:

a. <u>Accident Cases</u>. As a means of recording and depicting graphically what was gleaned from written reports. Concept maps depicted, on single sheets of paper both cognitive structure and viewpoints of the authors.
b. <u>Non-Accident Cases</u>. In the two non-accident cases, maps were developed from information gleaned during two 1-hour interviews with key stakeholders. The initial interview was taped and a transcript made. From interview notes and the transcript a cognitive map was built. This was followed by a debriefing session to confirm that the respondents views had been properly captured. The interview / feedback process was repeated as necessary in action learning approach. This process, whilst highly successful in its own right and accepted very well by those involved, was not incorporated as an integral part of either BPR of DPRM activities. Indeed, it was an afterthought, commencing too late to impact significantly on the conduct of the planned interventions. It should have been among the first activities undertaken, hence providing vital input to establishing requirements for the conduct of subsequent interventions, regardless of whether they were to involve modelling.

Concept maps were recorded using Banxia® *Decision Explorer*. This facilitated both handling vast quantities of information and subsequent analysis.

Insights Produced Through Concept Mapping

Some concept maps were exceedingly detailed, containing 200-300 concepts. Unfortunately, building such detailed maps took considerable time. Building very detailed maps is not recommended as a consultancy method. Mapping is a powerful technique, but it is necessary to work at the appropriate level of aggregation to save time and effort. Coyle, 1996; Coyle and Exelby, 2000, depict the working at higher or lower levels of aggregation in a 'cone of influence diagrams.' Cognitive mapping revealed:

a. The detail and dynamic complexity facing managers and decision-makers.
b. Political pressures on decision-makers.
c. Constraints on decision-making in terms of time available and resources.
d. Forces militating against the sharing of information.
e. Significantly different 'mental models' among stakeholders.
f. Where there were candidates for system dynamics modelling.

Identifying Candidates for Management Intervention

Figure 1 is a map of the Chief of Army's Report to the Minister of Defence regarding the Black Hawk helicopter crash. The concepts and links in hidden detail at the top of the map are those identified as directly causal to the ultimate accident, noting Concept No. 33 was *collision and destruction of two Black Hawk helicopters during CT/SRO training*. When the clock was wound back to a 'normal' period well before the accident, what was found to exist was that part of the map shown in black and white. In that portion of the map, the highlighted concepts (with the exception of Concept No. 33) are those to which intensive, but routine, management effort might have been applied, with the probable outcome of preventing the accident. In Figure 1, the text has been removed from one such map to reveal underlying structure.

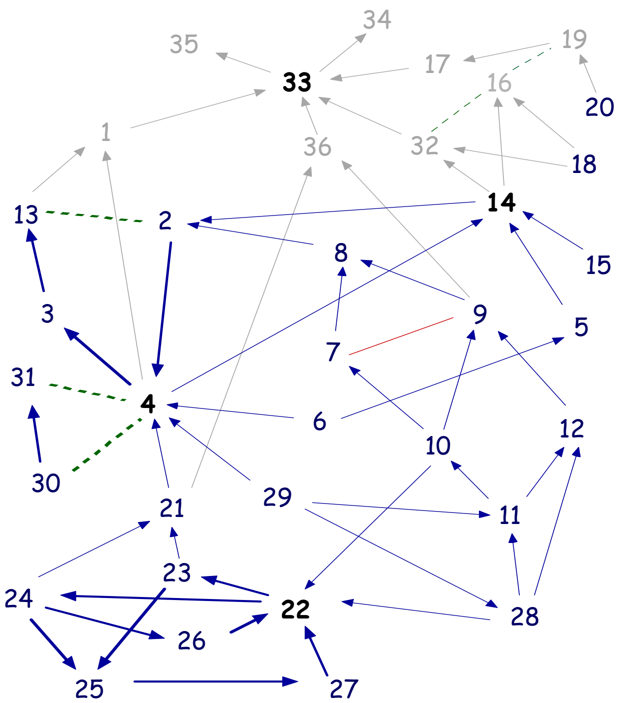

Figure 1. Bare Concept Model Depicting Underlying Structure

It should be noted that this map depicts the outcome of many months of evidence gathering and deliberation by the Board of Inquiry, all concepts and links other than those in shadow were reasonably known weeks, months or years before the accident occurred. A reasonable level of awareness should have led managers to focus their attention on the following in the weeks, months or years beforehand:

a. Concept No 4 - *failure to inform the judgement of those responsible for designing combined arms training and associated safety.*
b. Concept No 14 - *inadequate oversight and control of this combined arms activity [counter-terrorist / special recovery operations].*
c. Concept No 22 - *declining morale [amongst pilots and qualified flying instructors].*

This choice of concepts for management focus is made largely, but certainly not exclusively, on the basis of the numbers of connected concepts (McLucas, 2000). The significance of this map is that in the preceding weeks, months or even years, management effort applied to the concepts identified should have obviated the creation of circumstances which led to the final catastrophic culmination of events. It is important to note that this did not happen for a variety of organisational, cultural, and political reasons, as summarised later. It is disturbing that here also existed a 'culture of denial': no-one was prepared to admit there was a problem requiring scrutiny.

Identifying Candidates for System Dynamics Modelling

Those concepts having large numbers of links combined with feedback as shown in Figure 2 are often candidates for system dynamics modelling. Concept 22, from the Black Hawk map suggests a prime candidate for system dynamics modelling.

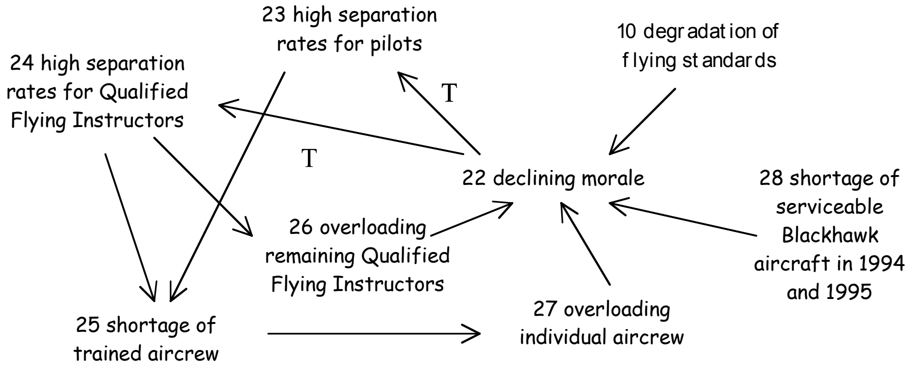

Figure 2. Expanding Consideration of Contribution to Declining Morale

An appropriate system dynamics (stock-flow) model, using Figure 2 as the start point, might examine:

a. Numbers of pilots (in various levels of competence) and qualified flying instructors would be the stocks.
b. Recruiting, training, employment and separation would be the rates.
c. Another, but more detailed map, might be need to assist in development of the model(s).
d. Recruiting, training, employment, conditions of service and separation which would be linked, in the model, through a set of 'business rules'. These rules need to be developed, verified and validated in detail with close and continual client involvement.

Candidates for System Dynamics Found in These Cases

In the cases studied, candidates for modelling were:

a. Black Hawk helicopter crash. - aircraft availability, servicing and associated logistics; and retention of pilots and qualified flying instructors were clear candidates for system dynamics modelling.
b. Death of Katie Bender - no candidates for system dynamics modelling were found. However blast effects likely to be produced by the explosives used during the planned implosion should have been modelled. This would have revealed vital information regarding safety distances and exclusion zones.
c. Fire in the engine room of HMAS WESTRALIA - no candidates for system dynamics modelling were found, but modelling in the form of hazard and interoperability studies (HAZOPS) would have provided valuable insights leading to risk reduction and fire protection strategies.
d. Explosion and fire at Esso's Longford Gas Plant No.1 - no candidates for system dynamics modelling were found, but HAZOPS modelling, would have provided valuable insights to inform risk mitigation strategies.
e. Business Process Re-engineering (BPR) of the Defence Acquisition Organisation (DAO). Numerous candidates were identified. Models were built and demonstrated to clients who chose not to accept the insights gained from the models because to do so would have resulted in a major re-think of partially completed BPR initiatives. BPR failed to deliver changes to many old ways of doing business. In 2000, the DAO is to be again re-organised and re-engineered with the loss of some 500 people.
f. Defence Preparedness Resource Modelling (DPRM) during 1998 and 1999. Numerous candidates for system dynamics modelling were identified. This was the most extensive system dynamics modelling activity ever undertaken in Australia. This project was managed by Defence without recognition of the important nexus between modelling and learning. Models were built with little involvement of the senior executives who were the intended users, and based on poorly defined requirements. Models were delivered but failed to produce significant revision of mental models of the principal Preparedness managers in Defence. (McLucas and Linard, 2000).

Reasons for Failure in System Dynamics Modelling

In each of the cases where models were built, none led to the successful implementation of strategic interventions (McLucas, 2000). The main reason for this was a lack of close and continual involvement of stakeholders. Other reasons for this are:

a. Modelling activities take time, resources and commitment. These activities are often not managed as projects with clear focus on delivery of quality products in accordance with the client's requirements.
b. Projects without a 'champion' are unlikely to be successful. Unfortunately, many executives who might provide the needed support, critical to the success of system dynamics modelling efforts, often do not appreciate the complexity of the problems being addressed and the importance of their role.
c. Executive decision-makers, generally amongst the busiest in the organisation, prefer to avoid impositions on their time, and the extensive delays that often accompany the application of analytical techniques.
d. Over-simplification leads to the practice of seeking a single 'golden nugget' as the cause of what, in fact are messy problems (Meadows, 1989).
e. It takes time to build models, gather data and conduct analysis. This does not does not fit well within decision cycles. Consequently, decision-support systems are often circumvented and decision-makers revert to using intuition and judgement.
f. Executive decision-makers, who are often intimidated by the complicated appearance of analytical methods, fail to appreciate their value, mistrust them along with those who advocate their use (Nutt 1989, 32-33).
g. There is a strong aversion by decision-makers to have their deeply ingrained assumptions, their mental models (Senge 1990), psychological constructs (Kelly 1955), schemata and sysreps (Kline 1995, 31), 'systems of meaning' (Flood 1999, 110-115) surfaced and critically analysed (Mason and Mitroff 1981).
h. Strategic decision-makers are also political players, frequently more concerned about the impact particular decisions have on their careers in the short-term.
i. Information is compartmentalised within organisations. Compartments can be sealed by organisational hierarchies and politics. The 'need to know' principle also militates against sharing information. Essential information can be withheld from those building models, leading to production of erroneous models.
j. 'Systems of knowledge - power', in which executive decision-makers are central players, militate against the sharing and flow of information (Flood 1999, 116-122; Davenport and Prusak, 1998).
k. Reward systems in organisations, are rarely centred on rewarding the sharing of knowledge.
l. In the worst cases there can be a strong sense, or even a culture, of denial that problems exist despite strong evidence that serious problems really do exist.

Sterman, 1994, and Morecroft and Sterman, 1994, argue a compelling case for learning and understanding complexity through modelling. What is important is that 'double loop' learning is experienced by those involved in decision-making and strategy development in the organisation (Argyris 1982) (Sterman 1994, 318). Unfortunately evidence from this research suggests learning is stifled even when system dynamics models are built (McLucas and Linard, 2000).

CONCLUSIONS

Success in use of both qualitative and quantitative techniques is highly dependent on the way we go about helping clients deal with their messy problems (McLucas and Linard, 2000). Politics, systems of knowledge-power, compartmentalisation of information, incompetence, ignorance, resistance to having ingrained and potentially erroneous assumptions surfaced, mistrust of analytical methods, bounded rationality and defensive routines are all part of the organisational decision-making environment. We must recognise these and design interventions accordingly. Where and how to apply modelling efforts must be based on a deep appreciation of the nature of complexity, and how the militant issues described above are likely to affect organisational decision-making and strategy development. The nature of the problems at hand must be first investigated and understood, say, through the use of quantitative analysis described in this paper. This must occur at the earliest opportunity in the requirements formulation stage. Then it will be obvious where system dynamics modelling efforts might be applied, if at all. Further to Jay Forrester's observation, our goal must be to guide both short-term and long-term development of decision-makers' mental models, by whatever means is most appropriate, qualitative or quantitative, or a combination of both.

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